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2021-00122).

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Glossary of abbreviations

aHR  Adjusted hazard ratio
AVB  Atrioventricular block
BMI  Body mass index
CI   Confidence interval
CTSN Cardiothoracic Surgery Trials Network
MACE Major adverse cardiovascular events
OR   Odds ratio
PPM  Permanent pacemaker implantation
TA   Tricuspid valve annuloplasty
TR   Tricuspid regurgitation

30-day pacemaker implantation rate after tricuspid annuloplasty is 14%. Risk factors were mitral surgery, ablation, and being operated in a low-volume center.

The 30-day pacemaker implantation rate following tricuspid annuloplasty varies from 3 to 15%. In a recent randomized trial of concomitant mitral and tricuspid operations, the incidence was higher than expected. The implantation rate in this nationwide study was 14%. Mitral valve surgery, surgical ablation and a low surgical center volume were associated with permanent pacemaker implantation.
Disclosures

SR - None

AT - Dr Taha receives consulting fees for being a member of the Medtronic European Advisory Board.

SJN - None

AA - Dr. Amabile receives consulting fees from JOMDD.

AG - Dr. Geirsson receives consulting fees for being a member of the Medtronic Strategic Surgical Advisory Board and from Edwards Lifesciences

MK - Dr. Krane is a physician proctor and a member of the medical advisory board for JOMDD, a physician proctor for Peter Duschek, is a medical consultant for EVOTEC and Moderna and has received speakers’ honoraria from Medtronic and Terumo.

DM – Dr Mörtsell works as a proctor and has received lecturing honoraria from Medtronic, Abbott and Boston Scientific and is a member of advisory boards for Medtronic and Abbott for pacemaker and implantable cardioverter defibrillator development, unrelated to the present study.

JS – None

AJ – Dr. Jeppsson has received consulting fees from AstraZeneca, Werfen, and LFB Biotechnologies unrelated to the present study.

AM - None
Abstract (250/250 words)

Objective

Tricuspid valve ring annuloplasty (TA) is associated with increased risk of atrioventricular block, and subsequent implantation of a permanent pacemaker (PPM). However, the exact incidence of PPM, associated risk factors, and outcomes in this frame remain debated. The aim of the study was to report PPM incidence, risk factors, and outcomes following TA from nationwide databases.

Methods

Using data from multiple Swedish mandatory national registries, all patients (n=1502) who underwent TA in Sweden 2006-2020 were identified. Patients who needed PPM within 30 days from surgery were compared to those who did not. The cumulative incidence of PPM implantation was estimated. A multivariable logistic regression model was fit to identify risk factors of 30-day PPM implantation. The association between PPM implantation and long-term survival was evaluated with multivariable Cox regression.

Results

The 30-day PPM rate was 14.2% (214/1502). Patients with PPM were older (69.8±10.3 vs 67.5±12.4 years, p=0.012). Independent risk factors of PPM implantation were concomitant mitral valve surgery (Odds ratio (OR) 2.07 [95% CI 1.34-3.27]), ablation surgery (OR 1.59 [95% CI 1.12-2.23]), and surgery performed in a low-volume center (OR 1.85 [95% CI 1.17-2.83]). PPM implantation was not associated with increased long term mortality risk (adjusted hazard ratio 0.74 [95% CI 0.53-1.03]).
Conclusions

This nationwide study demonstrated a high risk of PPM implantation within 30 days of TA.

However, patients who needed a PPM did not have worse long-term survival, and the cumulative incidence of heart failure and MACE was similar to patients who did not get a PPM.

Keywords: tricuspid valve repair, tricuspid annuloplasty, pacemaker implantation,
Introduction

The most common mechanism of tricuspid valve insufficiency (TR) is annular dilatation secondary to mitral or aortic valve diseases. Functional TR is best addressed with tricuspid valve annuloplasty (TA). According to clinical guidelines, which are largely based upon observational studies, TA should be used liberally in patients undergoing left-sided surgery and who have severe TR. In addition, a recent prospective randomized trial showed that performing concomitant tricuspid valve repair for moderate TR or severely enlarged annuli at the time of mitral valve surgery, reduces progression of TR. One of the major concerns in performing TA is the proximity of the tricuspid valve to the atroioventricular node and the bundle of His, which makes the risk of postoperative bradyarrhythmia requiring permanent pacing particularly high.

The rate of PPM implantation following TA varies considerably in observational studies, ranging from 2.5% to 15.0%. In the abovementioned trial by Gammie et al., patients who underwent TA had a 30-day PPM implantation rate of 14.1%, and at 2-year follow-up, the total rate was 16.0%.

The incidence of PPM and associated risk factors are not fully understood, and this has not been investigated in contemporary multicenter studies. Furthermore, the long-term associations between PPM implantation after TA and long-term survival, incidence of heart failure, and major adverse cardiovascular events (MACE) have not previously been reported.

The aim of the study was therefore to report PPM incidence, to identify independent risk factors, and determine outcomes following TA using nationwide data from multiple mandatory Swedish registries.
METHODS

Study population

All patients in Sweden, who underwent tricuspid valve annuloplasty between January 2006 and December 2020, and who did not have a pacemaker at the time of surgery, were initially included. Exclusion criteria were: 1) placement of an implantable cardioverter defibrillator and 2) placement of a PPM the same day as tricuspid valve surgery. We excluded patients who had a PPM on the day of surgery as these PPM implantations are usually scheduled prior to the tricuspid valve surgery. Seven patients were lost to follow-up due to emigration during the study period. These patients contributed with follow-up time until the day of their emigration, at which time they were censored. A flowchart of the included and excluded patients is presented in Figure 1. The study was approved by the Swedish Ethical Review Authority with the approval number 2021-00122, approved March 31, 2021.

Data sources

The study population was collected from the Swedish Cardiac Surgery Registry, which is a part of the SWEDHEART Registry. (9,10) The registry holds information on all cardiac operations in Sweden since 1992 and had full coverage throughout the study period. In the registry, details of the performed surgery, preoperative patient data, and comorbid conditions are entered at the time of surgery. Everyone who lives in Sweden receives a personal identification number at the time of birth or immigration. This unique identifier was used to link the data from the Swedish Cardiac Surgery Registry with the National Patient Registry and the Cause of Death Registry. Both registries have nationwide coverage and reported excellent validity. (11,12) The National Patient Registry contains data regarding the primary and any secondary diagnoses that are associated with every hospitalization in the country. The financial reimbursement to the departments is
based on that these diagnosis codes are entered into the registries. Therefore, the accuracy of the registries tends to be satisfactory.(12) The Registries used the International Classification of Disease version 10 (ICD-10) during the study period, a list of ICD-10 codes used in the study can be found in Supplementary Table 1. The data was thereafter linked to the Swedish ICD and Pacemaker Registry, which has been operational since 1989. The Swedish ICD and Pacemaker Registry (http://www.pacemakerregistret.se) records data on all pacemaker procedures in Sweden and data is entered at the time of the procedure. It contains data on the type of electronic device implanted and the reason for device implantation. All centers in Sweden that offer cardiac electronic device implantation contribute to the Registry.

**Statistical analysis**

There were several outcomes estimated in the study, the first was PPM implantation within 30 days from the index procedure. Additional outcomes were the risk of mortality, heart failure or MACE: a composite of all-cause mortality, myocardial infarction, or stroke, in patients who had a pacemaker placed after tricuspid annuloplasty. Baseline data was stratified by pacemaker implantation within 30 days. Normally distributed continuous variables were presented as means with standard deviation (SD). Categorical variables are presented as numbers and frequency (percentage). Several variables had missing data, BMI (n=1, (0.07%)), left ventricular ejection fraction (n=8, (0.5%)) surgical center volume (n=530, 35.3%), tricuspid ring size (n=421), and type of ring model (n=254). Missing data was handled using multiple imputation, employing logistic regression or polytomous regression, as appropriate depending on the type of variable. The cumulative incidence of PPM implantation was estimated with the Kaplan-Meier function for the first 30 days. Long-term cumulative incidence was plotted with a cumulative incidence function where competing risk of death was taken into account. To identify risk factors associated
with PPM implantation within 30 days after TA, a logistic regression analysis was performed. The analysis was extensively adjusted, with adjustments decided on prior to analysis based on previous studies. The logistic regression analysis was adjusted for the following risk factors: age, sex, prior myocardial infarction, heart failure, low ejection fraction, atrial fibrillation, diabetes, concomitant coronary surgery, concomitant aortic valve surgery, concomitant mitral valve surgery, concomitant arrhythmia surgery, type of annuloplasty performed (use of ring or suture annuloplasty), if a ring was used, the size of the tricuspid ring used at the time of surgery, and operational volume of the hospital. Surgical case volume was dichotomized with hospitals with annual volume below 10 procedures were considered low-volume centers and hospitals with an annual volume of over 10 procedures were considered high-volume centers. Tricuspid annuloplasty size was dichotomized into large rings (31 mm or more) and smaller rings (30 mm and smaller). Sensitivity analyses were performed with tricuspid annuloplasty size as a continuous variable and another model where low volume center was excluded from the analysis. A multivariable logistic regression was performed to identify risk factors of late (>30 days) PPM implantation.

Long-term survival in the two groups was estimated with the Kaplan-Meier function. Cox proportional hazards models were used to calculate adjusted hazards ratios (aHR) with 95% confidence intervals (CI) associated with pacemaker implantation for MACE, heart failure and mortality. As these analyses were used to evaluate the association between pacemaker implantation within 30-days and long-term outcomes, all patients had to survive 30-days to be included. A sensitivity analysis evaluating long-term mortality, after one year of follow-up, and using the Kaplan-Meier was included, patients had to survive the first year after surgery to be included in this analysis. The proportional hazards assumption was tested with the use of scaled
Schoenfeld residuals, the model did not meet the assumption for MACE and all-cause mortality. Therefore, robust standard errors were used to account for the invalid hazards proportionality. The model was adjusted for the same variables as the logistics regression analysis. Sensitivity analyses were performed on the same Cox regression models were PPM implantation within 30 days was replaced with PPM implantation occurring between 30 days and 1 year after surgery. Using the Kaplan-Meier function, we also compared long-term survival in patients who got a pacemaker within the first year from surgery to those who did not get a pacemaker within the first year from surgery.

All tests were two-tailed and interpreted at the 0.05 significance level. All analyses were performed using R version 4.03 (R Foundation for Statistical Computing, Vienna, Austria).

**Ethical considerations**

The study was approved by the Swedish Ethical Review Authority (registration number 2021-00122). The need for individual patient consent in this retrospective, population-based study was waived by the committee. The linkage of the databases was carried out by the Swedish National Board of Health and Welfare (Socialstyrelsen) and the final dataset was handed over to the authors without personal identification numbers. The study was performed in accordance with the 1975 Declaration of Helsinki. The manuscript was composed in agreement with the suggestions in the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.
Results

Early incidence and cumulative incidence of PPM implantation

Out of 1,502 patients who underwent TA, 214 patients (14.2%) received a PPM within the first 30 postoperative days. The rate of PPM implantation was highest between 4 and 16 days after the surgery (Figure 2). Thirty-day mortality in the PPM group was 1.9% (n=4) compared to 3.8% (n=49) in the no-PPM group (p=0.22).

The cumulative incidence of PPM implantation with the Kaplan-Meier method is shown in Supplementary Figure 1. The estimated cumulative long-term PPM rate, where competing risk of death was taken into account, is shown in Figure 3. The 1-year PPM rate was 16.9% (95% confidence interval [CI] 14.9%-18.7%), the 2-year PPM rate was 17.9% (95% CI 16.0%-19.9%) and the 5-year rate was 20.5% (95% CI 18.5%-22.7%). The 30-day PPM rate per year during the study period is shown in Supplementary Figure 2. There was no significant association between year of surgery and the 30-day PPM rate. During the study period, a total of 7539 mitral valve surgeries (repair or replacement) were performed in Sweden on patients without previously implanted pacemakers and without TA. The proportion of patients undergoing mitral valve surgery who had concomitant TA was 13.0% (1127/8666). The incidence of PPM implantation following mitral valve surgery without concomitant TA was 6.2%.

Indications for PPM implantation

Overall, the most common indication for PPM was atrioventricular block (AVB) (70.1%, n=150/214), while the rest had sinus node dysfunction. The proportion of patients with AVB as
the indication was 75.8%, (n=69/91) in patients who had concomitant mitral valve surgery compared to 40.5% (n=30/74) in patients who had concomitant ablation surgery (p<0.001).

Unadjusted comparison of patients with and without PPM implantation within 30 days.
Baseline characteristics of both groups are shown in Table 1. The PPM group was older (mean age 69.8 years (SD 10.3) vs 67.5 years (SD 12.4), p=0.012). The sex distribution was similar in both groups. Patients in the PPM group were more likely to have had atrial fibrillation, to have had concomitant ablation surgery and to have undergone concomitant mitral valve surgery compared to patients in the no-PPM group. Mitral valve replacement was more common in the PPM group compared to the no-PPM group, while the proportion of mitral valve repair was similar in both groups. Compared to the no-PPM group, the PPM group received, on average, larger annuloplasty rings. Isolated TA was more common in the no-PPM group compared to the PPM group. The type of annuloplasty rings used during the study period are shown in Supplementary Table 2. The PPM rate in patients who underwent tricuspid suture annuloplasty compared to those who had a ring annuloplasty is shown in Supplementary Figure 3.

Factors associated with permanent pacemaker implantation
In multivariable analysis, mitral valve surgery, ablation surgery, and being operated in a low-volume center were independent risk factors of permanent pacemaker implantation within 30 days, Table 2. By fitting a risk model with the risk factors of concomitant mitral valve surgery, concomitant ablation surgery, and low volume center, a patient with any of the three risk factors would have had an OR of 2.43 (95% CI 1.22-5.39) to receive a PPM, a patient with two risk factors would have an OR of 3.08 (95% CI 1.54-6.88) while a patient with all three risk factors would have had an OR of 4.41(2.04-10.44). Two sensitivity analyses were performed: one
model with tricuspid ring size as a continuous variable and another where low center volume was excluded (Supplementary Tables 3 and 4). Risk factors of late PPM implantation, i.e. more than 30 days after surgery, are shown in Supplementary Table 5.

Associations between PPM implantation within 30 days and long-term outcome

The cumulative survival of the PPM group and the no-PPM group is shown in Figure 4. Long-term survival was significantly better in the PPM group compared to the no-PPM group. Figure 5 shows the adjusted hazard ratios of MACE, heart failure, and death associated with PPM implantation within 30 days from tricuspid valve annuloplasty. PPM was not associated with MACE or heart failure. The aHR for death from PPM implantation was 0.73 (95% CI 0.53-1.01), p 0.059. See Figure 6 for a graphical abstract of the study.

Sensitivity analyses on PPM implantation and long-term outcome

In unadjusted analysis, we found no significant difference in survival between all patients who got a pacemaker within one year from surgery compared to patients who did not get a pacemaker within a year from surgery (Supplementary Figure 4). We performed sensitivity analyses to see whether the hazard ratios from PPM implantation between 30 days and one year after surgery were any different than PPM implantation within 30 days of surgery. In these analyses PPM implantation was associated with aHR of 1.49 (95% CI 0.89-2.48, p=0.13) for all-cause mortality, aHR of 0.95 (95% CI 0.42-2.18, p=0.92) for heart failure, and aHR of 1.42 (95% CI 0.88-2.23, p=0.15) for MACE.
This nationwide study, with complete long-term follow-up, shows that there was a significant risk of PPM need following TA, with a PPM implanted in >14% of the patients during the first 30 days after surgery. In the recent Cardiothoracic Surgical Trials Network (CTSN) study by Gammie et al., patients who underwent concomitant tricuspid annuloplasty for moderate tricuspid regurgitation or dilated tricuspid annulus during surgery for degenerative mitral regurgitation, had a similar risk of PPM implantation as patients in the current study. Observational studies have reported pacemaker rates between 2.4% and 15% (5-7,14). The current data thus showed a rate at the higher end of this spectrum. Although these previous studies are valuable for comparison to the current study, it is important to note that the cohorts presented in these studies differ from the current cohort: an all-comers cohort where concomitant mitral valve surgery was performed in 75% only. In addition, the current study included patients who underwent suture tricuspid annuloplasty (DeVega annuloplasty).

Pacemaker implantation is associated with several short- and long-term complications such as thrombosis, infection, pacemaker-induced TR, and pacing-induced ventricular dysfunction. An area of uncertainty in previous studies on PPM following TA, has been the effect, if any, on long-term outcomes. In the present study, we could not determine the long-term risk of thrombosis, infective endocarditis, or grade of TR at follow-up. However, in unadjusted analysis, we were able to demonstrate that PPM implantation within 30 days following TA was associated with better long-term survival compared to no PPM implantation. In the adjusted Cox regression analysis, PPM was associated with a similar benefit (effect size) as seen in the unadjusted analysis, albeit with no statistical significance. We furthermore found that PPM implantation
within 30 days was not associated with increased hazard of readmission for heart failure and/or MACE.

The above results are in contrast to previously published findings, where right ventricular apex pacing has been shown to be associated with both heart failure and worse survival. (15-19) We therefore compared the long-term survival of patients who got a pacemaker within the first year from surgery to those who did not and found the estimated survival in these two groups to be the same. Furthermore, we performed sensitivity analyses on the hazards of getting a PPM between 30 days and 1 year after surgery. The model for all-cause mortality showed an aHR of 1.49 instead of the aHR of 0.73 seen in the original model. Although both models were non-significant, the sensitivity analysis shows that the patients who got a PPM within a year of surgery but after the initial 30 days may have had a higher hazard from PPM implantation than those who got a pacemaker within 30 days. A possible explanation for these findings may be that patients who received a permanent pacemaker within 30 days may have been healthier in some capacity and had a less complicated postoperative phase. In other words, there may be an inextricably attached confounding factor driving the outcome.

Our study demonstrated that being operated at a surgical center that performs fewer than 10 TA per year was a significant risk factor of PPM implantation. Technical factors are likely to play a significant role in the development of conduction abnormalities following TA. Given the previously well established relationship between right ventricular apical pacing and worse outcomes, it is important that all surgeons performing TA be very familiar with the anatomy of the tricuspid valve and that those who have little experience in performing TA learn from experienced colleagues how to minimize the risk of conduction abnormalities.
An important finding of this study was that the indication for pacemaker was primarily AVB. However, a significant proportion of the patients had sinus node disease as the main indication, especially in the subgroup of patients that had concomitant ablation surgery. Ailawadi et al. reported that 76% of patients in the CTSN trial had AVB (8), which is the same proportion as in patients who had concomitant mitral surgery in the current cohort. The findings that a majority of patients who had concomitant ablation surgery had sick sinus syndrome, suggests that many of these patients needed a pacemaker not because of the TA itself, but because a sinus node dysfunction caused by or unmasked by the ablation surgery.

The rate of PPM implantation was high early in the postoperative period and a significant proportion of patients got a PPM within 7 days from surgery. Some of the PPMs may have been implanted prematurely. However, the findings are similar to what was reported by Ailawadi et al., where the majority of pacemakers were implanted within 10 days of surgery (8). The current dataset did not contain data from pacemaker interrogations, and we could therefore not determine the proportion of patients who had restoration of sinus rhythm following PPM implantation.

The current study shows that the cumulative incidence of PPM continues to rise at late follow-up, which prompts the question whether the risk factors of late PPM implantation differ from risk factors for early PPM implantation. We found that age, female sex, and surgical ablation were predictors of late implantation. Surgical ablation was therefore an indicator of both early and late implantation.
Strengths and limitations

This study included all patients who underwent tricuspid valve repair in Sweden during a 15-year period. The study reflects real world practice using high-quality data from national registries. Patients with previously implanted pacemakers were excluded from the study, but the study had limited access to preoperative data regarding preexisting conduction abnormalities. Data on tricuspid annular size and the type of tricuspid annuloplasty ring was not available. Data on other surgical details such as aortic cross-clamp time had too many missing values to be used for statistical analysis. Data on lesion sets used in surgical ablation procedures were not available.

Conclusion

The current study showed that tricuspid valve repair with annuloplasty was associated with a high requirement of PPM implantation. The main risk factors for PPM were concomitant ablation surgery, concomitant mitral valve surgery, and being operated in a low-volume center. Early PPM implantation did not translate into higher long-term risk for heart failure, MACE, or mortality.
References


18. Udo EO, van Hemel NM, Zuithoff NP, Doevendans PA, Moons KG. Risk of heart failure- and cardiac death gradually increases with more right ventricular pacing. Int J Cardiol 2015;185:95-100.

### Table 1: Patient baseline characteristics of patients who had a pacemaker implanted within 30 days of tricuspid annuloplasty and patients who did not have a pacemaker implanted within 30 days of surgery.

<table>
<thead>
<tr>
<th></th>
<th>All patients (n=1,502)</th>
<th>Patients without pacemaker implanted (n=1,288)</th>
<th>Patients with pacemaker implanted (n=214)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (SD)</td>
<td>67.8 (12.2)</td>
<td>67.5 (12.4)</td>
<td>69.8 (10.3)</td>
<td>0.012*</td>
</tr>
<tr>
<td>Sex (male)</td>
<td>974 (64.8%)</td>
<td>831 (64.5%)</td>
<td>143 (66.8%)</td>
<td>0.51</td>
</tr>
<tr>
<td>BMI</td>
<td></td>
<td></td>
<td></td>
<td>0.068</td>
</tr>
<tr>
<td>-Underweight</td>
<td>120 (8.0%)</td>
<td>105 (8.2%)</td>
<td>15 (7.0%)</td>
<td></td>
</tr>
<tr>
<td>-Normal</td>
<td>665 (44.3%)</td>
<td>554 (43.0%)</td>
<td>111 (51.9%)</td>
<td></td>
</tr>
<tr>
<td>-Overweight</td>
<td>519 (34.6%)</td>
<td>453 (35.2%)</td>
<td>66 (30.8%)</td>
<td></td>
</tr>
<tr>
<td>-Obese</td>
<td>198 (13.2%)</td>
<td>176 (13.7%)</td>
<td>22 (10.3%)</td>
<td></td>
</tr>
<tr>
<td>Diabetes</td>
<td>143 (9.5%)</td>
<td>119 (9.2%)</td>
<td>24 (11.2%)</td>
<td>0.36</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Preoperative</td>
<td>951 (63.3%)</td>
<td>805 (62.5%)</td>
<td>146 (68.2%)</td>
<td>0.11</td>
</tr>
<tr>
<td>-New onset postoperative</td>
<td>227 (15.1%)</td>
<td>192 (14.9%)</td>
<td>35 (16.4%)</td>
<td>0.58</td>
</tr>
<tr>
<td>All AF</td>
<td>1,178 (78.4%)</td>
<td>997 (77.4%)</td>
<td>181 (84.6%)</td>
<td>0.018*</td>
</tr>
<tr>
<td>Heart failure</td>
<td>883 (58.8%)</td>
<td>776 (59.5%)</td>
<td>117 (54.7%)</td>
<td>0.19</td>
</tr>
<tr>
<td>Previous MI</td>
<td>132 (8.8%)</td>
<td>115 (8.9%)</td>
<td>17 (7.9%)</td>
<td>0.64</td>
</tr>
<tr>
<td>Previous stroke</td>
<td>130 (8.7%)</td>
<td>115 (8.9%)</td>
<td>15 (7.0%)</td>
<td>0.36</td>
</tr>
<tr>
<td>Perioperative endocarditis</td>
<td>72 (4.8%)</td>
<td>64 (5.0%)</td>
<td>8 (3.7%)</td>
<td>0.44</td>
</tr>
<tr>
<td>LVEF (&lt;50%)</td>
<td>672 (44.7%)</td>
<td>578 (44.9%)</td>
<td>94 (43.9%)</td>
<td>0.97</td>
</tr>
<tr>
<td>Coronary surgery</td>
<td>263 (17.5%)</td>
<td>231 (17.9%)</td>
<td>32 (15.0%)</td>
<td>0.29</td>
</tr>
<tr>
<td>Mitral surgery</td>
<td>1127 (75.0%)</td>
<td>944 (73.3%)</td>
<td>183 (85.5%)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>-Mitral valve repair</td>
<td>769 (51.2%)</td>
<td>659 (51.2%)</td>
<td>110 (51.4%)</td>
<td>0.95</td>
</tr>
<tr>
<td>-Mitral valve replacement</td>
<td>358 (23.8%)</td>
<td>285 (22.1%)</td>
<td>73 (34.1%)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Procedure</td>
<td>High Volume Center</td>
<td>Control</td>
<td>P-value</td>
<td></td>
</tr>
<tr>
<td>----------------------------------</td>
<td>--------------------</td>
<td>---------</td>
<td>---------</td>
<td></td>
</tr>
<tr>
<td>Aortic valve surgery</td>
<td>239 (15.9%)</td>
<td>211 (16.4%)</td>
<td>28 (13.1%)</td>
<td>0.22</td>
</tr>
<tr>
<td>Ablation surgery</td>
<td>374 (24.9%)</td>
<td>300 (23.3%)</td>
<td>74 (34.6%)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Isolated TA</td>
<td>152 (10.1%)</td>
<td>145 (11.3%)</td>
<td>7 (3.3%)</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Tricuspid ring size</td>
<td>32.4 (2.7)</td>
<td>32.4 (2.6)</td>
<td>32.9 (3.4)</td>
<td>0.034*</td>
</tr>
<tr>
<td>High volume center</td>
<td>1163 (77.4%)</td>
<td>988 (76.7%)</td>
<td>175 (81.8%)</td>
<td>0.99</td>
</tr>
</tbody>
</table>

AF, atrial fibrillation; BMI, body mass index; LVEF, left ventricular ejection fraction; MI, myocardial infarction; TA, tricuspid annuloplasty, SD, standard deviation; *Statistically significant
Table 2. Associations between pre- and perioperative factors and permanent pacemaker implantation within 30 days after surgery (multivariable logistic regression analysis).

<table>
<thead>
<tr>
<th>Factor</th>
<th>RR</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (per year)</td>
<td>1.01 (1.00-1.03)</td>
<td>0.09</td>
</tr>
<tr>
<td>Sex (Male)</td>
<td>1.10 (0.81-1.52)</td>
<td>0.56</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>1.10 (0.61-1.88)</td>
<td>0.75</td>
</tr>
<tr>
<td>Heart failure</td>
<td>0.79 (0.58-1.09)</td>
<td>0.15</td>
</tr>
<tr>
<td>LVEF &lt;50%</td>
<td>1.05 (0.76-1.43)</td>
<td>0.77</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>1.18 (0.76-1.87)</td>
<td>0.48</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>1.35 (0.81-2.16)</td>
<td>0.23</td>
</tr>
<tr>
<td>Coronary surgery</td>
<td>0.81 (0.52-1.23)</td>
<td>0.33</td>
</tr>
<tr>
<td>Mitral surgery</td>
<td>2.07 (1.34-3.27)</td>
<td>0.001*</td>
</tr>
<tr>
<td>Aortic valve surgery</td>
<td>1.06 (0.65-1.67)</td>
<td>0.81</td>
</tr>
<tr>
<td>Ablation surgery</td>
<td>1.59 (1.12-2.23)</td>
<td>0.008*</td>
</tr>
<tr>
<td>Suture anuloplasty</td>
<td>1.30 (0.90-1.85)</td>
<td>0.15</td>
</tr>
<tr>
<td>Tricuspid ring size &gt;30 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(only in patients with ring)</td>
<td>1.67 (1.00-2.91)</td>
<td>0.058</td>
</tr>
<tr>
<td>Low volume center</td>
<td>1.85 (1.17-2.83)</td>
<td>0.007*</td>
</tr>
<tr>
<td>Age (per year)</td>
<td>1.01 (1.00-1.03)</td>
<td>0.09</td>
</tr>
</tbody>
</table>

95% CI, 95% confidence interval; LVEF, left ventricular ejection fraction; OR, odds ratio
*statistically significant
Legends

**Figure 1:** Study flow chart

**Figure 2:** Kaplan-Meier curve showing the estimated rate of PPM implantation in the first 30 days following tricuspid valve repair (red line, percentage; shaded area, 95% confidence interval).

**Figure 3:** Cumulative incidence function curve showing the estimated long-term rate of PPM implantation following tricuspid valve repair (red line, percentage; shaded area, 95% confidence interval).

**Figure 4:** Kaplan-Meier curve comparing the cumulative survival in patients who underwent tricuspid valve repair with and without PPM within 30 days after surgery (red line, percentage; shaded area, 95% confidence interval).

**Figure 5.** A Forest plot showing the adjusted Hazard Ratios of MACE, Heart failure, and Death from PPM implantation following tricuspid valve repair. Adjusted for: age, sex, aortic surgery, coronary surgery, mitral surgery, myocardial infarction, arrhythmia surgery, heart failure, low EF (<50%), atrial fibrillation, diabetes mellitus.

**Figure 6.** Graphical abstract.

**Supplementary Figure 1:** Kaplan-Meier curve showing the long-term cumulative rate of PPM implantation (red line, percentage; shaded area, 95% confidence interval).
**Supplementary Figure 2:** Incidence of pacemaker implantation within 30 days after surgery, by year of surgery (red line, percentage; shaded area, 95% confidence interval).

**Supplementary Figure 3:** Kaplan-Meier curve showing the estimated rate of PPM implantation in the first 30 days following tricuspid valve repair in patients who had tricuspid annuloplasty with an annuloplasty ring compared to those who had tricuspid annuloplasty with a suture (De Vega annuloplasty). Red line, percentage; shaded area, 95% confidence interval.

**Supplementary Figure 4:** Kaplan-Meier curve showing the long-term survival in patients who got a permanent pacemaker within one year from surgery compared to those who did not get a pacemaker within the first year from surgery (red line, percentage; shaded area, 95% confidence interval).
Tricuspid annuloplasty

14.2% needed a pacemaker

Risk factors

Surgical ablation
Mitral surgery
Low-volume center
Patients with tricuspid annuloplasty 2006-2020 (n=1,570)

n=1,515

Patients who had ICD implantation (n=55)

Patients who had a pacemaker implanted the same day as the index procedure (n=13)

Final study population (n=1,502)
Survival

\[ p = 0.02 \]

<table>
<thead>
<tr>
<th>Strata</th>
<th>Years</th>
<th>Number at risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pacemaker</td>
<td>0</td>
<td>1288</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1043</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>813</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>560</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>367</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>192</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>81</td>
</tr>
<tr>
<td>Pacemaker within 30 days</td>
<td>0</td>
<td>214</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>141</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>106</td>
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<tr>
<td></td>
<td>8</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>13</td>
</tr>
</tbody>
</table>
**Adjusted model**

<table>
<thead>
<tr>
<th>Event</th>
<th>aHR (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MACE</td>
<td>0.90 (0.68-1.19)</td>
<td>0.45</td>
</tr>
<tr>
<td>Heart failure</td>
<td>0.99 (0.67-1.45)</td>
<td>0.94</td>
</tr>
<tr>
<td>Death</td>
<td>0.73 (0.53-1.01)</td>
<td>0.059</td>
</tr>
</tbody>
</table>
Pacemaker implantation following tricuspid annuloplasty

January 2006 - December 2020

1502 patients underwent tricuspid annuloplasty in Sweden

14.2% needed a permanent pacemaker within 30 days

Independent risk factors

Concomitant mitral valve surgery
OR 2.07
(95% CI 1.34-3.27)

Concomitant surgical ablation
OR 1.59
(95% CI 1.12-2.23)

Low surgical volume center
OR 1.85
(95% CI 1.17-2.83)

Long-term outcome

<table>
<thead>
<tr>
<th>Event</th>
<th>OR (95% CI)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MACE</td>
<td>0.69 (0.50-1.00)</td>
<td>0.05</td>
</tr>
<tr>
<td>Heart failure</td>
<td>0.98 (0.67-1.74)</td>
<td>0.94</td>
</tr>
<tr>
<td>Death</td>
<td>0.73 (0.39-1.37)</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Adjusted for age, sex, anti-coagulation, concomitant tricuspid surgery, and frailty, diabetes, and thrombosis.

Conclusion

- The pacemaker implantation rate within 30-days was high.
- Concomitant mitral valve surgery, ablation surgery, and low-volume center were risk factors.
- Pacemaker implantation was not associated with long-term risk of death, heart-failure or MACE.

CI, confidence interval; LVEF, left ventricular ejection fraction; MACE, major adverse cardiovascular events; OR, odds ratio
Pacemaker implantation following tricuspid valve annuloplasty: A SWEDGEHEART study

Sigurdur Ragnarsson, Amar Taha, Susanne J. Nielsen, Andrea Amabile, Arnar Geirsson, Markus Krane, David Mörtsell, Johan Sjögren, Anders Jeppsson, Andreas Martinsson
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Low surgical volume center
OR 1.85
(95% CI 1.17-2.83)

Long-term outcome

<table>
<thead>
<tr>
<th>Event</th>
<th>OR (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>MACE</td>
<td>0.09 (0.04-1.18)</td>
<td>0.45</td>
</tr>
<tr>
<td>Heart failure</td>
<td>0.26 (0.07-1.05)</td>
<td>0.04</td>
</tr>
<tr>
<td>Death</td>
<td>0.73 (0.39-1.37)</td>
<td>0.38</td>
</tr>
</tbody>
</table>

MACE: major adverse cardiovascular events; CI: confidence interval

Conclusion
- The pacemaker implantation rate within 30-days was high.
- Concomitant mitral valve surgery, ablation surgery, and low-volume center were risk factors.
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CI, confidence interval; LVEF, left ventricular ejection fraction; MACE, major adverse cardiovascular events; OR, odds ratio