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# Permanent pacemaker implantation following mitral valve surgery. State-of-the-art scoping review

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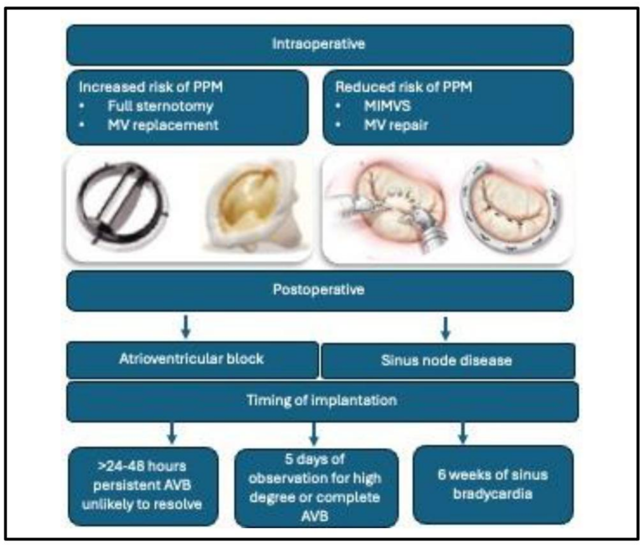
## Abstract

**Permanent pacemaker implantation following mitral valve surgery**

**Summary**

In adults undergoing mitral valve surgery, valve replacement vs. valve repair increases the risk of permanent pacemaker implantation, often due to AV block. Risk factors, timing (2–12 days), and procedural aspects influence outcomes. This review provides insights to guide clinicians and surgeons in managing post-operative rhythm disturbances and decision-making.




PPM-permanent pacemaker, MVS-mitral valve surgery, AVB-Atrioventricular block

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**OBJECTIVES:** This scoping review investigates the prevalence, indications, risk factors, timing and outcomes related to permanent pacemaker implantation following mitral valve surgery.

**METHODS:** A comprehensive search of PubMed, Embase and Cochrane databases was conducted to identify studies on permanent pacemaker implantation after mitral valve surgery. Relevant articles discussing prevalence, indications, risk factors, optimal timing, device choice and long-term dependency were included, prioritizing clinical studies and reviews published in the last 2 decades.

**RESULTS:** The incidence of permanent pacemaker implantation after isolated mitral valve surgeries varies from 1% to 10%, with observation periods ranging from 2 to 12 days across centres. Atrioventricular block is the most common indication. Risk factors include older age, atrial fibrillation, reduced left ventricular function and prior cardiac surgery. Patients undergoing mitral valve replacement face a higher risk compared to those having mitral valve repair, while minimally invasive surgery and left atriotomy approach are linked to a lower permanent pacemaker rate. Long-term pacemaker dependency ranges between 20% and 60%, with increased rates observed in patients with atrioventricular block or those operated in the setting of infective endocarditis.

**CONCLUSIONS:** This review highlights the complex interplay of factors influencing permanent pacemaker implantation after mitral valve surgery. Future research should focus on strategies to reduce postoperative conduction abnormalities and better identify patients who may require permanent pacemaker during long-term follow-up.

**Keywords:** Mitral valve surgery • Permanent pacemaker implantation • Risk factors • Timing • Dependency • Mortality

**ABBREVIATIONS**

| | |
|---|---|
| AF | Atrial fibrillation |
| AVR | Aortic valve replacement |
| CABG | Coronary artery bypass grafting |
| IE | Infective endocarditis |
| LBB | Left bundle branch |
| LV | Left ventricular |
| MAC | Mitral annulus calcification |
| MR | Mitral regurgitation |
| MS | Mitral stenosis |
| MVr | Mitral valve repair |
| MVR | Mitral valve replacement |
| MVS | Mitral valve surgery |
| PASE | Pacemaker Selection in the Elderly |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analyses |
| RCT | Randomized controlled trials |
| SA | Surgical ablation |
| SND | Sinus node disease |
| TA | Tricuspid annuloplasty |
| TEER | Transcatheter edge-to-edge repair |

## INTRODUCTION

Mitral valve disease is among the most prevalent indications for cardiac surgery and is experiencing significant growth in annual case numbers [1]. Mitral regurgitation (MR) is the most common indication for surgery followed by mitral stenosis (MS). Although there has been an increase in transcatheter procedures for MR in recent years, particularly transcatheter edge-to-edge repair (TEER), surgical mitral valve repair (MVr) remains the treatment of choice for symptomatic patients or asymptomatic patients with left ventricular (LV) dysfunction who are at acceptable surgical risk. Mitral valve surgery (MVS) is often accompanied by additional interventions including tricuspid or aortic valve surgery, coronary artery bypass grafting (CABG) or surgical ablation (SA) in patients with underlying atrial fibrillation (AF).

In the postoperative period, some patients who underwent MVS may require permanent pacemakers (PPM) due to symptomatic bradycardia resulting from sinus node disease (SND) or atrioventricular block (AVB). Several preoperative and intraoperative risk factors have been associated with this complication [2–8]. The need for PPM implantation has significant implications for both short- and long-term patient outcomes, influencing recovery, morbidity and healthcare utilization. However, there is no universally standardized approach to determine which patients require PPM implantation, as decisions often depend on individual physician discretion or institutional policies [9].

This scoping review was conducted to systematically map the existing research on PPM implantation following MVS. The primary objective was to identify key risk factors, timing and long-term dependency associated with PPM implantation in this patient population. Additionally, this review aimed to explore existing preventive strategies and knowledge gaps to guide future research and clinical decision-making.

## METHODS

### Search strategy

This review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines for scoping reviews. A comprehensive literature search was performed across 3 major electronic databases: PubMed, Embase, and Cochrane Library. The search was conducted to identify studies on PPM implantation following MVS. The search strategy included combinations of the following keywords: 'permanent pacemaker implantation', 'mitral valve surgery', 'atrioventricular block', 'risk factors', 'cardiac surgery', 'sinus node dysfunction', 'surgical ablation', 'tricuspid valve surgery', 'minimally invasive cardiac surgery'. The search strategy was adapted for each database and refined by reviewing relevant studies and their reference lists.

### Inclusion and exclusion criteria

Studies were included if they met the following criteria: Investigated PPM implantation following MVS, included adult patients undergoing MVr or replacement, with or without concomitant procedures, reported outcomes such as incidence, risk factors, timing, dependency or preventive strategies. Clinical studies [randomized controlled trials (RCTs), observational cohort studies, case–control studies] and narrative or systematic reviews published in peer-reviewed journals in the last 20 years (2004–2024) were included. Studies were excluded if case reports, conference abstracts or editorials, focused primarily on PPM implantation in congenital heart disease or paediatric populations, did not provide sufficient data on PPM implantation rates or were not in English.

## Data extraction and synthesis

Two independent reviewers (J.F. and M.Pa.) screened titles and abstracts for relevance, followed by full-text review to confirm eligibility. Data extraction was performed using a structured format, including study design, sample size, patient characteristics, surgical characteristics (e.g. surgical approach, concomitant procedures), PPM implantation rates, indication for PPM, risk factors and PPM dependency at follow-up. Disagreements were resolved through consensus or consultation with a third reviewer (M.K.). A PRISMA flowchart (Supplementary Material, Fig. S1) outlines the selection process. The extracted data were synthesized using a descriptive approach to summarize key findings from the included studies. Given the nature of the scoping review, no formal meta-analysis was conducted. Instead, results were presented in a tabular and narrative format to identify patterns, trends, and knowledge gaps related to PPM implantation following MVS.

## INCIDENCE

The incidence of PPM implantation after isolated MVS varies significantly between studies starting from <1%, reaching more than 10% of patients (Table 1). The wide margins are a result of heterogeneity of patients baseline characteristics such as preoperative SND and conduction system disorders, symptoms of sinus bradycardia or AVB and diverse operators' choices regarding surgical techniques or appliances [3, 5–7, 11]. A lack of clear recommendations leads to centre-specific practices and different operator experiences—different PPM implantation rates and timing. Furthermore, socioeconomic factors may influence the reported prevalence since reimbursement strategy may favour longer observation and implanting PPM after index hospitalization.

## INDICATIONS FOR PERMANENT PACING

The atrioventricular node, the bundle of His and the left bundle branch (LBB) are situated in the proximity to the posterior-medial commissure and anterior leaflet of the mitral valve. Histo-topographic study on 20 human hearts revealed that, in 50% of cases, AV node was at the level of mitral valve leaflet attachment, in the remaining cases, the distance was <2.5 mm [15]. Moreover, atrioventricular node artery, although its significance has been disputed, in a significant proportion of patients runs in the proximity of mitral annulus [16, 17]. Postoperative local oedema or direct mechanical injury to these structures may, therefore, result in advanced or complete AVB, which is the most common indication for PPM after MVS. The second most common indication is symptomatic sinus bradycardia, sino-atrial blocks, sinus pauses, junctional escape rhythm below 40 bpm or tachy-bradycardia syndrome—often pooled together as electrocardiographic features of SND. The reported indications for PPM implantation are presented in Table 2.

**Table 1:** Incidence of PPM implantation after mitral valve surgery

| Study reference | Incidence of PPM implantation after isolated MV surgery |
|---|---|
| **MV repair** | |
| Moskowitz *et al.* [2] | 3.5% |
| Kowalewski *et al.* [7] | 1.1% |
| Iribarne *et al.* [10] | 7.7% |
| **MV replacement** | |
| Moskowitz *et al.* [2] | 8.9% |
| Kowalewski *et al.* [7] | 1.8% |
| **Not specified** | |
| Koplan *et al.* [5] | 3.5% |
| Helmers *et al.* [6] | 7.8% |
| Chi *et al.* [11] | 2.5% |
| DeRose *et al.* [3] | 7.7% |
| Gammie *et al.* [8] | 2.5% |
| Leyva *et al.* [12] | 10.8% |
| Patel *et al.* [13] | 6.3% |
| Olsthoorn *et al.* [14] | 3.7% |

MV: mitral valve; PPM: permanent pacemaker.

## PREOPERATIVE RISK FACTORS

Several preoperative factors play a role in augmenting the risk of PPM implantation [2, 3, 20] (Fig. 1). From a pathophysiological standpoint, every factor that contributes to more vulnerable conduction system would increase the odds for PPM implantation after surgery. Thus, older age [2, 20], AF [20], LV dysfunction [20] and previous cardiac surgery have all been described to put patients at higher risk for PPM postoperatively. Moskowitz and colleagues, using a large New York state database, showed that older age and preoperative conduction disturbances increase the risk of PPM during index hospitalization, while peripheral artery disease, endocarditis, congestive heart failure and chronic kidney disease were found to be associated with a higher risk of PPM implantation between 30 days and 1 year after surgery. Several investigations pointed to the influence of sex on PPM implantation with a higher prevalence among men [12, 21]. This could be partly explained by the larger valve prosthesis used and greater comorbidity burden in male patients [22]. Moreover, between 20 and 80% of patients who had PPM implanted have had preoperative conduction disorders with clinically overt symptoms or electrocardiographic evidence [5, 18, 19]. Right bundle branch block has been repeatedly shown to be associated with a higher need for PPM, due to a risk of injury to LBB during MVS and finally advanced or complete AVB.

Koplan *et al.* created a 9-point 'Risk Score to Predict Permanent Pacing After Valve Surgery' [5] and so divided patients into low- (score of 0–1), moderate- (score of 2–3) and high-risk (score ≥4) groups. Authors used significant independent predictors that overlap with the most often mentioned elsewhere risk factors: left and right bundle branch blocks, PR intervals >200 ms in preoperative electrocardiogram (ECG), inclusion of tricuspid valve in a multivalve surgery, age ≥ 70 years

**Table 2:** Indications for PPM implantation

| Study reference | AV block | | Sinus node disease | Other rhythms | |
|---|---|---|---|---|---|
| Koplan *et al.* [5] | 63% | | 37% | | |
| Glikson *et al.* [18] | Complete block with narrow-complex escape | 37% | 11% | Nodal rhythm | 8% |
| | | | | AF <50 bpm | 7% |
| | Complete block with wide-complex escape | 18% | | Rapid AF with drug-induced pauses | 2% |
| | | | | Asystole | 7% |
| | Mobitz type II atrioventricular block | 3% | | Symptomatic carotid sinus hypersensitivity | 2% |
| | | | | New LBBB | 1% |
| | | | | Wenckebach block | 1% |
| | | | | Preoperative findings leading to postoperative PM | 5% |
| Onalan *et al.* [4] | 70% | | 20% | Slow AF | 11% |
| Raza *et al.* [19] | 55% | | 45% | | |
| Chi *et al.* [11] | 37.3% | | 22% | AF | 25.6% |
| DeRose *et al.* [3] | 51% | | 43% | | |

AF: atrial fibrillation; AV: atrioventricular; LBBB: left bundle branch block; PPM: permanent pacemaker.

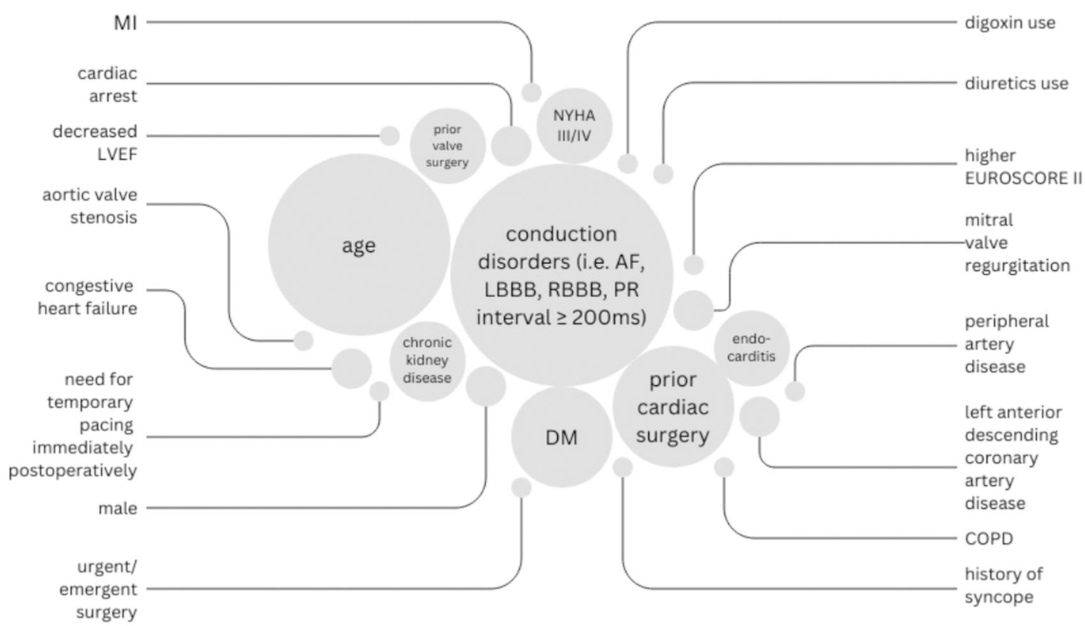


**Figure 1:** Preoperative characteristics predisposing to permanent pacemaker implantation after mitral valve surgery. Size of each bubble is an approximation the HR of each risk factor. AF: atrial fibrillation; DM: diabetes mellitus; LBBB: left bundle branch block; LVEF: left ventricular ejection fraction; MI: myocardial infarction; NYHA: New York Heart Association; RBBB: right bundle branch block.

and prior valve surgery. Nevertheless, as a simplified single-centre risk score, its reliability and clinical application remain unknown.

## PREVENTION

Several pharmacological strategies have been explored to mitigate the risk of postoperative AV conduction abnormalities, though data specific to MVS remain limited. One randomized controlled trial assessed the effectiveness of postoperative steroids, showing a significantly higher percentage of AV block resolution by day 5; however, this effect was no longer present by day 10, and the overall rate of PPM implantation remained unchanged between the steroid and control groups [23]. The study demonstrated the potential of steroids to temporarily improve conduction recovery, possibly by reducing postoperative oedema, but failed to establish a lasting benefit in preventing pacemaker dependency.

Beyond steroids, no other pharmacological interventions have been rigorously studied in the context of preventing conduction disturbances following MVS. While some research has examined pharmacological strategies in transcatheter aortic valve implantation, these findings may not be directly applicable given the differences in procedural mechanisms and patient populations. Given the lack of high-quality evidence, further studies are needed to determine whether pharmacological therapies or other preventive measures could effectively reduce the incidence of PPM implantation in this surgical setting.

## MITRAL PATHOLOGY

While MR is the most common indication for MVS, a significant percentage of patients undergo surgery due to MS or endocarditis as the primary indication. Moreover, MR is not a homogeneous entity; rather, it encompasses several distinct pathologies, most often divided into functional and degenerative MR.

There is evidence suggesting that the indication for MVS influences the rate of postoperative PPM. AVBs were shown to be more common after surgery for MS [17]. One study showed a higher prevalence of MS among patients who required PPM implantation; however, MS was not included in the risk factor analysis [6]. Of note, majority of MS patients undergo valve replacement, which itself is associated with a higher need for PPM postoperatively. Similarly, in endocarditis patients, the disease process itself may put patients at a higher risk for PPM implantation due to bacterial destruction of conduction system tissue. Several reports have suggested that endocarditis as a primary indication for surgery was associated with a higher risk of postoperative need for PPM [6, 7, 24, 25]. However, an analysis by Helmers showed that endocarditis was not an independent risk factor for PPM [6]. Notably, a study assessing the incidence and risk factors for PPM implantation after surgery for valvular endocarditis showed that mitral valve involvement was a negative predictor for the need for PPM implantation. This finding was likely caused by the more fulminant nature of aortic valve endocarditis with the formation of intracardiac abscesses in this patient cohort [26]. The authors listed preoperative conduction abnormalities, *Staphylococcus aureus* infection, intracardiac abscess, tricuspid valve involvement and previous valvular surgery as risk factors for PPM implantation in this setting. The ESC guidelines recommend that if any of the above conditions are met, intraoperative PPM placement should be considered [27].

Regarding MR type, Berdajs *et al.* showed no association between MR aetiology and the prevalence of AVB [17]. A single-centre registry focused mainly on the risk of adding tricuspid annuloplasty (TA) to MVr concluded that the risk of PPM associated with TA is significantly higher in degenerative disease but no different in functional MR [28]. Conversely, in the Cardiothoracic Surgical Trials Network (CTSN) RCT trial assessing SA, no significant associations were observed regarding PPM implantation and MR type; however, a trend was observed towards a higher prevalence in ischaemic MR (14.3% of patients with PPM had ischaemic MR vs 7.8% in the no PPM group). As of now, there is not sufficient evidence to draw a definite conclusion about the interaction between MR type and the need for PPM postoperatively.

## MITRAL ANNULUS CALCIFICATION

Mitral annulus calcification (MAC) poses a difficult task for surgeons during MV intervention. Its pathogenesis remains not fully understood and we typically divide it into 2 types: anterior and posterior. Posterior MAC is a primary degenerative process, often involving posterior leaflet, papillary muscle, part of the left atrial of LV wall. Anterior MAC is usually associated with a pathology of aortic valve with calcification spreading down to mitral apparatus. Historically, in the Framingham study, MAC was described in 2.8% of the population, more prevalent in women and elderly [29]. Either by attempted decalcification or by forcing sutures through the calcium, the heart, conduction system may get damaged during surgery. The presence of MAC is associated with an increased postoperative mortality and higher risk for several complications, including PPM implantation, especially when the atrioventricular groove must be reconstructed with pericardial patch or 'sliding atrioplasty'. The incidence of PPM implantation in the setting of severely calcified mitral annulus historically was reported in up to 20% of the cases; however, more recent studies showed a prevalence of 7–9% [30, 31]. Of note, in older patients, the mitral valve replacement (MVR) without decalcification may be a preferable strategy to avoid prolonged operative times as well as the risk of involved cardiac structure rupture. When MAC is preserved for any reason, the likelihood of requiring a postoperative PPM has been reported to increase. This is attributed to the placement of deeper sutures, as surgeons aim to avoid direct decalcification [32]. Interestingly, in a series of 64 patients with severe MAC who underwent robotic MVr, no PPM implantation was necessary [33]. It should be noted that robotic mitral valve centres usually are highly experienced in MVS; therefore, the observed lower rate of PPM may reflect the surgeon's experience rather than the technique itself.

## SURGICAL ASPECTS

Different operative techniques and concomitant procedures significantly impact the risk for PPM after MVS. MVR was found to carry greater risk than MVr [24]. Additional procedures, most prominently tricuspid intervention, biatrial AF SA and ganglionate plexi ablation were also associated with increased chance for PPM. The risk is also greater among patients with a history of previous cardiac surgery [24]. It is crucial to keep in mind here that PPM implantation is not a direct complication of surgery; rather, it results from conduction disturbances or sinus node dysfunction, which are the true complications.

## SURGICAL ACCESS

Minimally invasive MVS (MIMVS) has emerged as a promising alternative to traditional median sternotomy approaches, offering potential benefits such as reduced trauma, shorter hospital length of stay and faster recovery times. One notable aspect of this technique is its impact on the need for PPM implantation. Multiple propensity-matched studies have consistently shown that minimally invasive approaches may be associated with a lower incidence of postoperative PPM implantation compared to median sternotomy [34, 35]. Similar results were observed with the robotic approach [35]. It has been hypothesized that traction on the right atrium necessary to achieve adequate exposure of the left atrium during sternotomy (regardless of the access to the atrium) could cause damage to the right atrium conduction system and thus result in higher rates of PPM postoperatively [16]. The result may also be attributable to better visualization during MIMVS, which facilitates more precise suture placement. Reduced inflammation response and lower blood loss and need for postoperative transfusions could lead to fewer cases of transient conduction abnormalities and thus reduce the non-necessary PPM implantations. However, these results may be a surrogate of surgeon's experience—MIMVS is performed in experienced mitral centres and thus the surgeon's experience may bias the results [33–35]. A large retrospective study in high-volume centres comparing right anterior thoracotomy with partial upper sternotomy showed almost 16-fold reduction in PPM implantation postoperatively in the right anterior thoracotomy group [36]. The authors point out that the result may be partially attributable to greater prevalence of transeptal approach to mitral valve in the partial upper sternotomy group. Overall, the adoption of MIMVS holds a strong promise for reducing the incidence of postoperative pacemaker implantation.

In recent years, transcatheter mitral valve techniques have gained increasing attention as alternatives to conventional surgery. While a detailed analysis of PPM incidence following transcatheter procedures and its comparison to surgical approaches lies beyond the scope of this article, interesting comparisons have been made between transcatheter MVR and redo surgical MVR among patients with bioprosthetic valve failure. A recent meta-analysis suggested a lower PPM implantation rate in the transcatheter cohort; however, this finding was based on a limited sample size of just over 100 patients, highlighting the need for further investigation [37]. As transcatheter technologies continue to evolve, larger comparative studies will be essential to better understand their impact on conduction disturbances and PPM implantation rates.

The surgical approach to the left atrium has also been presumed to be a factor of possible automaticity and conduction disturbances requiring PPM. Most studies published focus on the difference between the left atrial versus transseptal approach (the anatomical differences are shown in Fig. 2). Several observed a higher rate of PPM implantation after the transseptal approach. The possible explanation lies in anatomical relations. The nodal artery, a branch of the right coronary artery supplying the sinus node artery, travels through the superior posterior border of the interatrial septum [38]. The injury to this vessel during incision of the septum may be the cause of postoperative heart rhythm disturbances. Moreover, the incision of the interatrial septum may lead to damage to interatrial pathways. Indeed, a case of persistent bradycardia after transeptal approach was followed by an electrophysiological study, which revealed that the cause of rhythm disturbances was interatrial conduction block caused by the incisional line [39]. On the other hand, the atrial conduction disturbances associated with the ligation of the nodal artery were described to be transient—regular atrial rhythm develops after approximately 2 weeks [40]. Some authors speculate that collateral blood flow to the sinus node develops or a new atrial rhythm originates from the coronary sinus area, which is clinically indistinguishable from normal sinus rhythm [41]. To date, no large randomized controlled trial has compared the 2 approaches; two small studies were conducted, which were underpowered for this comparison. One showed a higher prevalence of PPM implantation in the transeptal approach (10.6% vs 4.5%) [42], the other in the left atriotomy group (2.7% vs 4.0%) [43]. Data from observational studies are prone to bias since the transeptal approach is used in the context of the conventional sternotomy approach, and more often in patients with previous valve surgery, where best possible visualization and access are essential. The results are inconclusive—several studies showed higher prevalence of PPM [44–46] in the transseptal group others showed no differences [47, 48] although in many of them the rate of PPM implantation was higher in the transseptal group, without statistical significance. Indeed, one recent meta-analysis indicated a slightly higher prevalence of PPM after the transseptal approach [49]. Moreover, the transeptal approach is considered to generate longer operative times, whereas aortic cross-clamp has been repeatedly shown to be strongly associated with a higher prevalence of PPM implantation postoperatively. However, up till now, there is not enough evidence to determine whether access to the left atrium influences the PPM implantation risk.

An alternative, albeit less frequently utilized approach for mitral valve procedures involves the left atrium roof. The prevalence of PPM implantation after the atrial roof approach ranges from 2.4% to 4% [50, 51]. Additionally, a study comparing the atrium roof approach with transeptal and right-lateral approaches found no significant differences in pacemaker implantation rates between the groups [51].

## CARDIOPULMONARY BYPASS TIME, VALVE TYPE, REPAIR TYPE, CARDIOPLEGIA

The duration of aortic cross-clamp time has consistently been linked to an increased risk of PPM, as prolonged ischaemia poses a threat to heart conduction system cells [52]. Similarly, cardiopulmonary bypass time has also been associated with elevated risk, possibly due to prolonged exposure to cannulae leading to increased inflammatory response or as a proxy for technical challenges during surgery, potentially increasing the risk of sinus node and conduction system injury [19].

Regarding the type of prosthetic valve used, current evidence suggests it does not significantly affect the prevalence of PPM implantation [53]. A propensity-matched study showed no difference between biological vs mechanical bio prosthesis used in MVR and the risk for PPM. However, in MVr, annuloplasty ring placement was associated with an significantly increased risk for PPM implantation compared to annuloplasty with a band (5.8% vs 1.9%) [6]. Moreover, recent meta-analyses have indicated a higher prevalence of PPM implantation after "resect" MVr techniques compared to "respect" methods [54]. This difference may stem from the undersizing of mitral valve annuli more commonly seen in 'resect' repairs, leading to potential overstretching and subsequent AV node injury. Nonetheless, it is important to note that some studies included in these analyses had significantly higher rates of concomitant tricuspid valve surgery in the 'resect' group, potentially influencing the results. The observation that MVr techniques can influence postoperative pacemaker rates suggests that a percentage of pacemaker implants may not solely be attributable to surgical incisions and suture placements but also to changes in valve geometry post-repair. Indirect evidence supporting this notion can be drawn from analyses comparing TEER to neochord placement. For instance, a recent study comparing MV surgery with surgical repair with TEER reported an annual incidence of 7.4% for PPM implantation in the TEER group [55]. This incidence is unlikely to be solely attributable to septum puncture, given the rarity of PPM implantation after percutaneous left atrial appendage closure. Conversely, reports on transapical neochord placement, each involving over 200 patients, have shown no need for PPM implantation postoperatively [56, 57]. This suggests that techniques resulting in more tension on the mitral annulus may increase the risk of pacemaker placement.

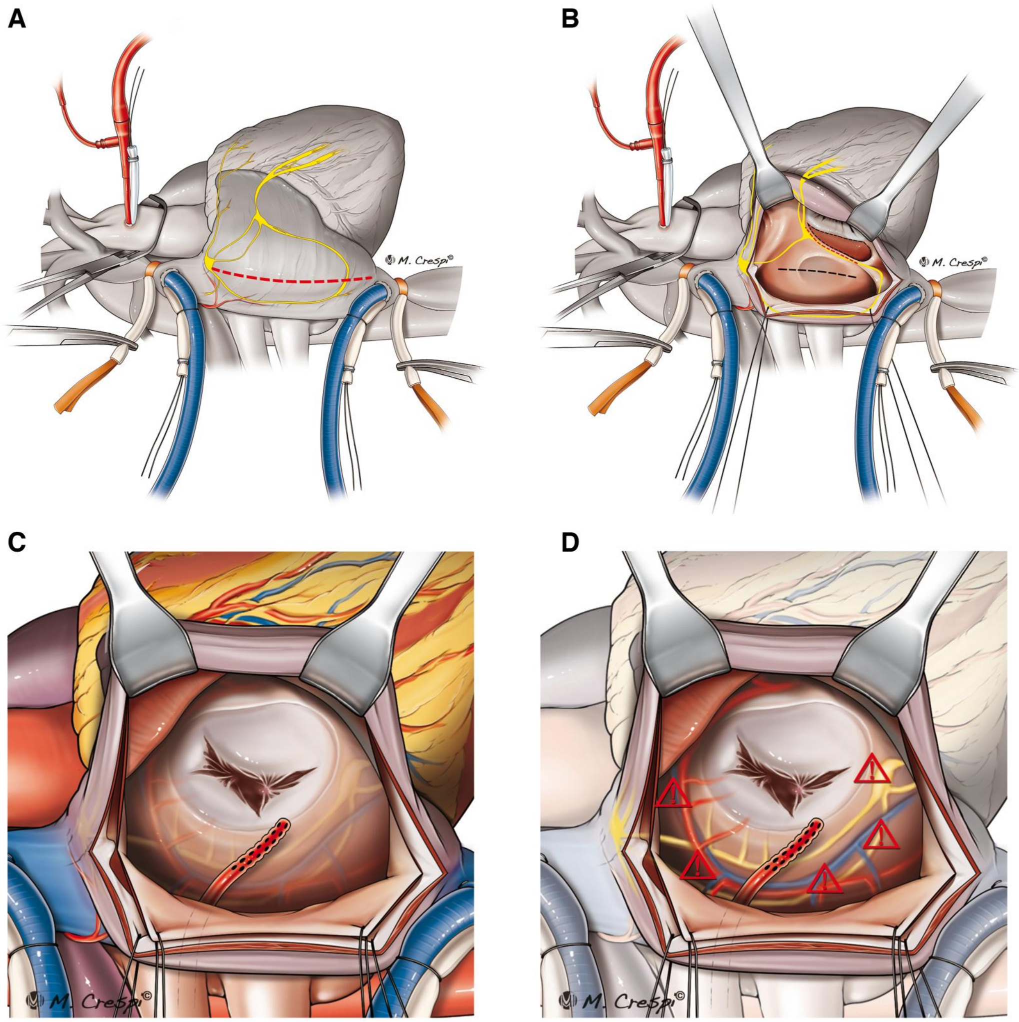


**Figure 2:** Surgical approach to mitral valve. Operative field view for mitral valve surgery (**A**). Incision line through the right atrium (red dashed line), together with the position of the conduction system elements: sinus node and accessory pathways. View after opening of the right atrium (**B**), with the incision line through the interatrial septum. Triangle of Koch is to be seen at the floor of right atrium together with atrioventricular node position against the preferred incision line (black dashed line). Operative view of the mitral valve after opening of the left atrium and stay sutures placement (**C**); posteromedial commissure of the mitral valve remains within close proximity to the bundle of His. Left vent positioned at the floor of left atrium. Detailed anatomical relationship of mitral valve annulus with surrounding critical structures (**D**): circumflex artery and its branches, bundle of His, left bundle branch and coronary sinus.

Several studies showed, in the context of CABG, an elevated incidence of postoperative heart rhythm disturbances following the use of crystalloid cardioplegia [58]. However, these disturbances predominantly manifested as fascicular blocks, often transient in nature. Conversely, in both CABG and valve surgeries, various studies have noted a heightened rate of PPM implantation after the administration of blood cardioplegia [59–61]. Notably, a study assessing patients undergoing isolated MVr revealed no significant differences in PPM incidence, although the rate was numerically 3 times less frequent in the crystalloid group (2% vs 6.4%) [60]. Future investigations comparing different cardioplegia types should prioritize examining their association with the necessity for postoperative PPM implantation [62].

## CONCOMITANT PROCEDURES

The influence of concomitant heart procedures, such as interventions on the tricuspid valve or treatment for AF, has been extensively studied and shown to significantly affect the likelihood of postoperative PPM implantation. This factor is likely the most significant determinant of pacemaker risk.

### Tricuspid annuloplasty

Tricuspid regurgitation often coexists with mitral valve disease, leading to about 15% of patients requiring tricuspid intervention during MVS [63]. However, due to the proximity of the atrioventricular node to the septal leaflet of the tricuspid valve, the addition of tricuspid valve repair or replacement poses an increased risk of postoperative heart block, necessitating PPM.

Several registries have identified TA as an independent predictor of postoperative PPM implantation. In a recent prospective randomized trial by CTSNET comparing TA with a conservative approach in patients with mild to moderate tricuspid regurgitation undergoing MVS, a significantly higher rate of pacemaker implantation was observed in the TA group (14.1% vs 2.5%). TA and age were the only factors independently associated with pacemaker implantation within 30 days, with no relationship found for TA implant size, concomitant Maze procedure, preoperative AF or access to the mitral valve. Importantly, pacemaker implantation did not affect mortality at 2 years, as there were no deaths in the pacemaker group. While previous RCTs did not report pacemaker rates, the numbers fell within the higher range reported in retrospective studies [63, 64].

In a single-surgeon analysis from an experienced mitral centre, the incidence of pacemaker implantation in patients undergoing mitral and tricuspid repair was reported at 2.4%, while an Society of Thoracic Surgeons (STS) analysis, representing a broader range of centres and surgeons, reported a higher rate of 14.5% [63, 64]. A recent nationwide study from the Netherlands by Olsthoorn *et al.,* encompassing over 1000 patients showed no significant difference in PPM implantation rates between MV surgery alone and combined MV + TA after adjusting for covariates. After robust sensitivity analysis, TV surgery was still not an independent risk factor for PPI [14]. The authors of the CTSN trial rightly highlight the importance of prospective follow-up in detecting pacemakers implanted after the index hospitalization, cases which may be inherently missed in retrospective registries. However, a recent analysis found that the prevalence of pacemaker implantation after TA is strongly associated with surgeon experience, with centres performing fewer than 10 tricuspid annuloplasties annually being an independent risk factor [65]. In the CTSNET trial, surgeon eligibility criteria required only 5 cases annually over a 2-year period.

In the context of MIMVS, recent analysis of an international registry also found a higher incidence of pacemaker implantation after the addition of TA (9% vs 5.8%) [66]. Authors have suggested that utilizing a beating-heart approach for tricuspid valve repair could potentially allow for early identification of rhythm disturbances induced by surgery, enabling prompt adjustments during the procedure, such as the removal of incorrectly placed annuloplasty sutures [66]. However, trials comparing both approaches have not shown significant differences in postoperative pacemaker rates [67–69]. Notably, in the CTSN trial, where 14% of tricuspid annuloplasties were performed on a beating heart, no patients required pacemaker implantation.

## Surgical ablation

Up to 60% of patients referred for MVS suffer from AF [68]. According to the 2024 ESC Guidelines, concomitant SA is recommended in the setting of MVS (class IA recommendation), and the prevalence of concomitant SA is increasing [70]. One of the concerns with SA is the presumed increased risk of PPM implantation. However, the Cox Maze IV-related right atrium lesion set does not include lines that run through the atrial septum or in proximity of the septal leaflet of the tricuspid valve (and thus AV node and bundle of His). Therefore, when adequately performed, Cox Maze IV should not increase the risk of AVB. On the other hand, SND is inherently associated with successful treatment of AF, which can unmask underlying sinus node insufficiency. This was demonstrated in a study where preoperative screening for sinus node dysfunction revealed that around 10% of patients had sinus node insufficiency. Among remaining patients 107 underwent Cox Maze IV and only 1 patient required PPM implantation (Supplementary Material S1). Moreover, the use of anti-arrhythmic drugs in patients with AF has been proved to increase the risk of PPM implantation 5-fold. Importantly, after successful SA, a junctional rhythm can often be observed due to surgical traction on the upper atrial pacemaker complex slowing the SA node rate, while left atrial lesions lead to the release of vagal suppression on the AV node, resulting in a faster AV node rate [16]. However, this phenomenon is temporary, and the decision to implant a pacemaker should follow a prolonged period of observation, which could also take place in an outpatient setting [16]. Implanting a PPM preemptively may contribute to the observed association between SA of AF during MVS and the increased risk of pacemaker implantation reported by Gillinov *et al.*, where the ablation group had a PPM implantation rate of 21.5% compared to 8.1% in the non-ablation group (per 100 patient-years, $P = 0.01$), with similar findings reported by DeRose *et al.* [3] (Supplementary Material S2). This interpretation is supported by Kowalewski *et al.*, who showed that SA itself is not an independent risk factor for PPM implantation. Moreover, when PPM implantation does occur after ablation, it does not adversely affect prognosis. In fact, the survival benefit associated with SA is sustained even in patients who ultimately require a pacemaker (log-rank $P < 0.001$) [7]. Additionally, the 2024 ESC Guidelines, based on contemporary data from 2011 to 2020, confirm that SA does not significantly impact the need for pacemaker implantation.

## TIMING AND CHOICE OF PACEMAKER SYSTEM

The timing of PPM implantation following MVS is a critical consideration, balancing the need for earliest possible discharge, reinforced by most reimbursement strategies, with the potential risks of unnecessary implantation due to conduction abnormalities that would otherwise resolve spontaneously. European guidelines recommend a period of 5 days of observation for high-degree or complete AVB. However, the authors point out that complete AVB with no or low escaped rhythm occurring within 24 hours of surgery and not resolving in 48 hours is unlikely to resolve, and the period of observation could be shortened [27]. For SND, the recommended period is 6 weeks. American guidelines do not recommend any specific observation period. There is significant variety in clinical practice, with studies reporting optimal observation periods ranging from 2 to 12 days [71, 72] (Supplementary Material S3). Studies showed that waiting longer than 5–7 days may lead to increased, rather than decreased, rate of PPM dependency at follow-up [13, 25]. An interesting study by Tindale and colleagues showed that retrospective analysis of the optimal waiting period is inherently biased, as the calculated optimal waiting period will always be close to the average waiting period in the reporting centre [73]. An appropriately designed RCT would be cumbersome to perform, as it should randomize patients to PPM implantation on each day of the reported spectrum and compare clinical outcomes and PPM dependency for each arm. Ultimately, a multidisciplinary approach involving close collaboration between cardiac surgeons, cardiologists, and electrophysiologists is crucial in individualizing management strategies and optimizing outcomes for patients undergoing MVS.

Clinical evidence, only if combined with patients' comorbidities, life-expectancy and goals of therapy, should result in a joined decision of the clinician and informed patient. Cardiac physiologic pacing seems advantageous in this multifactorial decision-making process [74]. However, studies of MVS patients still base on clinical [5] choice between single and dual-chamber devices.

Dual-chamber pacemakers constitute the majority of PPMs ranging from 54.3% up to 82% and 83% [3, 19, 75]. According to the Pacemaker Selection in the Elderly (PASE) study (Supplementary Material S4), dual-chamber pacing greatly benefits patients with SND but shows no benefit for AV block, the most frequent indication after MV surgery, as shown in this study. Single lead pacemakers constitute 13–34.3% [3, 19, 75] of PPM implanted but this percentage may be as high as 75% [76]. Isolated atrial pacing (recommended in SND) preserves the AV synchrony but is inappropriate in AVB. On the other hand, single-chamber ventricular stimulation can be used in all indications, but—according to ACC/AHA/HRS 2008 Guidelines [9]—right ventricular (RV) apical pacing may affect the possible benefits of pacing and negate it. Raza *et al.* and Onalan *et al.* [4, 19] have coinciding results, showing that a single RV apical lead stimulation is related to greater long-term pacemaker dependency than dual-chamber/single-chamber atrial pacing in a statistically significant way. In a similar case, Koplan *et al.* [5] recommend surgical epicardial ventricular pacing, even in a permanent mode, for patients with reduced LV ejection fraction, for whom RV pacing alone would be detrimental and insufficient haemodynamically. Despite the recommendations for biventricular pacing in the group of patients with reduced LVEF, it still constitutes only up to 1–11.4%, as outlined in Table 3.

According to 2023 HRS/APHRS/LAHRS guidelines, conduction system pacing including His bundle pacing and LBB area pacing are more likely to preserve or improve the LVEF than RV stimulation, especially when pacing requirements are substantial, i.e. >20–40% of the rhythm stems from the pacemaker [74]. However, long-term consequences and risk–benefit ratio of these pacing systems are still lacking: extraction considerations for deep septal leads, consequences of delayed RV activation, technical challenges seen in widely variable (80–100%) reported rates of procedural success, risk of unacceptably high His bundle lead capture threshold, dislodgment, loss of capture and oversensing (of atrial or His potentials) should be taken into consideration. This further decreases the chance of choosing these newer systems in such a specific scenario as MVS [74].

A specific scenario constitutes surgery due to infective endocarditis (IE). Since transvenous lead may precipitate IE recurrence, it seems reasonable to opt for epicardial lead placement intra-operatively, as is recommended in ESC guidelines. However, results of meta-analysis comparing epicardial implantation versus temporary pacing with subsequent endocardial placement in the context of PPM-dependent patients who require lead extraction due to infection, showed superiority of temporary pacing strategy (Supplementary Material S5). New, growing in popularity technologies, i.e. leadless PMs or subcutaneous implantable cardioverter-defibrillators (ICDs) could be the preferred choices in endocarditis patients with or without extraction of previous Cardiac Implantable Electronic Devices (CIEDs) to minimize the risk of reinfection. However, the long-term effectiveness is still under investigation and the risk of late infections is unknown (Supplementary Material S6).

Figure 3 lists preoperative, intraoperative and postoperative risk factors for PPM implantation together with long-term dependency risk factors and impact of implantation timing.

## DEPENDENCY

Although researchers agree that AVB strongly predicts PPM dependency, its definition differs in each research paper, and so do the percentages of long-term PPM-dependent patients: they vary from 30 to 60% [4, 18, 19]. As mentioned before, the conductive system may recover its sinus rhythm, when the adjacent tissue injury or oedema subsides, which can lead to independence from a freshly implanted pacemaker. However, it does not deem it unnecessary; PPM lets patients relieve their symptoms and clinicians weigh out the morbidity and cost of it compared with prolonged hospitalization for a temporary pacemaker [19]. The decision of PPM implantation and its timing is still based on individual preferences, socioeconomic background and reimbursement as well as centres' policies [7] instead of risk scores or guidelines.

Different studies show a variety of numbers concerning PPM dependency. The rates of PPM dependency across studies are presented in Table 4. Raza *et al.* found it to be 40% in the long term, while Merin *et al.* stated it to be 63% [19, 78]. In another study, 33% of patients were PM dependent due to AVB and 18% were dependent for non-AVB indication. New PM dependency had developed in 23% of the patients in that study [4]. As for prognostic clinical features, preoperative history of syncope, body mass index >28.5 kg/m$^2$, cardiopulmonary bypass time >105 min, PR interval >200 ms, preoperative LBBB and persistent postoperative third-degree AV block are shown to be predictors of long-term PM dependency (Table 4).

Onalan *et al.* compare dependency between patients undergoing different types of cardiac surgery [4]. Among patients with PM implanted for AVB indications, the ones after mitral surgery are less likely to be PM dependent, compared to those after aortic valve and coronary bypass surgery (33%, 49% and 42%,

**Table 3:** Pacemaker device type implanted after cardiac surgery

| Study reference | No. of patients with PPM | Dual chamber | Single chamber | Other systems | |
|---|---|---|---|---|---|
| DeRose *et al.* [3] | 35 | 54.3% | 34.3% | Biventricular | 11.4% |
| Greason *et al.* [75] | 146 | 82% | 13% | Single-chamber with an intracardiac defibrillator | 2% |
| | | | | Dual-chamber with an intracardiac defibrillator | 1% |
| | | | | Biventricular pacemaker | 1% |
| | | | | Biventricular with an intracardiac defibrillator | 1% |
| Jokinen *et al.* [77] | 28 | 25% | 75% | | |
| Onalan *et al.* [4] | 102 | 55.9% | 44.1% | | |
| Raza *et al.* [19] | 141 | 83% | 17% | | |
| Glikson *et al.* [18] | 127 | 37% | 63% | Epicardial | 6% |

PPM: permanent pacemaker.

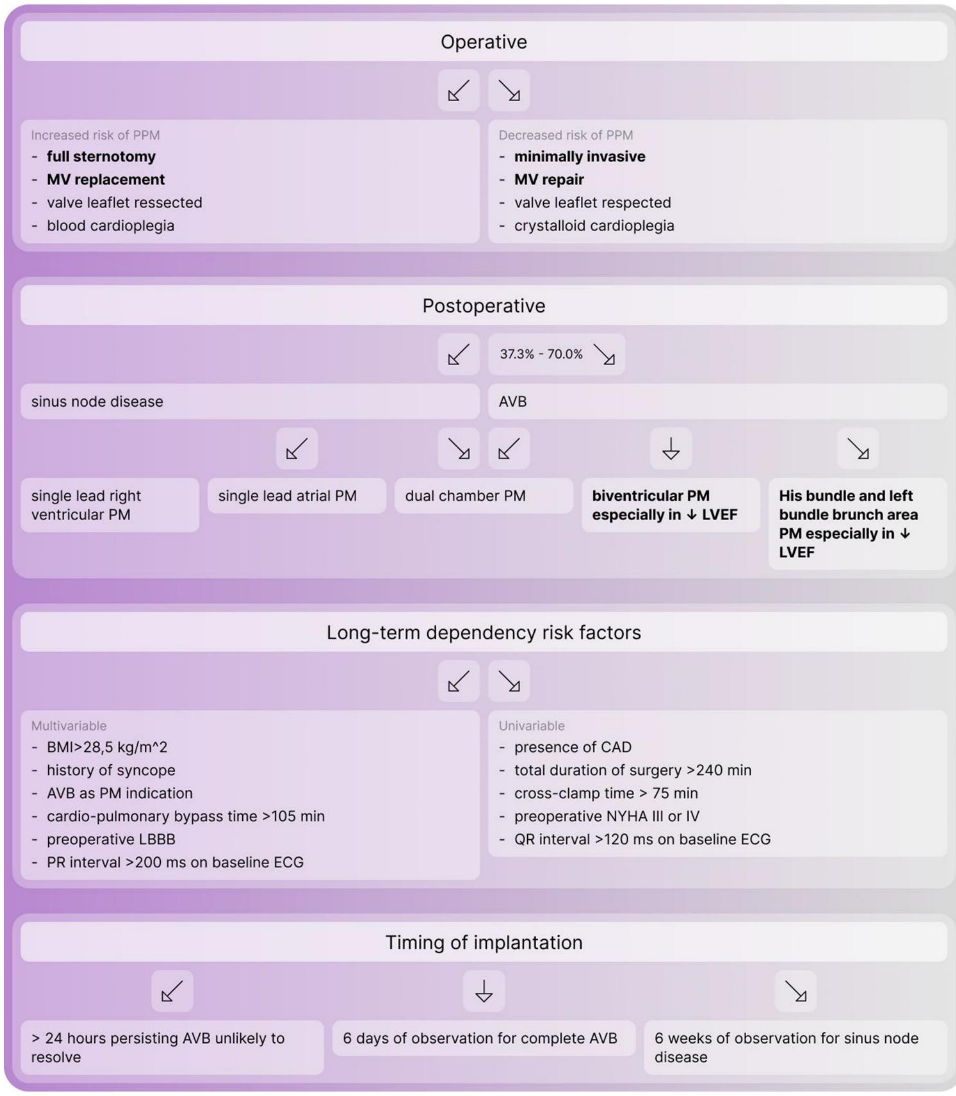


**Figure 3:** Summary of the evidence on permanent pacemaker implantation following mitral valve surgery. The intensity of the background's colour reflects the increasing risk of complications as the colour intensifies. Bolded pacemaker types as in recommendations. AVB: atrioventricular block; BMI: body mass index; COPD: chronic obstructive pulmonary disease; DM: diabetes mellitus; LAD: left anterior descending; LBBB: left bundle branch block; LVEF: left ventricle ejection fraction; MV: mitral valve; PM: pacemaker; RBBB: right bundle branch block.

respectively) [4]. At the same time, among patients with PPM due to non-AVB indications (sinus node dysfunction, slow AF), those after MVS are shown to be more PPM-dependent in long term, compared to patients after aortic valve and coronary bypass surgery (18%, 8% and 13%, respectively) [4]. In a study of endocarditis patients, not limited to mitral valve patients, of those available, 90% were PPM dependent at a mean follow-up of 4 years [29]. This result suggests greater PPM dependency in the setting of endocarditis compared to the general cardiac surgery cohort.

## COMPLICATIONS AND LONG-TERM MORTALITY

Patients undergoing MVS with subsequent PPM implantation may experience both short- and long-term complications. Early post-procedural risks include pocket infections, lead dislodgement, tricuspid regurgitation, and pacing-related arrhythmias, with reported short-term complication rates around 5% [25]. In the long term, patients remain at risk for heart failure and IE. A notable study by Iribarne and colleagues reported an almost 2-fold increase in the risk of IE among patients with PPM at a median follow-up of over 6 years. Similarly, the risk of heart failure hospitalization was significantly higher in the PPM cohort. Beyond heart failure risk, the impact of PPM implantation on long-term survival remains a subject of ongoing debate. While some studies on surgical aortic valve replacement (AVR) have found no significant impact of PPM on mortality, others—including Iribarne's study—have reported increased mortality in MVS with TA patients following PPM implantation [10] (Supplementary Material S7). Conversely, several other studies have found no significant difference in long-term survival between patients with and without PPM [7, 80] (Supplementary Material S8). Given these differences, further research is needed to distinguish whether increased mortality is

**Table 4:** Permanent pacemaker dependency across studies

| Study reference | Glikson *et al.* [18] | Onalan *et al.* [4] | Merin *et al.* [78] | Raza *et al.* [19] | Badoz *et al.* [79] | Bis *et al.* [71] | Patel *et al.* [13] | Waddingham *et al.* [25] |
|---|---|---|---|---|---|---|---|---|
| No. of patients that completed follow-up | 86 | 102 | 58 | 114 | 22 | 53 | 247 | 233 |
| Time of implantation postoperatively | 11 days median | 10 days median | 13 days median | 7 days median | 8 days median | 7 days median | 6.5 days median | 7 days median |
| Time of baseline dependency assessment | No data | 42 days median | No data | No data | No data | No data | No data | no data |
| Time of late dependency assessment | 41 months (median) | 32 months (median) | 72 months (median) | 67 months (median) | 38 months (median) | 29 months (median) | 141 days (median) | 6 months |
| Dependency definition | Even 1 occasion of continuous pacing (either ventricular or atrial) when the pacing rate was ≤50 or of tracking when atrioventricular delay was ≥220 | Presence of any pacing activity in VVI mode with a lower rate of 30 bpm | Paced rhythm with PPM turned down to 40 bpm for 40 s | 100% of the rhythm paced at 40 bpm for 30 s | Paced rhythm with PPM persisted at 40 bpm. Underlying heart rate showed high-grade AV block. 3rd-degree or 2$^{nd}$-degree Mobitz II | Absence of an intrinsic rhythm on sensing test in VVI mode at 40 bpm lasting up to 80 s | The PPM is not underutilized if there is more than 1% ventricular pacing between PPM interrogation visits, along with the absence of complete heart block and bradycardia <40 bpm | The PPM is not underutilized if there is more than 1% of A and V paced |
| Pacing rhythm threshold | 50 bpm | 30 bpm | 40 bpm for 40 s | 40 bpm for 30 s | 40bpm | 40 bpm for 80 s | 40 bpm | |
| **Causes of dependency and rates** | | | | | | | | |
| Overall | 59% | 32% | 63% | 40% | 22% | 41% | 87% | 46% |
| AVB | | 41% | | 49% | 71% | 82% | 100% | |
| Sinus node dysfunction (bradycardia) | | 15% | | 38% | 5% | 4% | Excluded | |
| Others | | 9% Brady-AF | | | 10% brady-AF | 14% brady-AF | | |
| **Late dependency predictors (in univariable analysis or in multivariable analysis)** | | | | | | | | |
| Clinical baseline | None | BMI 28.5 kg/m$^2$, history of syncope, presence of single-vessel LAD CAD | None | None | None | Hypertension 81% | None | None |
| Conduction baseline | None | AVB as PPM indication | Preop LBBB | PR > 200 ms and QRS > 120 ms on baseline ECG | None | Preop AVB 11% | AF, pre-existing LBBB or intraventricular conduction delay | None |
| Intraoperative and postoperative | Complete postop AV block, CPB time >120 mins, X-clamp time > 75 min. Preop NYHA III or IV complete AVB with narrow-complex escape | CPB time ≥105 min; X-clamp time >95 min, total duration of surgery ≥240 min, aortic valve surgery, use of stentless aortic valve, and PPM mode of DDD or VDD | Persistent postoperative 3rd-degree AVB | Prolonged CPB | Implantation ≥7 days after surgery aortic valve replacement surgery 3rd-degree AV block | X-clamp ≥61 min. CPB time ≥85 min; Aortic valve replacement ± other cardiac surgical procedures | Implantation of PPM <5 days, combined aortic and mitral valve surgery | Implantation <5 days postoperatively, AVB |

AF: atrial fibrillation; AVB: atrioventricular block; BMI: body mass index; CPB: cardiopulmonary bypass; DDD: dual chamber sensing and pacing; LAD CAD: left anterior descending coronary artery disease; LBBB: left bundle branch block; NYHA: New York Heart Association; PPM: permanent pacemaker; VDD: ventricle pacing, dual chamber sensing; X-clamp: aortic cross-clamp.

directly related to PPM implantation or primarily driven by underlying comorbidities, baseline ventricular function, or surgical complexity.

## CONCLUSIONS

In conclusion, this review underscores the complex interplay of factors influencing the need for PPM implantation following MVS. The variability in PPM incidence highlights the impact of diverse patient characteristics, surgical techniques, and concomitant procedures on postoperative outcomes. Identifying key risk factors such as age, pre-existing conduction disorders, and specific surgical approaches is crucial for optimizing patient management and reducing PPM dependency. Minimally invasive techniques have shown promise in mitigating the risk of conduction disturbances. However, the decision to implant a PPM must remain individualized and centre-related, considering each patient's clinical context and the potential for spontaneous recovery of sinus rhythm. Long-term follow-up is essential to evaluate the durability and complications associated with PPM, ensuring that the benefits outweigh the risks. Future research should focus on refining risk prediction models and exploring novel pacing strategies to enhance postoperative care. Ultimately, a multidisciplinary approach involving surgeons, cardiologists, and electrophysiologists is vital to improving outcomes for patients undergoing MVS.

## SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

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## DATA AVAILABILITY

All data are incorporated into the article.

## Author contributions

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Writing—review & editing. **Aleena Benny:** Data curation; Visualization; Writing—original draft. **Łukasz Kozłowski:** Data curation; Visualization; Writing—original draft. **Krzysztof Pawelczak:** Data curation; Visualization; Writing—original draft. **Sebastian Stec:** Conceptualization; Supervision; Writing—review & editing. **Łukasz Kuźma:** Conceptualization; Writing—review & editing. **Tomasz Urbanowicz:** Writing—review & editing. **Roberto Lorusso:** Conceptualization; Supervision; Writing—review & editing. **Piotr Suwalski:** Conceptualization; Project administration; Supervision; Writing—review & editing. **Mariusz Kowalewski:** Conceptualization; Investigation; Methodology; Project administration; Supervision; Visualization; Writing—review & editing

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Review