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STATE-OF-THE-ART REVIEW

Incidence, Predictors, and Implications of Permanent Pacemaker Requirement After Transcatheter Aortic Valve Replacement

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ABSTRACT

Transcatheter aortic valve replacement (TAVR) is a safe and feasible alternative to surgery in patients with symptomatic severe aortic stenosis regardless of the surgical risk. Conduction abnormalities requiring permanent pacemaker (PPM) implantation remain a common finding after TAVR due to the close proximity of the atrioventricular conduction system to the aortic root. High-grade atrioventricular block and new onset left bundle branch block (LBBB) are the most commonly reported conduction abnormalities after TAVR. The overall rate of PPM implantation after TAVR varies and is related to pre-procedural and intraprocedural factors. The available literature regarding the impact of conduction abnormalities and PPM requirement on morbidity and mortality is still conflicting. Pre-procedural conduction abnormalities such as right bundle branch block and LBBB have been linked with increased PPM implantation and mortality after TAVR. When screening patients for TAVR, heart teams should be aware of various anatomical and pathophysiological conditions that make patients more susceptible to increased risk of conduction abnormalities and PPM requirement after the procedure. This is particularly important as TAVR has been recently approved for patients with low surgical risk. The purpose of this review is to discuss the incidence, predictors, impact, and management of the various conduction abnormalities requiring PPM implantation in patients undergoing TAVR. (J Am Coll Cardiol Intv 2021;14:115–34)

Transcatheter aortic valve replacement (TAVR) is a safe alternative to surgery for the management of symptomatic severe aortic stenosis in patients at all levels of surgical risk (1,2). Despite improvements in procedural safety and efficacy, permanent pacemaker (PPM) implantation remains a common finding after the procedure compared with surgical replacement (3,4). Owing to the close proximity of the atrioventricular conduction system to the subaortic region, there is an inherent risk of mechanical injury with TAVR during guidewire insertion, balloon pre-dilation, and valve deployment. Hence, high-grade atrioventricular block (AVB) and new onset left bundle branch block (LBBB) may arise after TAVR (5). Several studies have tried to identify the anatomical, electrocardiographic, and procedural factors that could predict PPM implantation and better stratify the risk of conduction abnormalities after TAVR (6,7). Additionally, data regarding the impact of PPM implantation and

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ABBREVIATIONS AND ACRONYMS

AVB = atrioventricular block

BEV = balloon-expandable valve

CI = confidence interval

ECG = electrocardiography

H-V = His ventricular

HR = hazard ratio

LBBB = left bundle branch block

LVEF = left ventricular ejection fraction

PPM = permanent pacemaker

RBBB = right bundle branch block

SEV = self-expanding valve

TAVR = transcatheter aortic valve replacement

post-TAVR conduction abnormalities on morbidity and mortality are still unclear. This is particularly important, as the U.S. Food and Drug Administration has recently approved the use of TAVR for the low-risk population (8). This review will summarize the available literature about the incidence, predictors, and impact of conduction disturbances and PPM implantation in TAVR recipients.

METHODS

We conducted a systematic computerized search using PubMed and Cochrane databases through June 7, 2020. We manually screened the reference list against title and abstract and included randomized clinical trials, observational studies, multicenter registries, systematic reviews, and meta-analyses that reported incidence, predictors and outcomes of conduction abnormalities requiring PPM after TAVR. Case reports and papers published in a non-English language were excluded. Further, we manually added additional references when relevant.

DISCUSSION

INCIDENCE OF CONDUCTION DEFICITS AND PPM IMPLANTATION IN TAVR. The most common conduction disturbances after TAVR include high-grade AVB and new onset LBBB. However, almost half of these conduction abnormalities may improve over time even without PPM implantation due to resolution of the inflammation and edema caused during the TAVR procedure (5).

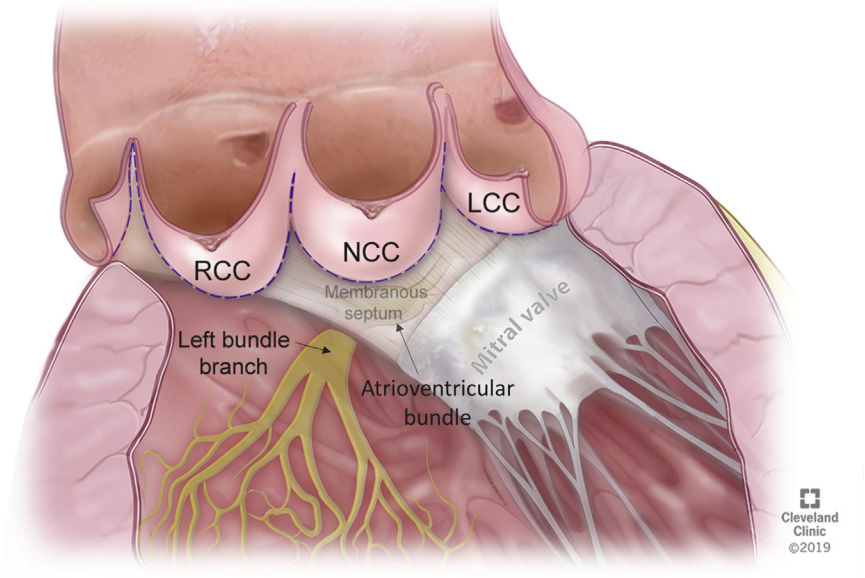
The rate of new onset LBBB after TAVR ranges from 4% to 65% depending on the valve type. The 2 most commonly used valves are the self-expanding Medtronic CoreValve series (Medtronic Inc, Minneapolis, Minnesota) and the balloon-expandable Edwards SAPIEN series (Edwards Lifesciences, Irvine, California). In studies that differentiate between these 2 valves, patients who received a CoreValve demonstrate a substantially higher rate of new onset LBBB (27%; range 9% to 65%) compared with those receiving an Edwards SAPIEN valve (11%; range 4% to 18%) (9). New onset LBBB occurs mainly during the procedure or within 24 h afterward, though delayed presentation (after 24 h) is also possible. Although approximately one-half of patients resolve their new onset LBBB, the rest either persist or progress to high degree AVB requiring PPM implantation (10,11).

HIGHLIGHTS

- Numerous pre-procedural and procedural factors impact the risk for pacemaker implantation after TAVR and are outlined in this review.
- Although there is a lack of consensus on the duration of post-TAVR telemetry monitoring and the indications for PPM implantation, high-grade AVB, and new onset LBBB remain the most frequent indications for PPM.
- PPM implantation and new onset LBBB seem to have adverse effects on morbidity and mortality after TAVR. The long-term impact of pacing in younger population remain uncertain.
- Consideration may be given to immediate post-TAVR testing of the atrioventricular conduction to better understand the need for PPM.

According to a recent systematic review, the overall rate of PPM implantation after TAVR with new generation valves ranged between 2.3% and 36.1%. The early generation Medtronic CoreValve resulted in a higher risk of PPM implantation (range 16.3% to 37.7%), which remained relatively high with the newer Medtronic CoreValve/Evolut R valve (range 14.7% to 26.7%), whereas the newest Edwards SAPIEN 3 valve resulted in a lower risk (range 4% to 24%) (12). These rates could be underestimating the actual magnitude of the problem because some of the reporting studies included patients with pre-existing pacemakers in the denominators while calculating the new PPM incidence rate after TAVR. The indications also varied between different centers and operators, which may also result in higher PPM implantation rates in some studies than in others (5). The most commonly reported indications of PPM implantation in the current TAVR practice are high-grade AVB, worsening or new onset LBBB, progressive first-degree AVB with LBBB, unstable nodal conduction, and symptomatic bradycardia (13). High-grade AVB requiring PPM implantation usually occurs within 24 h of TAVR but can also have a delayed onset after 48 h in up to 30% of all patients with high-grade AVB (5,14). A recent analysis of 9,785 patients from the Society of Thoracic Surgeons/American College of Cardiology TVT (Transcatheter Valve Therapy) registry reported a median time of

FIGURE 1 **Anatomical Relationship Between the Atrioventricular Conduction System and the Aortic Root**



The atrioventricular bundle passes within the infra-anterior portion of the membranous septum before it divides. The left bundle branch runs very close to the base of the commissure between the noncoronary cusp (NCC) and the right coronary cusp (RCC). LCC = left coronary cusp.

3 days (interquartile range: 1 to 6 days) from TAVR to PPM implantation (15).

PREDICTORS OF CONDUCTION ABNORMALITIES AND PPM IMPLANTATION IN PATIENTS SELECTED FOR TAVR. When screening patients for TAVR, heart teams should be aware of various anatomical and pathophysiological conditions that make a patient prone to higher incidence of conduction abnormalities and pacemaker requirement after the procedure.

Anatomy of the AV node and His bundle. The AV node is situated in the right atrium within the triangle of Koch just below its apex (made by the union of the tendon of Todaro and the tricuspid valve insertion), while the triangle base is made by the coronary sinus ostium (**Figure 1**). The AV node continues as the AV bundle or the bundle of His within the infra-anterior portion of the membranous septum. The AV bundle then passes on the left side of the central fibrous body before it penetrates the ventricular septum and divides into the right and left bundle branches. The latter runs very close to the base of the commissure between the noncoronary and the right coronary cusps. Due to this close proximity of the His bundle and the left bundle branch to the aortic annulus, many conduction abnormalities arise secondary to mechanical manipulation of the aortic root during either surgical or catheter-based aortic valve replacement that cause tissue inflammation, edema, or ischemia (5,16).

Operators should be aware of the different anatomical variations of the AV conduction system that could potentially increase the incidence of conduction abnormalities after TAVR. The His bundle commonly pierces the right side of the ventricular septum (50%) but can also penetrate the left side (30%), and rarely it courses under the membranous septum just below the endocardium (20%). Indeed, conduction abnormalities were found to be lower with the right-sided AV bundle variant as compared with the other 2 variants (17). The different anatomic levels at which the left bundle branch changes course from the deeper part of the ventricular septum to the superficial part may also play a role in the development of conduction abnormalities. The left bundle branch was found to be more prone to injury with an earlier exit from the ventricular septum (17).

Impact of pre-existing conduction abnormalities among patients undergoing TAVR. Pre-procedural conduction abnormalities such as pre-existing right bundle branch block (RBBB) (seen in usually 10% to 14% of the patients) and pre-existing LBBB (seen in

9% to 12%) have been linked with increased PPM implantation after TAVR (18–21). Among patients undergoing TAVR, limited data are available regarding the outcomes of patients with pre-existing LBBB. In a study of 3,404 TAVR recipients, 11.7% patients had LBBB at baseline. Presence of pre-existing LBBB was associated with a higher risk of PPM requirement at 30 days, but there were no differences in all-cause mortality or cardiovascular mortality. Patients with pre-existing LBBB also had lower baseline left ventricular ejection fraction (LVEF), but they were found to have similar LVEF improvement after the procedure without showing any difference in repeat hospitalization for heart failure (Supplemental Table 1). It is unclear from the available data whether the underlying cause of the higher incidence of PPM implantation in these patients is related to pre-existing LBBB or the development of new onset high-grade AVB after TAVR (18,22). In another analysis of 886 SAPIEN-3 recipients, baseline LBBB was not associated with PPM requirement at 30 days or all-cause mortality at 1 year after TAVR, however, it was associated with lower LVEF at both baseline and 1 year (23).

The presence of pre-existing RBBB has been established as 1 of the most consistent predictors of PPM implantation after TAVR. This is explained by the increased incidence of bradyarrhythmia and high-grade AVB if the left bundle branch is injured during valve deployment or balloon aortic valvuloplasty in patients with pre-existing RBBB (24–26).

Watanabe et al. (27) studied 749 SAPIEN-XT TAVR recipients, of whom 13.6% had RBBB which was associated with higher PPM rate, all-cause mortality, and cardiovascular mortality. Early cardiovascular mortality was also in the subset of patients with pre-existing RBBB who did not receive PPM after TAVR. Auffret et al. (5) reported similar outcomes in a larger cohort of 3,527 patients who received both balloon-expandable valves (BEVs) and self-expanding valves (SEVs). In this study, 10.3% patients had RBBB and were found to have higher rates of PPM implantation and increased all-cause mortality at 30 days, along with increased all-cause mortality, cardiovascular mortality and a composite of sudden cardiac death and PPM implantation at 2 years. In the subset of patients with pre-existing RBBB who did not receive PPM, the incidence of cardiovascular mortality was higher at 2 years when compared with those who had RBBB and received PPM after the procedure (19) (Supplemental Table 1). It is possible that this is the result of eventual high-grade AV block without evidence of PPM need immediately post-TAVR. However, the survival benefit of routine PPM implantation in TAVR patients with pre-existing RBBB would require further investigation and does not appear to be a practical strategy. Other strategies to further risk-stratify these patients are presented subsequently. Further, Sammour et al. (23) identified 886 patients who received SAPIEN-3 valves and found that baseline RBBB did not have a negative impact on all-cause death or LVEF at 1 year after TAVR. It also did not affect a composite of stroke, myocardial infarction, heart failure hospitalization and mortality (23).

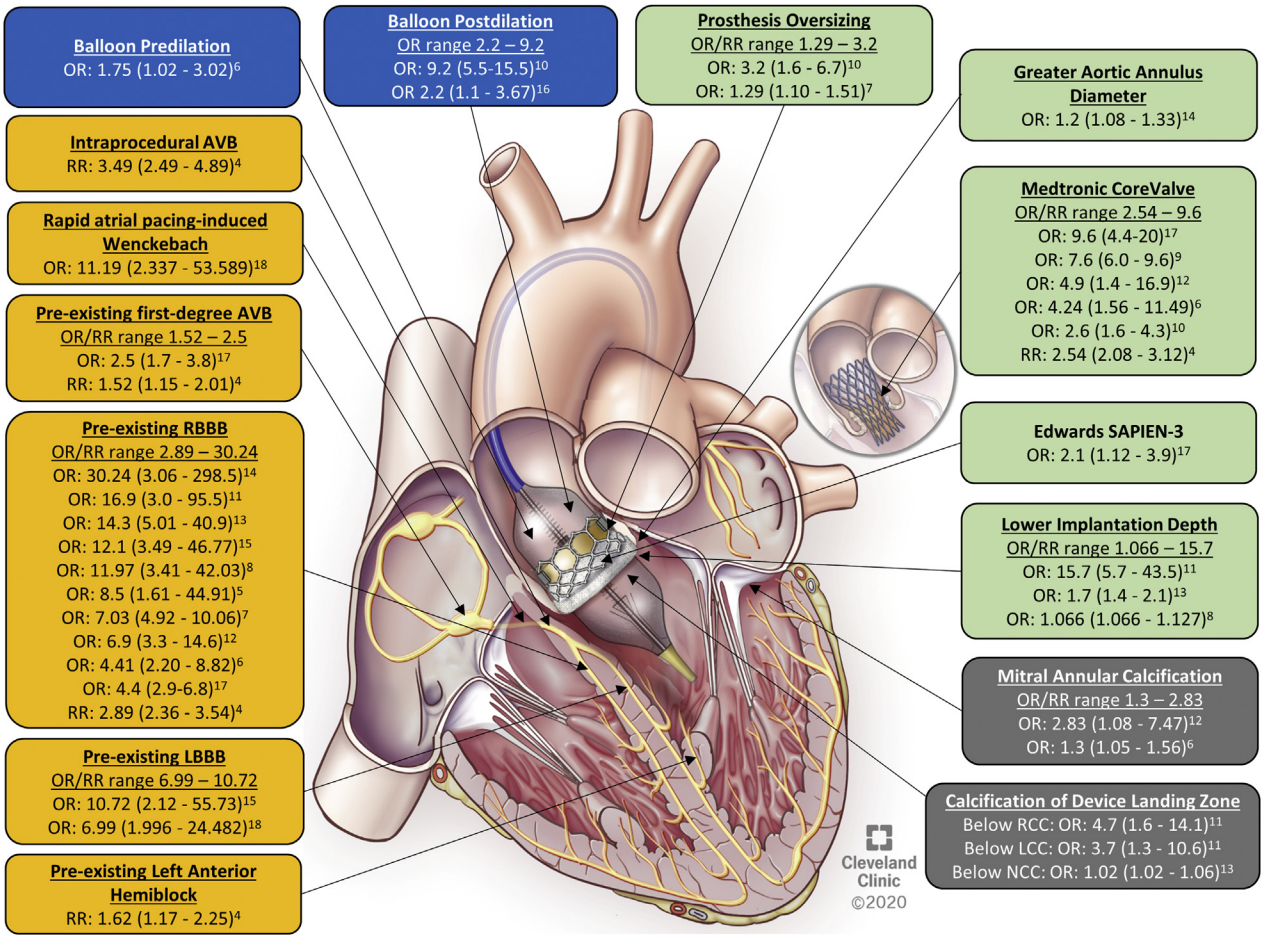
RBBB confers worse mortality in the general population, as well as in patients with systolic heart failure and myocardial infarction (26). Whether the risk of mortality among patients undergoing TAVR with pre-procedural RBBB is higher compared with the non-TAVR groups requires further investigation. It is worth mentioning that the separation of the survival curves in TAVR patients with pre-existing RBBB was found to be earlier suggesting a procedure related effect rather than a long-term effect of RBBB (26).

Demographic, clinical, and valve-related risk factors of conduction abnormalities and PPM requirement after TAVR. The pre-procedural predictors of new onset LBBB after TAVR include female sex, diabetes mellitus, prior coronary artery bypass grafting, first degree AVB, prolonged QRS duration, aortic annulus calcification, and larger left ventricular end-diastolic volume. Procedural factors include CoreValve implantation, transapical access, pre-dilation, oversizing, and lower implantation depth (5).

Siontis et al. (6) in their meta-analysis reported that men, along with patients receiving a CoreValve and those with RBBB, LBBB, first-degree AVB, left anterior hemiblock, and patients who developed intraprocedural AVB demonstrated a higher incidence of PPM implantation after TAVR. Subsequent studies have demonstrated numerous anatomic and electrocardiographic factors that contribute to increasing PPM risk as detailed in **Figure 2** and Supplemental Tables 2 and 3.

Given the higher risk of PPM implantation in patients receiving a self-expanding valve, it may be reasonable, especially in patients with pre-existing RBBB or LBBB, to consider a balloon-expandable valve with lower inherent risk of PPM after the procedure (5). Similarly, another important procedural factor that impacts PPM risk is valve implantation depth whether with SEVs or BEVs. In a prospective study by Jilaihawi et al. (28), the length of the membranous septum was specifically measured by computed tomography scan for each patient prior to TAVR. They found that implanting the

FIGURE 2 **Predictors of PPM Requirement**



Summary of the most commonly reported predictors of permanent pacemaker (PPM) with their respective odds ratios (ORs) or relative risks (RRs) and 95% confidence intervals (CIs) (references of the reported studies are available in the Supplemental Appendix). AVB = atrioventricular block; other abbreviations as in **Figure 1**.

CoreValve Evolut SEV at a depth less than the membranous septum length (as measured on computed tomography) reduced the PPM rates from 9.7% to 3% and new onset LBBB from 25.8% to 9%. Furthermore, patients who receive valve-in-valve have been reported to have lower rates of PPM requirement after TAVR. This could be related to the rigid structure of the stented valve that allows less compression of the conduction system compared with other TAVR recipients (29).

A recent study by Kiani et al. (30) developed the Emory Risk Score for the prediction of PPM requirement after TAVR. The scoring system included: history of syncope (1 point), RBBB (2 points), QRS interval ≥140 ms (1 point), and valve oversizing ≥16% (1 point). The score strongly predicted the need for PPM, with an area under the receiver-operating characteristic curve of 0.778 ($p < 0.001$) and an odds ratio (OR) of 2.2 per point increase ($p < 0.001$) (30). Shivamurthy et al. (31) validated another scoring system that included: baseline LBBB without bradycardia (2 points), sinus bradycardia without LBBB (3 points), baseline RBBB (3 points), LBBB and bradycardia (4 points), second-degree AVB (5 points), and transfemoral access (1 point) with area under the receiver-operating characteristic curve of 0.6743 (95% confidence interval [CI]: 0.618 to 0.729). The scoring system showed a 7% risk of PPM requirement with score ≤3, 19% with score 4 to 6, and 38% with score ≥7.

POST-PROCEDURAL RISK FACTORS OF PPM IMPLANTATION. Jorgensen et al. (32) investigated the predictive value of immediate post-procedural

TABLE 1 Clinical Impact of New Onset LBBB After TAVR

First Author (Ref. #)	Publication Date	Type of Study	Patients	Years of Study	Valve Type	Follow-Up Length
Houthuizen et al. (41)	2012	Retrospective analysis of a multicenter registry	679	November 2005–December 2010	57% SEV 43% BEV	15 months
Nazif et al. (36)	2013	Retrospective analysis of PARTNER trial and registry	1,151	N/A	100% BEV	1 yr
Testa et al. (38)	2013	Multicenter retrospective study	1,060	June 2007–April 2011	100% SEV	1 yr
Urena et al. (37)	2014	Multicenter prospective study	668	N/A	100% BEV	1 yr
Schymik et al. (42)	2015	Single-center retrospective study	634	May 2008–April 2012	81% BEV 19% SEV	1 yr
Regueiro et al. (9)	2016	Meta-analysis	4,756	2011–2015	64% BEV 36% SEV	1 yr
Walther et al. (40)	2018	Multicenter prospective study	198	December 2011–September 2015	100% SEV	1 yr
Jorgensen, et al. (43)*	2019	Single-center prospective study	816	2007– September 2017	83% SEV 9% BEV 8% MEV	30 months
Nazif et al. (44)	2019	Retrospective analysis of PARTNER II trial and S3 intermediate-risk registry	1,179	N/A	100% BEV	2 yrs
Chamandi et al. (39)	2019	Multicenter prospective study	1,020	May 2007–February 2015	52% SEV 48% BEV	3 yrs
Faroux et al. (45)	2020	Meta-analysis	42,927	2011–2019	N/A	1 yr
Hamandi et al. (77)	2020	Single-center retrospective study	424	January 2012–March 2016	87% BEV 13% SEV	1 yr
Sasaki et al. (78)	2020	Single-center retrospective study	230	January 2016–December 2018	87% BEV 13% SEV	14 months
Akdemir et al. (79)	2020	Single-center retrospective study	151	March 2012–June 2015	78% BEV 19% SEV 3% MEV	1 yr

*Impact of new onset BBB (96% new onset LBBB).

BEV = balloon-expandable valve; HR = hazard ratio; LBBB = left bundle branch block; LVEF = left ventricular ejection fraction; MEV = mechanically expandable valve; N/A = not available; PARTNER = Placement of Aortic Transcatheter Valves; PPM = permanent pacemaker; RR = relative risk; S3 = SAPIEN-3; SEV = self-expanding valve; TAVR = transcatheter aortic valve replacement.

electrocardiography (ECG) and found that patients who had no RBBB and were in sinus rhythm with PR interval <240 ms and QRS interval <150 ms or in atrial fibrillation with QRS interval <140 ms had a very low risk of new high-grade AVB within 30 days, rendering them safe for immediate removal of temporary pacemaker after TAVR. Toggweiler et al. (33) also found that normal immediate ECG after TAVR without first-degree AVB or bundle branch block predicted a very low risk of 30-day high-grade AVB and may not require telemetry monitoring. The problem with this strategy is that relying on early ECG does not take into account the delayed onset of conduction disturbances as mentioned previously. Further, more than one-half of the post-procedural conduction disturbances are self-resolving (34). Mangieri et al. (35) studied the utility of ECG after 48 h from TAVR, and found that pre-existing RBBB and longer PR interval predicted delayed advanced conduction disturbances and late PPM (≥48 h) requirement.

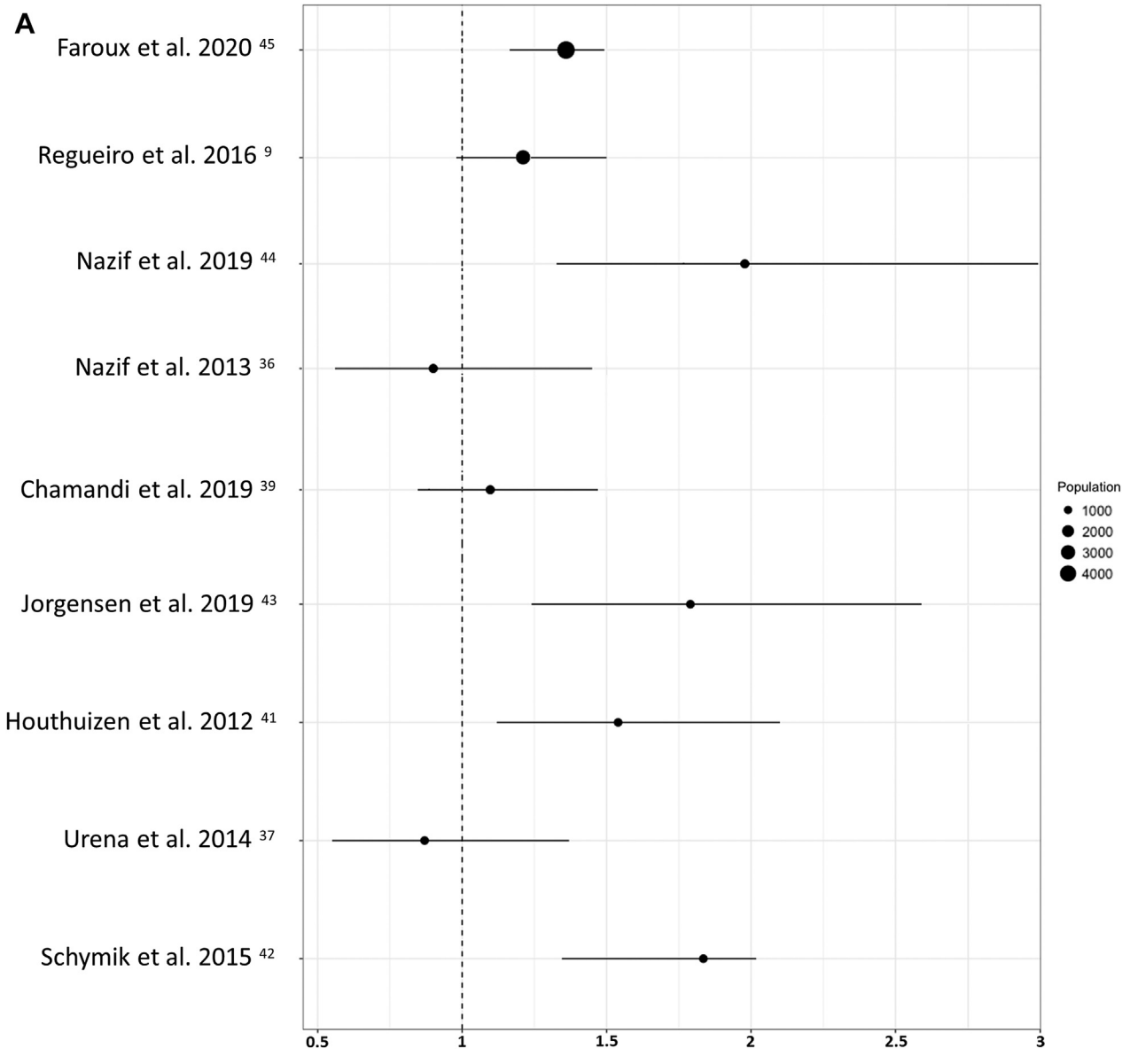
TABLE 1 Continued

Incidence of New Onset LBBB	Impact on PPM	Impact on All-Cause Mortality	Impact on Cardiovascular Mortality	Impact on LVEF
34% SEV 51% BEV 12%	N/A	Increased risk at 1 yr (26.6% vs. 17.5%) but not at 30 days	Increased risk (18% vs. 9.4%)	N/A
10%	Increased risk at 30 days (9.9% vs. 2.9%) and at 1 yr (12.9% vs. 4.3%)	No association	No association	Decreased LVEF at 6 to 12 months after TAVR
27%	Increased risk at 30 days (4.9% vs. 2%) but not at 1 yr	No association	No association	N/A
19%	Increased risk at 1 yr (13.4% vs. 3%)	No association	No association	Decreased LVEF after TAVR
31% SEV 47% BEV 27%	No association	Increased risk at 30 days (6.1% vs. 3.3%) and at 1 yr (20.8% vs. 13%)	N/A	N/A
22%	Increased risk at 1 yr RR: 2.18 (1.28–3.7)	No association RR: 1.21 (95% CI: 0.98–1.5)	Increased risk at 1 yr RR: 1.39 (95% CI: 1.04–1.86)	N/A
28%	No association	No association	No association	N/A
30% MEV 35% SEV 31% BEV 17%	Increased risk at 30 days (7.7% vs. 3.4%)	Increased risk of early mortality HR: 2.8 (95% CI: 1.18–3.67) and late mortality at ≥1 yr (48.4% vs. 32.8%) HR: 1.79 (95% CI: 1.24–2.59)	N/A	Decreased LVEF after initial improvement and increased risk of rehospitalization due to heart failure
15%	Increased risk at 30 days (5% vs. 1%) and at 2 yrs (12% vs. 4%)	Increased risk at 2 yrs (19.3% vs. 10.8%) HR: 1.98 (95% CI: 1.33–2.96)	Increased risk at 2 yrs (16.2% vs. 6.5%) HR: 2.66 (95% CI: 1.67–4.24)	Decreased LVEF at 2 yrs and increased risk of rehospitalization
20% SEV 37% BEV 6%	Increased risk at 3 yrs (17.7% vs. 9.4%)	No association	No association	Decreased LVEF recovery at 3 yrs No association with heart failure rehospitalization
N/A	Increased risk at 1 yr RR: 1.89 (95% CI: 1.58–2.27)	Increased risk at 1 yr RR: 1.32 (95% CI: 1.17–1.49)	Increased risk at 1 yr RR: 1.46 (95% CI: 1.2–1.78)	Increased risk of heart failure hospitalization at 1 yr
10% BEV 13% SEV 9%	No association at 30 days but increased risk from discharge to 1 yr (15% vs. 5%)	No association	N/A	N/A
39% (27% transient) SEV 31% BEV 10%	No association	No association	No association	Decreased LVEF at 1 yr with persistent LBBB
31% BEV 26% SEV 39% MEV 100%	Increased risk during index hospitalization, but not at 1 yr	No association	N/A	Decreased LVEF at 1 yr

LONG-TERM OUTCOMES AFTER NEW ONSET LBBB AND PPM IMPLANTATION IN PATIENTS UNDERGOING TAVR. Impact of new onset LBBB after TAVR. Intraventricular dyssynchrony secondary to LBBB can cause worsening of the LVEF, which may lead to ventricular arrhythmias, systolic dysfunction, and increased cardiovascular mortality (9). The available data about the impact of new onset LBBB in patients undergoing TAVR are scarce (**Table 1**).

Analysis of 1,151 patients from the PARTNER (Placement of Aortic Transcatheter Valves) trial showed that new onset LBBB developed in 10.5% of the study population. At 1 year, new onset LBBB resulted in a higher PPM risk and impaired LVEF recovery after the procedure but was not associated with higher all-cause mortality or cardiovascular mortality (36). In another cohort of 668 balloon-expandable TAVR patients, the incidence of new onset LBBB was 19.2%, immediately after the procedure. There was an increased risk of PPM implantation, failure of LVEF recovery, and worse New York Heart Association functional class in the group of patients who developed new onset LBBB as compared with patients without new onset LBBB.

FIGURE 3 Impact of New-Onset Left Bundle Branch Block on All-Cause Mortality

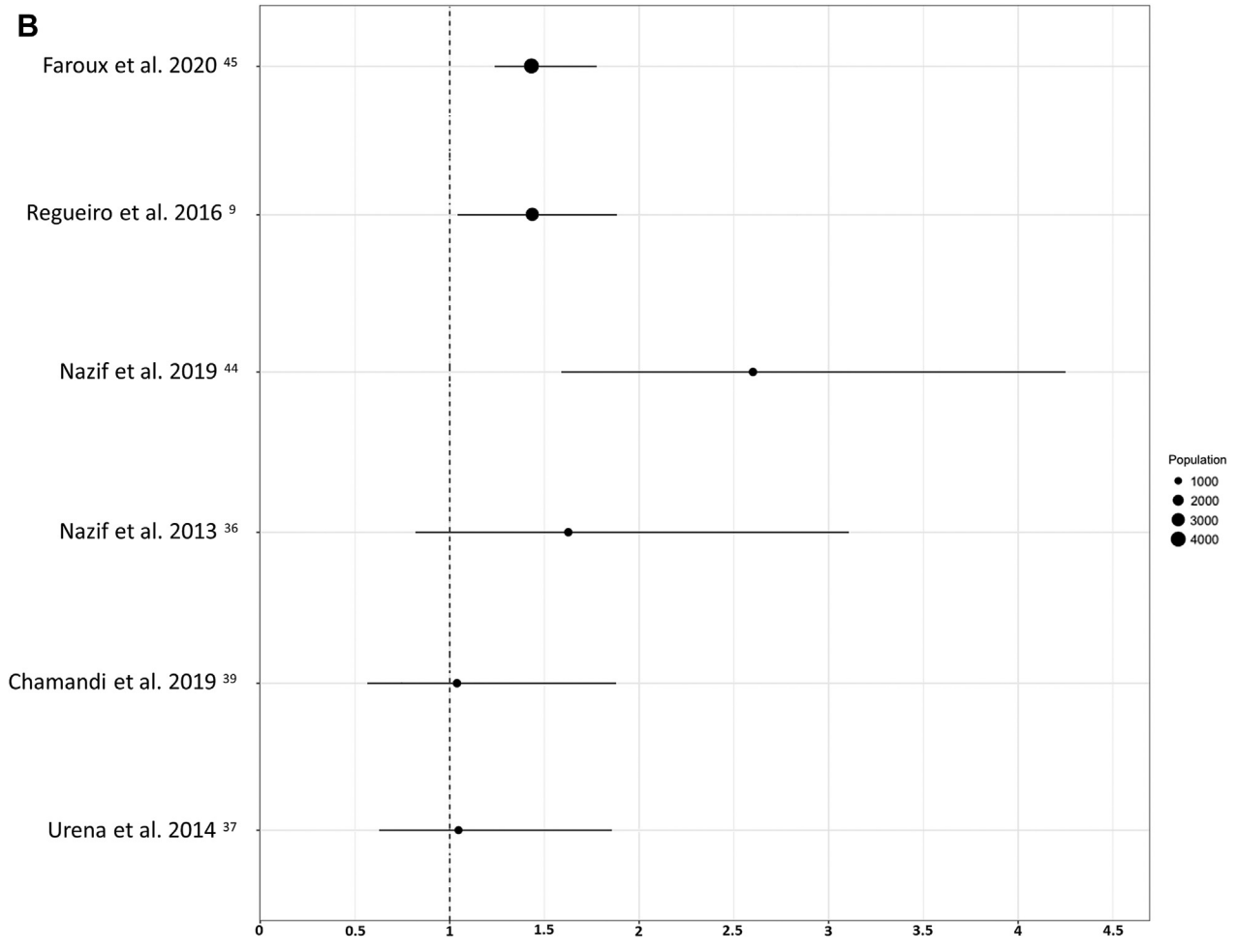


(A) Impact of new onset left bundle branch block on all-cause mortality. **(B)** Impact of new onset left bundle branch block on cardiovascular mortality. Representation of odds or hazard ratios and 95% confidence intervals of previously published studies arranged in a descending order of their respective sample sizes.

Continued on the next page

All-cause mortality and cardiovascular mortality were similar in both groups (37). In another cohort of 1,060 CoreValve TAVR patients, new onset LBBB occurred in 27.4%. After 1 year of follow-up, there was no difference in all-cause mortality, cardiovascular mortality, or rehospitalization due to heart failure in patients with new onset LBBB, but the PPM implantation rate at 30 days was higher (38). Chamandi et al. (39) recently published an analysis of 1,020 patients (52% SEV and 48% BEV) and also found no association between new onset LBBB and all-cause or cardiovascular mortality after 3 years of follow-up. In a study of 198 patients who received the self-expanding Portico valve (Abbott Structural

FIGURE 3 Continued



Heart, Santa Clara, California), new onset LBBB did not increase PPM risk, all-cause mortality, or cardiovascular mortality (40).

Contrarily, new onset LBBB was associated with significantly higher all-cause mortality and cardiovascular mortality in a multicenter registry of 679 patients. The incidence of new onset LBBB was 34.3% and was significantly higher with CoreValve than with the SAPIEN valve (51.1% vs. 12%), but the valve type did not affect the mortality (41). Schymik et al. (42) also reported higher 30-day and 1-year all-cause mortality in patients with new onset LBBB (31.1% of 634 patients). Further, CoreValve resulted in more new onset LBBB than Edwards SAPIEN valve (47.5% vs. 27.1%). Incidence of PPM implantation was also more frequent with CoreValve, while mortality was not different between the 2 subgroups (42). Jorgensen et al. (43) found that new onset BBB developed in 30% of their study population and resulted in higher 30-day PPM implantation rate, as well as increased risk of early and late all-cause mortality. Unlike the PARTNER I analysis, Nazif et al. (44) were able to demonstrate in their analysis of 1,179 TAVR patients from the PARTNER II trial and SAPIEN-3 intermediate-risk registry that new onset LBBB was associated with higher PPM, all-cause mortality (HR: 1.98; 95% CI: 1.33 to 2.96; $p < 0.001$), cardiovascular mortality (HR: 2.66; 95% CI: 1.67 to 4.24; $p < 0.001$), and worse LVEF recovery at 2 years after TAVR. Faroux et al. (45) demonstrated in a very recent meta-analysis that new onset LBBB was associated with a significant increase in all-cause mortality (relative risk [RR]: 1.32; 95% CI: 1.17 to 1.49; $p < 0.001$), cardiovascular mortality (RR: 1.46; 95% CI: 1.20 to 1.78; $p < 0.001$), heart failure hospitalization (RR: 1.35; 95% CI: 1.05 to 1.72; $p = 0.02$), and PPM implantation (RR: 1.89; 95% CI: 1.58 to 2.27; $p < 0.001$) after 1 year of TAVR (**Figures 3A and 3B**).

TABLE 2 Clinical Impact of New PPM Implantation After TAVR:

First Author (Ref. #)	Publication Date	Type of Study	Patients*	Years of Study	Valve Type	Follow-Up Length	Incidence of PPM*	Impact on All-Cause Mortality	Impact on Cardiovascular Mortality	Impact on LVEF	Other Pertinent Outcomes
D'Ancona et al. (80)	2011	Single-center prospective study	322	April 2008–March 2011	100% BEV	1 yr	6%	No association	N/A	N/A	–
Buellesfeld et al. (81)	2012	Multicenter prospective registry	305	August 2007–March 2010	87% SEV 13% BEV	1 yr	32% SEV 37% BEV 16%	No association	N/A	N/A	–
De Carlo et al. (82)	2012	Italian CoreValve prospective registry	275	September 2007–July 2010	100% SEV	1 yr	24%	No association	No association	N/A	–
Van Mieghem et al. (83)	2014	Single-center prospective study	216	November 2005–December 2011	95% SEV 5% BEV	13 months	23%	No association	N/A	N/A	–
Gensas et al. (84)	2014	Multicenter retrospective registry	353	January 2008–February 2012	86% SEV 14% BEV	5 yrs	25% SEV 28% BEV 10%	No association	No association	No association	–
Urena et al. (51)	2014	Multicenter retrospective study	1,556	January 2005–February 2013	55% BEV 45% SEV	2 yrs	15%	No association	No association	Decreased LVEF over time after initial improvement	Deceased risk of 30-day sudden cardiac death
Biner et al. (52)	2014	Single-center retrospective study	230	N/A	87% SEV 13% BEV	19.5 months	25% SEV 27% BEV10%	No association	No association	Decreased LVEF at 6 months	Decreased LV stroke volume Decreased RV index
Dizon et al. (85)	2015	Retrospective analysis of PARTNER trial and registry	1,945	N/A	100% BEV	1 yr	9%	Increased risk at 1 yr (26.3% vs. 20%; $p < 0.05$) HR: 1.38 (95% CI: 1.0–1.89); $p = 0.05$	No association	Decreased LVEF at 1 yr	Increased risk of rehospitalization Increased risk of a composite of mortality and rehospitalization
Schymik et al. (42)	2015	Single-center retrospective study	793	May 2008–April 2012	81% BEV 19% SEV	1 yr	14% SEV 25% BEV 12%	No association	N/A	N/A	–
Kawaguchi et al. (86)	2015	Single-center retrospective study from FRANCE-2 registry	160	February 2010–June 2012	66% SEV 34% BEV	3 yrs	18% SEV 23% BEV 7%	No association	N/A	N/A	Increased risk of rehospitalization and longer ICU stay
Mouillet et al. (49)	2015	Retrospective analysis of the FRANCE-2 registry	833	January 2010–October 2011	100% SEV	8 months	30%	No association	No association	N/A	–
Nazif et al. (50)	2015	Retrospective analysis of PARTNER trial and registry	1,973	N/A	100% BEV	1 yr	9%	No association	No association	No association	Increased risk of repeat hospitalization and increased risk of a composite of mortality and repeat hospitalization
Fadahunsi et al. (15)	2016	Retrospective analysis of STS/ACC TVT registry	9,785	November 2011–September 2014	89% BEV 11% SEV	1 yr	7% SEV 25% BEV 4%	Increased risk at 1 yr (24.1% vs. 21.8%) HR: 1.31 (95% CI: 1.09–1.58)	N/A	N/A	Increased risk of a composite of mortality and heart failure at 1 yr; HR: 1.33 (1.13–1.56)
Giustino et al. (87)	2016	Retrospective analysis of a multicenter registry	947	November 2005–December 2011	53% BEV 47% SEV	14 months	17% SEV 22% BEV 8%	No association	No association	No association	Increased risk of all-cause mortality and impaired LVEF recovery in patients with new PPM and post-procedural aortic regurgitation ≥1

Continued on the next page

TABLE 2 Continued

First Author (Ref. #)	Publication Date	Type of Study	Patients*	Years of Study	Valve Type	Follow-Up Length	Incidence of PPM*	Impact on All-Cause Mortality	Impact on Cardiovascular Mortality	Impact on LVEF	Other Pertinent Outcomes
Regueiro et al. (9)	2016	Meta-analysis	7,032	2011–2015	57% BEV 43% SEV	1 yr	16%	No association	No association	N/A	–
Engborg et al. (88)	2017	Single-center retrospective study	128	March 2008–September 2012	78% SEV 22% BEV	4 yrs	32% SEV 38% BEV 11%	Decreased risk at 1 yr (2% vs. 14%) and at 5 yrs (54% vs. 70%)	N/A	N/A	–
Dumonteil et al. (54)	2017	Prospective analysis of REPRISE II trial	226	N/A	100% MEV	1 yr	32%	No association	N/A	No association	–
Nijenhuis et al. (89)	2017	Single-center retrospective study	155	June 2007–June 2015	N/A	19 months	24%	Decreased risk at 1 yr in patients with new onset LBBB who received new PPM (11% vs. 29%) HR: 0.5 (95% CI: 0.2–0.9)	N/A	N/A	–
Lopez-Aguilera et al. (90)	2017	Single-center prospective study	217	April 2008–December 2015	100% SEV	37 months	18%	Increased risk at 3–3.5 yrs (28.6% vs. 17.3%) but not at 8 yrs	N/A	No association	Increased risk of rehospitalization due to heart failure
Mohananey et al. (91)	2017	Meta-analysis	20,287	2010–2016	71% BEV 29% SEV	1 yr	12.5%	No association	No association	Decreased LVEF improvement after TAVR	–
Chamandi et al. (92)	2018	Multicenter retrospective study	1,629	May 2007–February 2015	55% SEV 45% BEV	2 yrs	20% SEV 27% BEV 11%	No association	No association	Delayed LVEF over time	Increased risk of rehospitalization due to heart failure and increased risk of a composite of mortality and heart failure rehospitalization
Rogers et al. (66)	2018	Single-center retrospective study	614	January 2013–December 2015	78% BEV 22% SEV	1 yr	19% SEV 34% BEV 20%	No association	N/A	No association	–
Walther et al. (40)	2018	Multicenter prospective study	198	December 2011–September 2015	100% SEV	1 yr	17%	No association	No association	N/A	–
Gonska et al. (93)	2018	Single-center retrospective study	612	February 2014–September 2016	59% BEV 37% MEV 4% SEV	1 yr	28% MEV 44% BEV 18% SEV 15%	No association even in patients with reduced LVEF <45%	N/A	N/A	–
Aljabbary et al. (56)	2018	Retrospective analysis of CorHealth TAVR registry	1,263	April 2010–March 2015	N/A	33 months	15%	Increased risk at 1 yr (12.4% vs. 10.3%) HR: 1.25 (95% CI: 1.09–1.43) and at longest follow-up (44% vs. 31.7%) HR: 1.4 (95% CI: 1.01–1.94)	N/A	N/A	Increased risk of all-cause rehospitalization at 1 yr and at longest follow-up
Nadeem et al. (94)	2018	Single-center retrospective study	672	2011–2017	56% SEV 44% BEV	22 months	22% SEV 27% BEV 16%	No association	N/A	N/A	Increased risk of all-cause readmission and rehospitalization due to heart failure at 1 yr
Alasti et al. (53)	2018	Single-center retrospective study	166	April 2012–October 2016	100% MEV	21 months	25%	No association	N/A	N/A	–

Continued on the next page

TABLE 2 Continued

First Author (Ref. #)	Publication Date	Type of Study	Patients*	Years of Study	Valve Type	Follow-Up Length	Incidence of PPM*	Impact on All-Cause Mortality	Impact on Cardiovascular Mortality	Impact on LVEF	Other Pertinent Outcomes
Bhardwaj et al. (95)	2018	Single-center prospective study	383	January 2012–July 2016	82% BEV 18% SEV	9 months	12%	No association	N/A	N/A	—
Marzahn et al. (96)	2018	Single-center retrospective study	856	July 2008–May 2015	58% BEV 42% SEV	1 yr	17% SEV 20% BEV 15%	No association	N/A	N/A	—
Jorgensen et al. (43)	2019	Single-center prospective study	816	2007–September 2017	83% SEV 9% BEV 8% MEV	30 months	16% MEV 31% SEV 16% BEV 10%	Increased risk at ≥1 yr (46.7% vs. 32.8%) HR: 1.58 (95% CI: 1.01–2.46) but not early mortality	N/A	Decreased LVEF after initial improvement	Increased risk of rehospitalization due to heart failure
Maeno et al. (97)	2019	Single-center retrospective study	659	January 2013–December 2015	85% BEV 15% SEV	19 months	16% SEV 30% BEV 10%	No association	No association but increased risk at 2 yrs in patients who had low LVEF HR: 5.76 (95% CI: 2.18–15.24)	N/A	—
Arnold et al. (98)	2019	Retrospective analysis of PARTNER 2 studies	3,763	N/A	100% BEV	1 yr	9%	No association	N/A	N/A	—
Xi et al. (99)	2019	Meta-analysis	21,666	2002–2018	69% BEV 31% SEV	17 months	12.5% SEV 25% BEV 7%	Increased risk RR: 1.13 (95% CI: 1.01–1.25)	No association RR: 0.93 (95% CI: 0.79–1.09)	N/A	—
Costa et al. (57)	2019	Single-center prospective study	1,116	June 2007–February 2018	73% SEV 27% BEV	6 yrs	13% SEV 16% BEV 6%	No association at 30 days (6.2% vs. 4.5%) but decreased all-cause survival at 6 yrs (41.7% vs. 57%)	No association at 30 days (2.1% vs. 3.1%)	Decreased LVEF at 3 yrs. LVEF was still marginally lower with PPM at 5 yrs	Increased risk of moderate to severe aortic regurgitation at 30 days
Meduri et al. (55)	2019	Prospective analysis of REPRISE III trial	704	N/A	66% MEV 34% SEV	1 yr	35% MEV 41% SEV 22%	No association	No association	Decreased LVEF at 1 yr	No association with rehospitalization
Fujita et al. (58)	2020	Multicenter retrospective study	20,872	2011–2015	54% BEV 27% SEV	1 yr	17% SEV 27% BEV 12%	Increased risk at 1 yr HR: 1.29 (95% CI: 1.16–1.43)	N/A	N/A	—
Faroux et al. (45)	2020	Meta-analysis	42,927	2011–2019	N/A	1 yr	N/A	Increased risk at 1 yr RR: 1.17 (95% CI: 1.11–1.25)	No association at 1 yr RR: 0.84 (95% CI: 0.67–1.05)	N/A	Increased risk of heart failure hospitalization at 1 yr RR: 1.18 (95% CI: 1.03–1.36)

*Patients with prior PPM were excluded.

ACC = American College of Cardiology; FRANCE-2 = French Aortic National Corevalve and Edwards; ICU = intensive care unit; LV = left ventricular; REPRISE = Repositionable Percutaneous Replacement of Stenotic Aortic Valve Through Implantation of Lotus Valve System -Randomized Clinical Evaluation; RV = right ventricular; STS = Society of Thoracic Surgeons; TVT = Transcatheter Valve Therapy; other abbreviations as in Table 1.

This establishes a strong evidence that new onset LBBB can have detrimental effects on morbidity and mortality after TAVR. The fact that ~50% of new onset LBBB can potentially resolve within a short time after the procedure makes the decision to implant PPM for those patients a tough 1 (11,13).

Impact of new PPM implantation after TAVR. In the general population, PPM implantation can cause lead-induced tricuspid regurgitation, both acutely and chronically, which may contribute to higher mortality rates (46). Other complications include device infection, lead failure, pocket erosion,

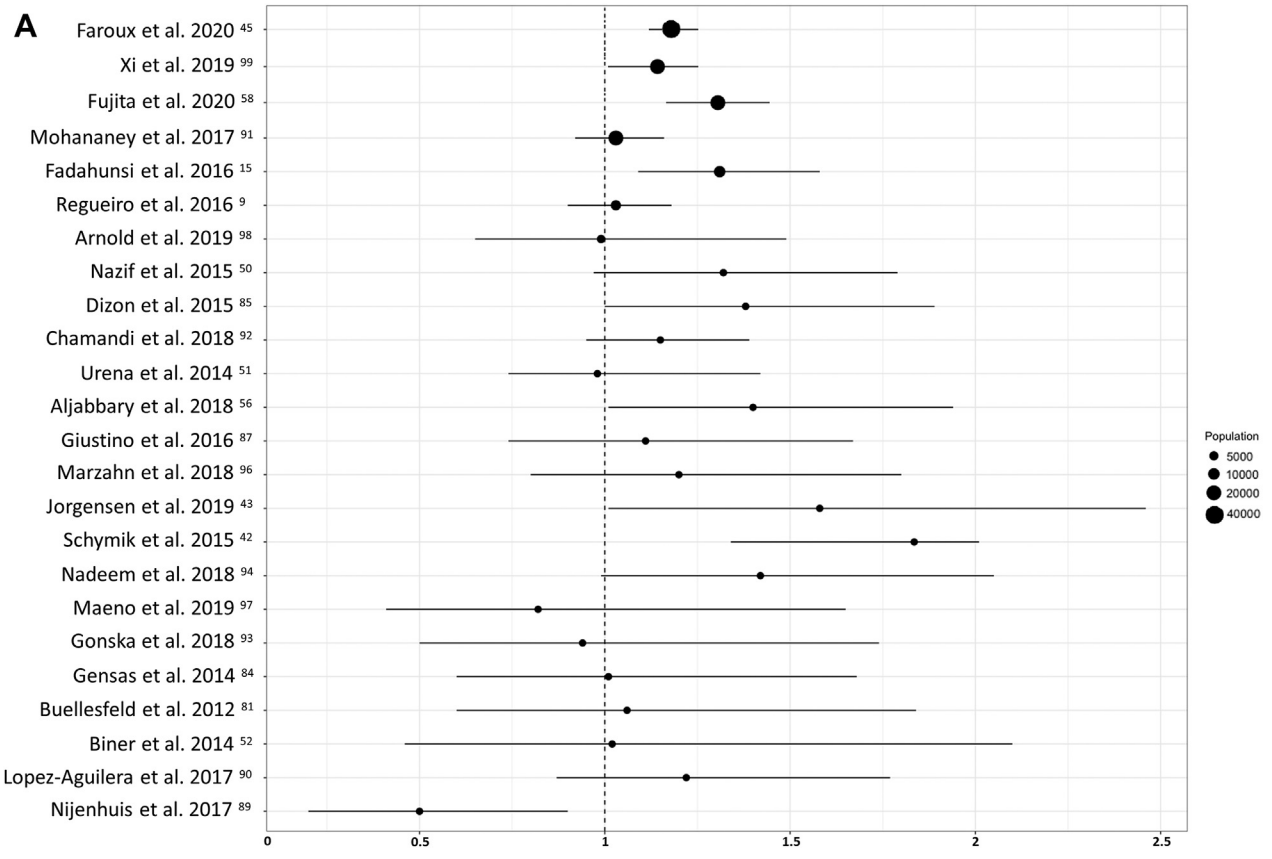
pocket hematoma, and right ventricular perforation (47). Additionally, age can play an important role in determining morbidity related to PPM implantation. Interestingly, younger patients may be more prone to certain PPM complications, which may be related to having the device for longer durations of time compared with the older population. (48). This is particularly relevant as TAVR is now being recommended for the younger low-surgical-risk patients. Data regarding the impact of PPM implantation on morbidity and mortality in TAVR patients with conduction disturbances have been conflicting among the different studies (**Table 2**).

Results of 883 patients from the FRANCE 2 registry showed that the rate of PPM implantation after CoreValve TAVR was 30.3%. All-cause mortality and cardiovascular mortality were similar with or without PPM implantation (49). Retrospective analysis of 1,973 patients without pre-existing PPM implantation from the PARTNER trial revealed that 8.8% required new PPM within 30 days after the procedure. At 1 year, there was no association between PPM implantation and all-cause mortality or cardiovascular mortality. However, PPM implantation was associated with higher rates of repeat hospitalization and a composite of mortality and repeat hospitalization but did not adversely affect LVEF recovery after TAVR (50). In a cohort of 1,556 patients, the rate of 30-day PPM implantation was 15.4% and was found to be protective against sudden cardiac death at 30 days. In this study, PPM was not associated with increased all-cause mortality or cardiovascular mortality at 2 years. However, PPM requirement was found to have a deleterious effect on LVEF over time after initial improvement, especially with dual-chamber pacemakers, as compared with patients who did not receive pacemakers (51). Biner et al. (52) studied 230 TAVR patients, of whom 25% required PPM which adversely affected the LVEF recovery after the procedure, left ventricular stroke volume, and right ventricular index after 6 months. There was no association between PPM implantation and mortality. With regard to the impact of PPM in LOTUS valves (Boston Scientific, Marlborough, Massachusetts), Alasti et al. (53) found no association between PPM and mortality. Dumonteil et al. (54) investigated 226 patients who received LOTUS valve in REPRISE (Repositionable Percutaneous Replacement of Stenotic Aortic Valve Through Implantation of Lotus Valve System–Randomized Clinical Evaluation) II trial, of whom 35% required PPM, but there was no association between PPM and all-cause mortality or LVEF recovery at 1 year. In an analysis from the REPRISE III trial (LOTUS and CoreValve, 2:1), PPM had no impact on all-cause or cardiovascular mortality, but LVEF was lower at 1 year in the PPM group (55). Among patients with the Portico valve, there was no association between PPM and all-cause or cardiovascular mortality (40).

On the contrary, results of a large cohort of 9,785 patients from the Society of Thoracic Surgeons/American College of Cardiology TVT registry showed that PPM was required in 6.7% of the cases and was associated with 31% increase in all-cause mortality and 33% increase in a composite of mortality and heart failure at 1 year (15). Aljabbary et al. (56) studied 1,263 patients, of whom 15% required PPM which also resulted in increased risk of all-cause mortality at 1 year. Jorgensen et al. (43) demonstrated in a cohort of 816 patients that PPM implantation increases the risk of late all-cause mortality at ≥1 year but had no effect on early mortality. Costa et al. (57) looked at the impact of PPM in 1,116 TAVR patients and found that PPM was associated with lower all-cause survival at 6 years after the procedure. LVEF was reduced with PPM at 3 years and was still marginally lower at 5 years. In a big analysis of 20,872 patients from the German aortic valve registry, post-TAVR PPM showed a negative impact on all-cause mortality at 1 year of follow-up, but it did not affect cardiac death (58). A very recent meta-analysis by Faroux et al. (45) included 42,927 TAVR patients and established that PPM increases the risk of all-cause mortality (RR: 1.17; 95% CI: 1.11 to 1.25; $p < 0.001$) and heart failure hospitalization (RR: 1.18; 95% CI: 1.03 to 1.36; $p = 0.02$), but there was no impact on cardiovascular mortality (RR: 0.84; 95% CI: 0.67 to 1.05; $p = 0.13$) (45) (**Figures 4A and 4B**). The need for PPM implantation after TAVR can also add to the financial burden as shown in a cost analysis by Ahmad et al. (59). PPM requirement resulted in an increase in the mean total costs of the TAVR hospitalization by $10,213 ($81,701 vs. $71,487; $p = 0.04$) (59).

In summary, the aforementioned data regarding the impact of post-TAVR PPM on mortality have shown conflicting results across the different studies. This inconsistency may be explained by the differences in valve types. On the one hand, we think that it may be possible that there may be some benefit of getting PPM with SEV in terms of preventing deaths secondary to heart blocks, which evens out the negative effects of PPM, resulting in no mortality differences. On the other hand, there may not be real value in preventing any deaths, with BEV leaving only the harmful effects of pacing. The length of follow-up, and baseline characteristics of the patient

FIGURE 4 Impact of Permanent Pacemaker on All-Cause Mortality



(A) Impact of permanent pacemaker on all-cause mortality. **(B)** Impact of permanent pacemaker on cardiovascular mortality. Representation of odds or hazard ratios and 95% confidence intervals of previously published studies arranged in a descending order of their respective sample sizes.

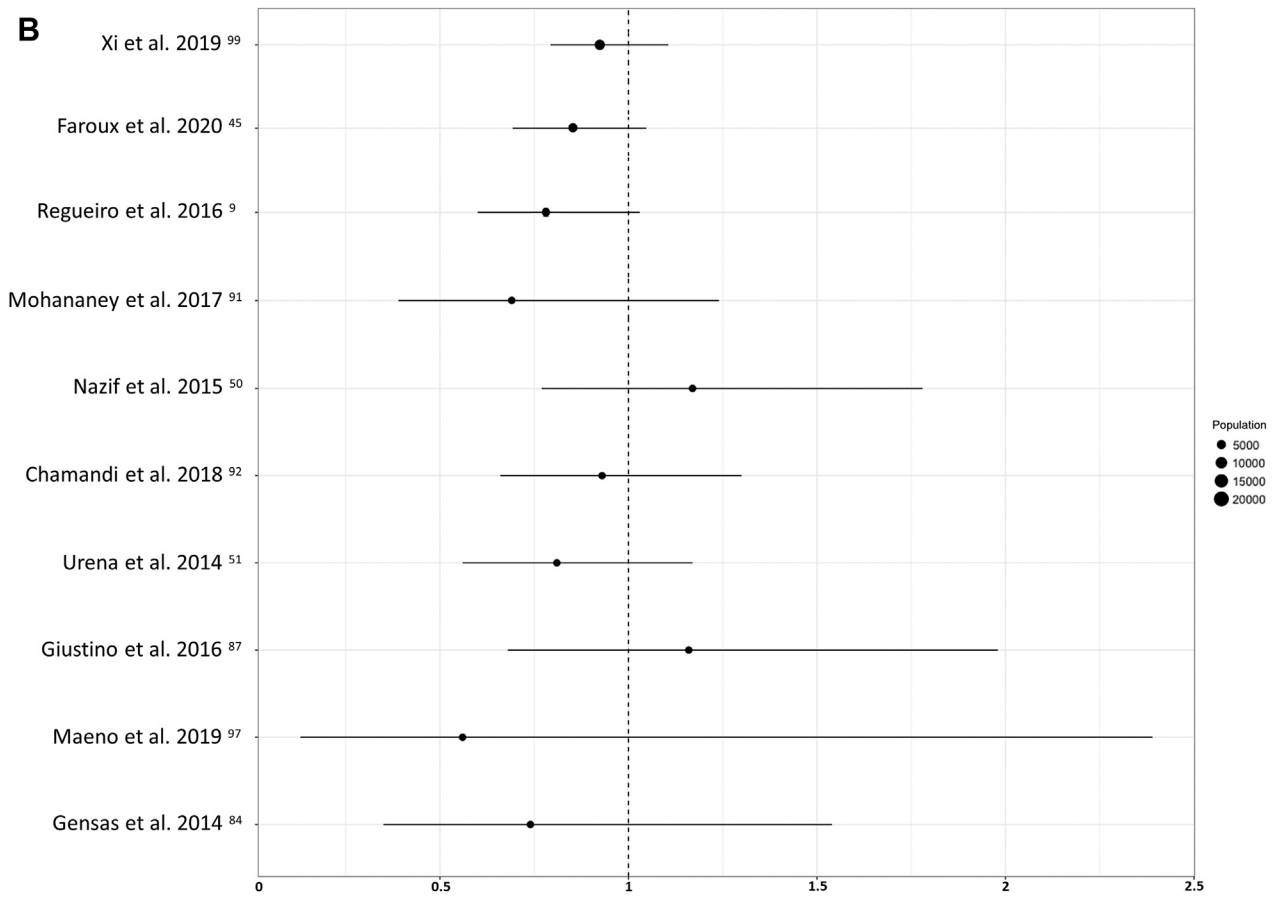
Continued on the next page

populations in different studies, may also modify the results due to confounding effects. That being said, the recent meta-analysis by Faroux et al. (45). creates strong evidence that PPM may actually increase all-cause mortality after TAVR. The long-term consequences of pacing in younger TAVR population remain uncertain.

MANAGEMENT OF CONDUCTION ABNORMALITIES AFTER TAVR. The duration of telemetry monitoring and clear indications for PPM implantation after TAVR are still unknown. The 2013 European Society of Cardiology guidelines, which are decidedly not contemporary given the substantial changes in devices, procedural technique, and understanding since that time, recommend that patients with persistent complete or high-degree AVB after TAVR should be monitored for up to 7 days before proceeding with PPM implantation (Class I recommendation; Level of Evidence: C) (60). Finding the optimal timing of PPM implantation is crucial as it is possible that complete AVB may resolve. Further, new onset LBBB may persist without evolving to complete heart block requiring PPM implantation. However, those patients may remain at a higher risk for recurrence of complete AVB during follow-up (11). Prophylactic PPM after TAVR without indications is not recommended and should be selectively offered for patients with recurrent AVB after adequate monitoring (3). The implantation of PPM before undergoing TAVR for patients with strong risk factors for developing new conduction defects such as baseline RBBB also failed to show value with regard to mortality or rehospitalization after TAVR (61).

Rodes-Cabau et al. (62) provided "JACC Scientific Expert Panel" suggestions on the management of patients with conduction disturbance post-TAVR. In summary, they recommend at least 48 h of

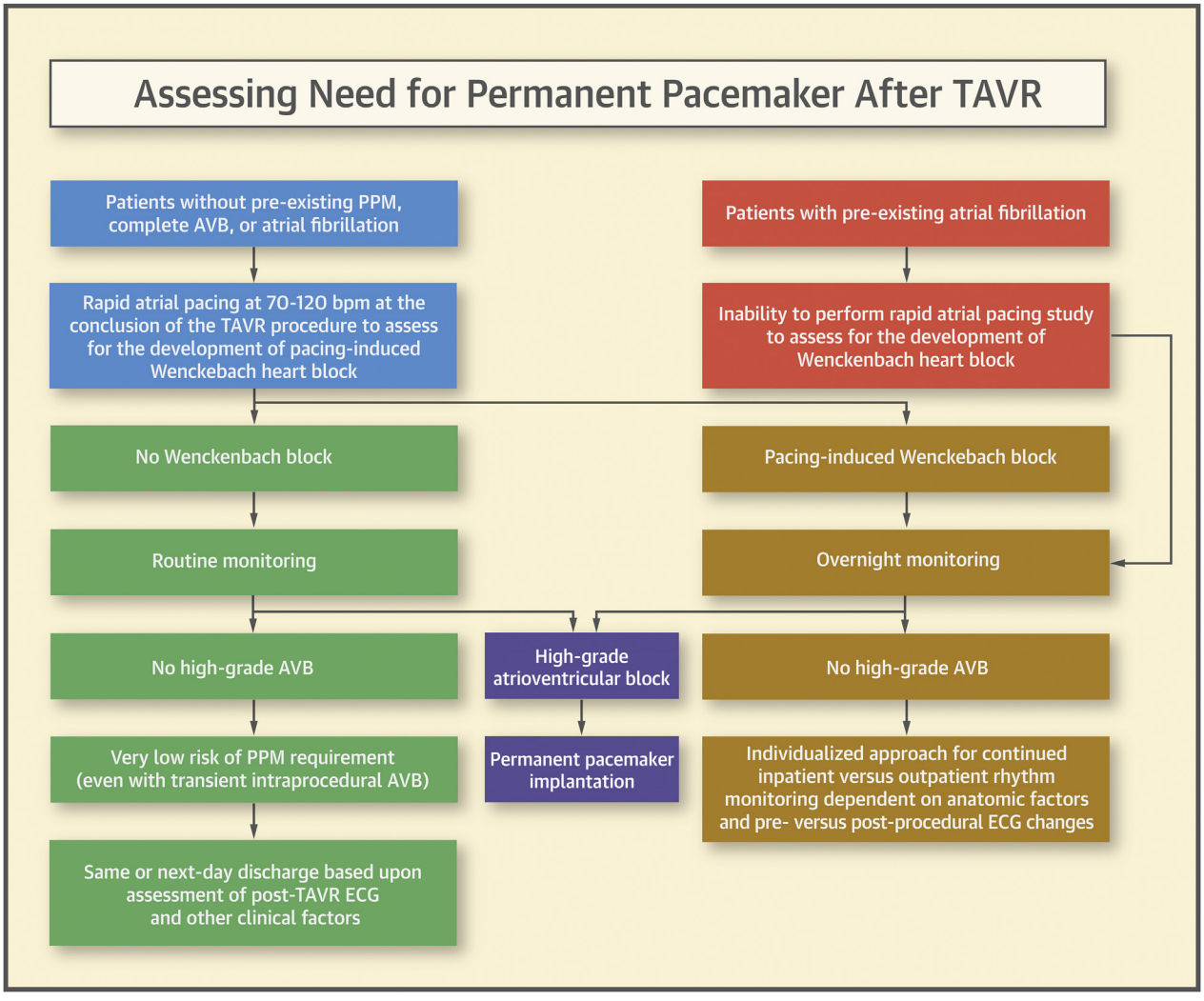
FIGURE 4 Continued



inpatient monitoring (at least 24 h with a temporary pacemaker wire in place) for all patients with: increase in PR or QRS intervals by >20 ms with pre-existing wide QRS interval or first-degree AVB, new onset LBBB, or high-degree AVB or complete heart block during the procedure (designated as "Groups 3-5" in their document). Although these recommendations are certainly reasonable, we believe that they may be a bit conservative and result in longer duration of temporary pacemaker placement or inpatient rhythm monitoring.

At our institution, we have been following a strategy to further risk-stratify patients beyond the pre- and post-TAVR ECG by routinely performing rapid pacing from the right atrium after withdrawing the right ventricular pacing wire utilized for TAVR. In a study we have recently published, we assessed patients for the development of Wenckebach heart block upon rapid atrial pacing from 70 to 120 beats/min (at 10-beats/min increments). We found that among 284 TAVR patients, 130 (46%) developed pacing-induced Wenckebach. Among the group who did not (n = 154, 54%), PPM was required in only 1.3% of patients, with a negative predictive value of 98.7%. Multivariable analysis demonstrated only pacing-induced Wenckebach (OR: 11.19) and pre-TAVR LBBB (OR: 6.99) as risks for post-TAVR PPM implantation. Further, the rate at which Wenckebach developed was also predictive of PPM need (OR: 30.4 for PPM at 80 beats/min; OR: 9.5 for PPM at 120 beats/min). For further clarification, the 2 (1.3%) patients in the no-Wenckebach group who required PPM did so due to unique situations. One developed new onset LBBB and required cardiac resynchronization therapy with defibrillator due to long-standing left ventricular dysfunction, while the other patient had pre-existing LBBB and developed a nonpathological pause of 2.5 s after TAVR (63). Given the very high negative predictive value of the pacing test, we now feel comfortable routinely discharging even patients who develop transient

CENTRAL ILLUSTRATION **Management Algorithm of Conduction Disturbances After TAVR**



Sammour, Y. et al. J Am Coll Cardiol Intv. 2021;14(2):115–34.

Different protocols for post-procedural monitoring depending on feasibility of rapid atrial pacing and the development of pacing-induced Wenckebach. Rapid atrial pacing is routinely performed in our institution at the conclusion of transcatheter aortic valve replacement (TAVR) by withdrawing the right ventricular pacing wire immediately after valve deployment and closure of the valve delivery sheath arteriotomy site then pacing the atrium at 10 beats/min increments from 70 to 120 beats/min, for a total of 20 beats at each increment to assess for the development of Wenckebach heart block. AVB = atrioventricular block; ECG = electrocardiography; PPM = permanent pacemaker.

intraprocedural complete AVB on same or next day after TAVR if they do not develop pacing-induced Wenckebach or experience further episodes of high-degree AVB. Although the data for same-day discharge are limited (64), using strict clinical, anatomic, electrocardiographic, and valve- and procedure-related criteria appears to be feasible and we are now routinely discharging 20% to 30% of TAVR patients on the same evening as the procedure. Patients who develop Wenckebach with atrial pacing, especially at lower rates, as well as patients with baseline atrial fibrillation who had rapid atrial pacing study is not feasible, or those who develop post-procedural high-degree AVB, may require an individualized approach while bearing in mind the peri-procedural ECG changes, valve or left ventricular outflow tract characteristics, and other factors that can guide the decision to continue inpatient versus outpatient rhythm monitoring (**Central Illustration**).

FUTURE DIRECTIONS. Post-TAVR electrophysiologic studies are becoming more widely used to risk-stratify patients with unclear indications of PPM. It is well known that TAVR leads to post-procedural prolongation of the His ventricular (H-V) intervals. However, there is lack of consensus regarding the cutoff values of H-V interval prolongation that predict the occurrence of complete heart block after TAVR (65). Rogers et al. (66) used a cutoff H-V interval >100 ms with or without Procainamide challenge to implant PPM. This electrophysiologic study-guided strategy has led to 70% reduction of PPM rates in their cohort of patients with equivocal indications without increasing the length of hospital stay or mortality. Knecht et al. (67) have shown that electrophysiologic studies can be used to identify patients with new onset LBBB after TAVR who will not develop complete heart block if they had H-V interval ≤55 ms on the electrophysiologic studies with a negative predictive value of 90%. There is need for large randomized studies to further identify the utility of electrophysiologic studies after TAVR, such as the clinical trial led by Massoullié et al. (68), who are using H-V interval cutoff of 70 ms for PPM implantation versus looper recorder and routine monitoring (NCT02482844).

Furthermore, there is growing interest in the field of His-bundle pacing to restore myocardial activation in patients with new conduction defects and potentially reverse new onset LBBB after TAVR (69). His-bundle pacing is done by implanting a lead into the right ventricle and screwing it at the level of the His bundle after capture is achieved. The concept is that His-bundle pacing would provide a more physiological form of ventricular activation compared with right or biventricular pacing (70). Sharma et al. (70) demonstrated that His-bundle pacing is feasible in patients with prosthetic valves including TAVR recipients. De Pooter et al. (71) evaluated the utility of His-bundle pacing among 16 TAVR patients, of whom 81% had successful capture of the His bundle, with successful reversal of new onset LBBB and reduction of QRS duration in 11 (69%) patients. Those 11 patients still ended up receiving devices but for the purpose of permanent His-bundle pacing instead of ventricular pacing. Future studies to determine the long-term outcomes of His-bundle pacing among larger cohorts are needed.

Novel pacing technologies such as leadless pacemakers have been adopted in TAVR patients (72–74). Leadless pacemakers are percutaneously implanted within the right ventricle with similar pacing and sensing efficacy (75). Micra TPS was the first Medtronic single chamber leadless pacemaker. The Food and Drug Administration recently approved the next generation Medtronic Micra AV, which provides accelerometer-based atrial sensing to achieve dual-chamber pacing without having any leads which enhances the AV synchrony in patients with complete AVB (76). The absence of leads may result in reduction of the rates of lead-induced tricuspid regurgitation and infections. The safety of leadless pacemakers, however, are yet to be known as they can lead to complications such as cardiac perforation, tamponade, and dislodgement with percutaneous retrieval if needed with elevated pacing thresholds (75). We believe that leadless pacemakers should be sparingly considered in old and frail patient population until we have randomized data of peri-procedural and long-term safety of these systems compared with conventional pacemakers.

CONCLUSIONS

As the clinical adoption of TAVR increases as a safe and effective alternative to surgical valve replacement, advanced conduction abnormalities such as new onset LBBB and high-grade AVB requiring PPM implantation remain a common finding after TAVR. The rate of PPM implantation after TAVR is highly variable and is dependent on many pre-existing and intraprocedural factors. Despite a great deal of controversy, the current evidence shows an apparent increase in mortality with new onset LBBB and PPM implantation among patients undergoing TAVR. The long-term consequences of pacing in younger population remain uncertain. Heart teams need to be cognizant of specific anatomic, electrical, and clinical risk factors while screening patients for TAVR. Further, operators must be vigilant when weighing different considerations for valve choice and in performing the implantation to minimize the risk of PPM. Finally, we provide herein our rationale for immediate post-TAVR atrial pacing to further risk-stratify patients and their need for permanent pacemaker implantation.

AUTHOR DISCLOSURES

The authors have reported that they have no relationships relevant to the contents of this paper to disclose.

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KEY WORDS conduction disturbances, PPM, state-of-the-art, TAVR

APPENDIX For a supplemental table and references, please see the online version of this paper.