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Permanent Pacemaker Implantation After Minimally Invasive Robotic Cardiac Surgery and Long-Term Pacemaker Dependence Rates

ABSTRACT

Background: The role of minimally invasive robotic heart surgery in the surgical field is swiftly expanding due to technological advancements and the acknowledgment that its safety is comparable to conventional cardiac surgery. The aim of this study was to evaluate permanent pacemaker (PPM) implantation rates, associated perioperative determinants, and the course of pacing rates during follow-up in a single-center cohort undergoing minimally invasive robotic cardiac surgery.

Methods: This retrospective study was conducted on 276 patients who received robotic heart surgery utilizing the da Vinci Si HD surgical system (Intuitive Surgical, Inc.) at the center. Patients were categorized into 2 groups: those who had PPM implantation post-surgery and those who did not. The general demographic data of patients, comorbidities, and intraoperative variables were retrospectively analyzed.

Results: Permanent pacemakers were implanted in 5.4% (n = 15) of patients after robotic cardiac surgery. Patients had an average age of 53.50 (±16.15) years. Age, gender, and comorbidities were similar between groups. Patients who received PPM implantation had substantially longer cardiopulmonary bypass (CPB) times (median = 210) than those who did not (median = 150) ($P = .035$). Additionally, the distribution of surgical types showed a significant difference according to PPM implantation status ($P = .033$), and mitral-tricuspid valve surgery was observed at a higher rate in the PPM group (40.0% vs. 10.3%).

Conclusion: This study shows that prolonged CPB duration and concurrent mitral-tricuspid valve surgery elevate the risk of PPM implantation in patients undergoing minimally invasive robotic heart surgery; furthermore, patients needing pacemaker implantation showed significant long-term pacing burden during follow-up.

Keywords: Cardiopulmonary bypass, pacemaker dependency, permanent pacemaker implantation, robotic heart surgery

INTRODUCTION

Minimally invasive robotic heart surgery is rapidly gaining popularity in the surgical area, having been demonstrated to be as safe as traditional heart surgery because of technological advancements. Numerous factors contribute to its significance in contemporary cardiac surgery, including minimal incisions without median sternotomy, reduced hospital stays, and early mobilization.[1-3] Despite these benefits, robotic cardiac surgery may result in a requirement for a permanent pacemaker (PPM), which is considered a clinically significant complication. Despite extensive research on PPM implantation following cardiac surgery, scarce data exist about the incidence of this complication, particularly long-term pacemaker dependency in cohorts specific to minimally invasive robotic heart surgery. A substantial amount of the current research relies on traditional or non-robotic minimally invasive techniques. The procedural attributes of robotic surgery may require assessment of their possible effects on the cardiac conduction system in a distinct setting. Postoperative PPM implantation remains a significant problem due to its potential to prolong hospital stays, affect patients' quality of life, increase healthcare system costs, and, although rare, cause mortality related to the procedure.[4-6] The aim of this study is to evaluate the PPM implantation rates,

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associated perioperative determinants, and the course of pacing burden in a single-center cohort undergoing minimally invasive robotic cardiac surgery.

METHODS

Between November 2016 and June 2022, patients who underwent minimally invasive robotic cardiac surgery at the center were retrospectively analyzed, resulting in the inclusion of 276 patients who were operated on using the robotic surgical system. The study was designed as a single-center, retrospective, and observational cohort analysis. Patient data was acquired from the hospital information management system and medical records. Patients who received cardiac surgery via minimally invasive robotic techniques and had follow-up data for a minimum of 12 months postoperatively were included in the evaluation; those with a history of conventional cardiac surgery, prior PPM implantation, or inadequate/unavailable follow-up data were excluded from the study. The patients' baseline demographic characteristics and comorbidities, including hypertension, diabetes, chronic renal failure, atrial fibrillation (AF), and coronary artery disease, were recorded. Minimally invasive and robotic surgical procedures conducted on patients were categorized as follows: mitral valve surgery, double valve surgery (concurrent mitral and tricuspid), coronary bypass surgery, septal defects [atrial septal defect (ASD)/ventricular septal defect (VSD) surgeries and others (myectomy for hypertrophic cardiomyopathy, cardiac mass excision)]. Due to the limited number of cases in the VSD subgroup (n = 3), ASD and VSD cases were analyzed together and categorized as septal surgeries. Left ventricular ejection fraction using preoperative transthoracic echocardiography, preoperative and postoperative electrocardiography (ECG) findings, and cardiopulmonary bypass (CPB) and cross-clamp times were recorded. Patients were categorized into 2 groups after the postoperative period: those who received pacemaker implantation and those who did not. In this study, pacemaker dependency was evaluated using pacing percentages obtained from device interrogation at the 1-, 6-, and 12-month follow-up visits, for which complete data were available for all patients who underwent PPM implantation. In pacemaker programming, the lower rate limit was set to 50 beats per minute. Since the standardized intrinsic rhythm test was not routinely performed, pacing percentages were used as an indirect indicator of pacemaker dependency in this retrospective real-world cohort. A predefined percentage threshold was not used to define dependency; instead, the temporal course of pacing burden during the follow-up period was reported descriptively.

Robotic Surgical Technique

All procedures were performed using the da Vinci Si HD platform (Intuitive Surgical, Sunnyvale, CA, USA) within the institution's structured robotic cardiac surgery program. Patients were positioned according to the planned procedure. In selected cases, single-lung ventilation was used to improve surgical exposure. Port placement and the configuration of the camera and working arms were planned according to the institutional standardized approach. CO_2 insufflation was used when needed to optimize the visual field. Cardiopulmonary bypass was established via peripheral femoral cannulation. Myocardial protection and aortic cross-clamping were performed in accordance with institutional protocols. Additionally, temporary pacing wires were not frequently utilized for postoperative rhythm control in all patients. The indications and duration of usage were assessed according to the patient's postoperative rhythm condition, with decisions made individually for each case.

In this research, no artificial intelligence–assisted technologies were used, like Large Language Models, chatbots, or image generators.

Ethics Approval and Consent to Participate

The study protocol was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Research Ethics Committee (decision date: October 17, 2022; decision number: 2022/295). Informed written consent was obtained from all the patients.

Statistical Analysis

The data was analyzed using the SPSS 26 statistical analysis software (IBM Corp., Armonk, NY, USA). In the study, continuous variables were represented as mean±standard deviation or median (min-max), while categorical data were represented as counts and percentages (%). Before analyzing the intergroup comparison, a normality assessment was performed with the Shapiro–Wilk test. To compare continuous variables between groups, the independent samples *t*-test was used for normally distributed data, whereas the Mann–Whitney *U*-test was utilized for non-normally distributed data. The chi-square test was used to compare categorical variables. The threshold for statistical significance was established at $P < .05$. Additionally, variables associated with PPM implantation were evaluated using multiple logistic regression analysis. Given the limited number of PPM events, a simplified modeling approach was used to reduce the risk of overfitting. Results are presented as odds ratios (ORs) with 95% CIs.

RESULTS

The mean age of the 276 patients in the study was 53.5 ± 16.15 years, with 50.4% (n = 139) being male. The majority of patients were aged between 41 and 60 (41.4%, n = 114). Atrial fibrillation was the predominant comorbidity, observed in

HIGHLIGHTS

- The need for a permanent pacemaker (PPM) after minimally invasive robotic cardiac surgery is a significant complication.
- In this study, the postoperative PPM implantation rate was determined to be 5.4%.
- Prolonged cardiopulmonary bypass time and surgical procedures involving both mitral and tricuspid valves were associated with the need for a PPM.
- The findings may contribute to the prediction of high-risk patients and the improvement of perioperative monitoring and pacing strategies.

22.5% (n=62) of patients, and preoperative left ventricular ejection fraction was 59.08% ± 9.80%.

Among the cardiac surgeries performed, 23.6% of patients underwent septal defect surgery (ASD, n=63; VSD, n=3), 51.4% (n=142) underwent mitral valve surgery, 6.9% (n=19) underwent coronary bypass surgery, 12% (n=33) underwent mitral and tricuspid valve surgery, and 6.2% (n=17) underwent various other procedures. The mean cross-clamp duration for the patients was 109.94 (±48.57) minutes, while the mean CPB time was 180.13 (±76.12) minutes.

Permanent pacemakers were implanted in 5.4% (n=15) of patients after robotic cardiac surgery. Among patients who underwent PPM implantation, 2 (13.3%) received a single-chamber ventricular pacemaker, whereas 13 (86.7%) received a dual-chamber pacemaker. The most common indication was complete atrioventricular (AV) block, accounting for 80% (n=12) of cases. Other indications were identified as sick sinus syndrome, paroxysmal complete AV block, and AF with slow ventricular response (Figure 1). The mortality rate in-hospital attributable to surgical complications among all patients in the study was 3.6% (n=10), but no mortality was observed in patients who received PPMs. The average duration for PPM implantation was determined to be 9.40 (±3.26) days after surgery.

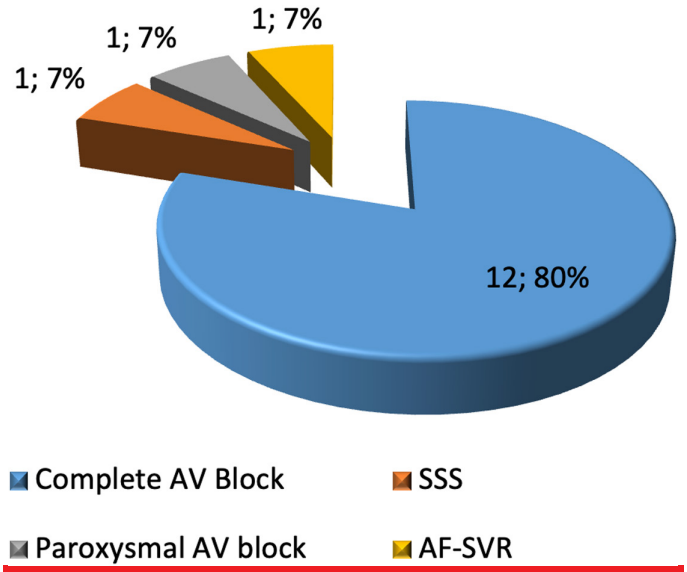

Figure 1. Distribution of clinical indications for permanent pacemaker implantation among patients who underwent robotic cardiac surgery. AF-SVR, atrial fibrillation with slow ventricular response, AV, atrioventricular; SSS, sick sinus syndrome.

Permanent pacemaker implantation was performed in 15 (5.4%) of the 276 patients included in the study. Patients who received PPM and those who did not showed comparable characteristics in terms of age, ejection fraction, preoperative PR and QRS durations, cross-clamp time, and the number of chronic diseases. However, the duration of CPB was significantly prolonged in the PPM group (210 minutes vs. 150 minutes; $P=.035$). Analysis by surgery type revealed a significant difference in the need for PPM ($P=.033$). The most significant need for PPM was noted in the mitral and tricuspid valve surgery cohort; while being at 12% of the total patient population, this group accounted for 40% of all PPM procedures performed. Although the incidence of PPM is low in patients undergoing septal defect (ASD/VSD) and mitral valve surgeries, it was not observed in all patients who underwent coronary bypass surgery (Table 1). Additionally, in the multiple logistic regression model, CPB duration, assessed per 10-minute increase, was not independently associated with PPM implantation (OR=1.01, $P=.863$, 95% CI: 0.93-1.09). In contrast, combined mitral-tricuspid valve surgery was independently associated with PPM implantation compared with other procedures (OR=4.78, $P=.024$, 95% CI: 1.23-18.52).

Table 1. Patient Distribution Following Robotic Heart Surgery, Classified by the Presence or Absence of a Permanent Pacemaker Implantation

	No PPM (n=261)		PPM implanted (n=15)		
Variables	**Median**	**Min-Max**	**Median**	**Min-Max**	***P***
Age (Years)	46	14-77	44.50	20-67	.601
Ejection fraction (%)	60	30-83	60	27-69	.305
Preop. ECG PR duration (ms)	140	84-260	150	124-225	.398
Preop. ECG QRS duration (ms)	92	5-180	95	78-136	.124
Cross-clamp time (min)	96	0-238	102.50	0-200	.506
Cardiopulmonary bypass time (min)	150	0-465	210	93-317	.035
Number of chronic comorbidities	0	0-3	0	0-1	.489
Type of surgery	n	%	n	%	*P*
Septal defect surgery	62	23.8	3	20.0	.033
Mitral valve surgery	137	52.5	5	33.3	
Coronary bypass surgery	19	7.3	0	0.0	
Mitral and tricuspit valve surgery	27	10.3	6	40.0	
Others	16	6.1	1	6.7	
Total	261	100.0	15	100.0	

ECG, electrocardiogram; ms, milliseconds; PPM, permanent pacemaker; PR, PR interval; QRS, QRS complex.

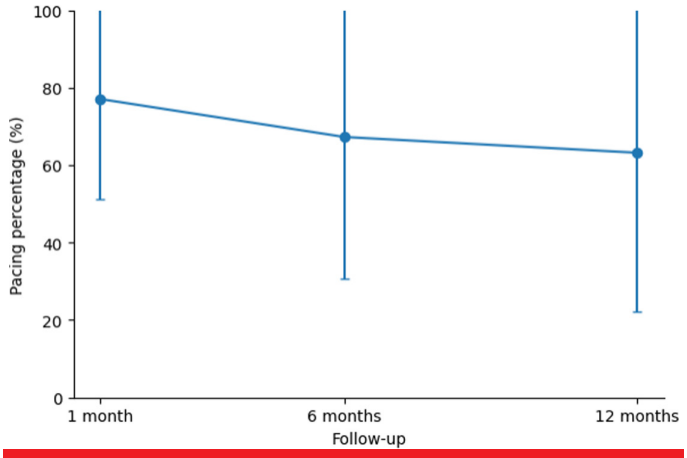

Figure 2. Pacing percentages during follow-up after PPM implantation. Data are presented as mean ± standard deviation.

Device interrogation data were available for all patients who underwent PPM implantation at the 1-, 6-, and 12-month follow-up visits. The mean ventricular pacing percentage was 77.05% ± 25.76 (range, 15.0%-99.8%) at 1 month, 67.26% ± 36.53 (range, 2.0%-99.7%) at 6 months, and 63.19% ± 41.03 (range, 1.7%-99.8%) at 12 months (Figure 2).

DISCUSSION

Although minimally invasive cardiac surgery and traditional cardiac surgery present very similar preoperative risks, a notable side effect is the occurrence of conduction abnormalities.[7,8] Research indicates that the incidence of PPM placement following heart surgery ranges from 0.8% to 34%.[4,8,9] PPM rates are similarly reported in percutaneous heart valve procedures.[10]

Data in the literature regarding the need for PPM after robotic cardiac surgery are limited and are not consistently reported in many robotic series. However, in a meta-analysis evaluating concomitant AF surgery with robotic mitral surgery, the PPM rate was reported to be 3.7%.[11] In this study, the rate of PPM implantation was found to be 5.6% (n = 15). Similar to the literature, the rate of PPMs was higher in patients undergoing valve surgery, and 62.8% (n = 11) of those who received a PPM were patients with valve surgery. Specifically, the rate of PPM was statistically significantly higher in robotic mitral and tricuspid valve surgery (n = 6) compared to other surgical types ($P = .033$). Among the reasons for this are the proximity of heart valves and their apparatus to the conduction system, which is thought to cause direct trauma, ischemic damage, and edema in the conduction system.

Studies have indicated an increase in the rate of PPM implantation, particularly among patients over 60 years of age.[12-14] The investigation revealed no statistically significant difference in the average age ratios between the groups that received PPMs and those that did not. Likewise, whereas several studies have identified a significant incidence of PPM implantation post-surgery in patients with diabetes mellitus and coronary artery disease,[14-16] the investigation revealed there was no difference.

Research indicates that prolonged CPB duration and aortic cross-clamp duration are risk factors for PPM implantation. In research conducted by Limongelli et al,[15] the average CPB duration was 112 minutes in the group requiring a pacemaker and 91 minutes in the group not requiring a pacemaker. Elahi and colleagues similarly discovered that the duration of CPB was, on average, 100 minutes longer in patients who received PM implantation post-surgery compared to those who did not undergo PM implantation.[17] The investigation corroborates existing literature, revealing that the duration of CPB was statistically significantly prolonged in individuals who underwent PPM implantation (210 minutes compared to 150 minutes; $P = .035$). Furthermore, the multiple logistic regression analysis revealed that although the duration of CPB did not retain its independent correlation with PPM implantation, combined mitral-tricuspid valve surgery was independently related to PPM implantation. This outcome is attributed to the adverse impacts on the conduction system, arising from the surgical complexity and prolonged duration. Prolonged CPB duration and restricted surgical visibility may elevate the risk of injury and ischemia-related injury to the conduction system.

Research indicated that an aortic cross-clamp duration >60 minutes was associated with an increased risk of PPM implantation.[18] In this study, although the cross-clamp time was longer in the group that received PPM (102.5 minutes vs. 96 minutes), the difference between the 2 groups was not statistically significant.

In this study, the average waiting time for PPM implantation was found to be 9 days, but the optimal timing for PPM implantation after cardiac surgery is unclear due to various factors. The American College of Cardiology/American Heart Association (ACC/AHA) guidelines do not provide a clear timeframe for PPM implantation and recommend individual decision-making. However, it is considered reasonable to perform the implantation within 3-5 days after surgery.[19] The European Society of Cardiology recommends observing patients who develop complete heart block after surgery for up to 3-7 days before PPM implantation and implanting it if there is no improvement.[20] In this study, the extended implantation time may have facilitated the repair of the cardiac conduction system. This may have resulted in a reduction in PPM implantation. However, due to the retrospective design, it would be inappropriate to reach a definitive conclusion on this issue.

Based on the assessment for pacemaker dependency, the long-term (12-month) pacing rates in patients with PPMs in this study were determined to be 63%. This rate is consistent with the literature.[5,21,22] A study by Raza and colleagues analyzed data from 6268 individuals who underwent cardiac surgery, including 141 patients who received PPM implants. The long-term pacemaker dependency of 90 patients was assessed for an average period of 4-5 years. The dependency on PM was determined to be 40% among the patients who were followed up. Subsequently, when patients with and without PM dependency were categorized into 2 groups, a prolonged CPB duration, a PR interval >200 milliseconds,

and a QRS duration >120 milliseconds were identified as correlating with long-term PM dependence.[4] In this investigation, the evaluation of preoperative ECGs revealed that the PR and QRS intervals were prolonged in the group undergoing PM implantation; nevertheless, no statistically significant difference was observed between the 2 groups.

Steyers III CM and colleagues' retrospective investigation revealed that the long-term pacemaker dependency rates for patients, with an average follow-up duration of 6 to 72 months, ranged from 32% to 70%.[5] When these findings and the study are assessed collectively, they suggest that conduction system problems post-surgery often become permanent due to several factors and that complete repair of the conduction pathways is unlikely in the long run. Consequently, it is evident that postoperative problems with communication require thorough assessment, and it is necessary to be ready for enduring rhythm abnormalities that may require PPM placement.

The study contributes to the literature by evaluating PPM implantation in the population undergoing minimally invasive robotic cardiac surgery, as well as the temporal trajectory of pacing burden during follow-up. In this respect, it adds real-world data specific to robotic surgery to the existing literature, which is mostly based on conventional or non-robotic minimally invasive surgical series. The findings suggest that cardiac conduction system-related outcomes should be evaluated more carefully, especially in patients undergoing combined mitral-tricuspid valve surgery. In patients experiencing postoperative conduction disturbances, the decision between early PPM implantation and careful rhythm monitoring to allow for possible spontaneous recovery should be meticulously evaluated on an individual basis. The findings underscore the importance of closer rhythm monitoring and tailored postoperative follow-up protocols, especially for patient populations at elevated risk for PPM implantation. However, the observational design of the study and the limited number of events restrict causal inference from the findings. Larger and multicenter studies will more clearly elucidate the determinants of PPM requirement and long-term device dependency in the robotic cardiac surgery population.

Study Limitations

This study has some limitations. The study is a single-center, retrospective analysis limited to patients who underwent robotic cardiac surgery. Consequently, the generalizability of the results is limited. Furthermore, the study lacks a comparable comparison group of patients who underwent non-robotic cardiac surgery. Consequently, the superiority or distinction of robotic cardiac surgery regarding PPM placement or pacemaker dependency in comparison to non-robotic surgery remains unassessable. The study is limited to comparing patients who received PPM implantation with those who did not, within the cohort who underwent robotic cardiac surgery.

In certain subgroups of robotic surgery, the limited number of PPM events diminishes the statistical accuracy of comparisons based on procedure type. Therefore, subgroup findings related to the type of surgery should be evaluated in a descriptive manner rather than producing definitive conclusions. Especially, the inclusion of different procedures within the same cohort increases clinical heterogeneity.

Multiple surgeons have conducted robotic cardiac surgeries. The retrospective dataset lacks data on surgeons' experience and case volume parameters, preventing an assessment of the influence of surgeon expertise on PPM implantation. Despite the fact that the procedures are performed inside a structured robotic surgery program and using an institutionally standardized technical approach, the potential impact of technical variations among surgeons cannot be totally ignored.

Pacing burden was limited to 12-month follow-up. Beyond 1 year, longer-term device follow-up data could not be obtained in a comparable manner for all patients because some patients were lost to follow-up and others did not have standardized follow-up assessments. Owing to the heterogeneity of follow-up data, a reliable median follow-up duration for the entire cohort could not be calculated. Finally, quality of life, functional status, and patient-reported outcomes were not systematically assessed in this study. Therefore, the impact of PPM implantation on patients' daily life could not be directly analyzed.

CONCLUSION

In patients having minimally invasive robotic heart surgery, prolonged CPB duration and concurrent mitral-tricuspid valve surgeries are substantial risk factors for PPM implantation. These patients require vigilant rhythm monitoring during the postoperative phase and meticulous observation of conduction abnormalities. Additionally, the possibility of a sustained high pacing requirement during follow-up should be considered in patients who undergo PPM implantation. In these patients, the decision to implant a PPM should be tailored to each individual, and the process must be meticulously evaluated.

Ethics Committee Approval: This study was approved by the Ethics Committee of Gülhane Training and Research Hospital, University of Health Science (Approval No: 2022/295, Date: 17 October 2022).

Informed Consent: Written informed consent was obtained from the patients who agreed to take part in the study.

Peer-Review: Externally peer-reviewed.

Author Contributions: Concept - Ö.E., H.K.K.; Design - Ö.E., S.Y.; Supervision - M.K., T.D.; Resources – A.A., M.Ç.; Materials – H.T., A.Ç., B.B.; Data Collection and/orProcessing – M.S.K., E.M., C.D.; Analysis and/orInterpretation – M.Ç., S.A., S.F.; Literature Search –E.Y., S.G., A.F.Y.; Writing – Ö.E.; Critical Review – O.E., C.B., U.Ç.Y.

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