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JACC STATE-OF-THE-ART REVIEW

Ambulatory Electrocardiogram Monitoring in Patients Undergoing Transcatheter Aortic Valve Replacement

JACC State-of-the-Art Review

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ABSTRACT

Transcatheter aortic valve replacement (TAVR) has changed the treatment of patients with severe aortic stenosis. However, the occurrence of conduction disturbances has not decreased significantly over time and remains the main drawback of the procedure. In addition, new-onset atrial fibrillation is the most frequent tachyarrhythmia during the hospitalization period and is associated with worse clinical outcomes. However, little is known regarding the incidence and clinical impact of arrhythmic events beyond the periprocedural TAVR period. Ambulatory electrocardiogram (AECG) monitoring has recently emerged as a tool to unravel the complex issue of arrhythmic disorders (bradyarrhythmias and tachyarrhythmias) before and after TAVR. To date, the preliminary results from the initial experience using AECG monitoring systems showed the safety, usefulness, and potential clinical implications of this diagnostic tool in TAVR recipients. This review provides an overview of the current status, clinical implications, and future perspectives of AECG monitoring in the TAVR setting. (J Am Coll Cardiol 2021;77:1344–56) © 2021 by the American College of Cardiology Foundation.

The development of transcatheter aortic valve replacement (TAVR) has brought a new era in the treatment of aortic stenosis. Despite the successive iterations in transcatheter heart valve systems and the growing experience in the field, the occurrence of conduction disturbances (CDs) has not decreased over time (1). The occurrence of CDs such as high-degree atrioventricular block (HAVB) or complete heart block (CHB) requiring permanent pacemaker implantation (PPMI) and new-onset left bundle branch block (LBBB) remains the most important drawback of the procedure (1). Furthermore, the lack of consensus regarding the management of CDs after TAVR has led to important differences between centers and published reports, highlighting the urgent need to establish a common strategy in this setting (2). Importantly, the simplification of the TAVR procedure has progressively led to a "minimalist" approach with a short length of stay (24 to 48 h) (3). However, this strategy could be compromised by the occurrence of late (>48 h) life-threatening arrhythmic events, particularly in patients with prior right bundle branch block (RBBB) or new-onset CDs (4–6). Recent evidence showed that whereas the length of stay after TAVR has declined in recent years, the rate of readmission for

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HIGHLIGHTS

- To date, studies using AECG monitoring detected symptomatic or asymptomatic bradyarrhythmias or tachyarrhythmias in ~15% of patients before TAVR, leading to treatment changes in about one-half of cases.
- AECG using mobile cardiac telemetry at the time of hospital discharge after TAVR revealed high-degree atrioventricular or complete heart block warranting permanent pacemaker implantation in close to 10% of patients.
- Large-scale studies are needed to define the optimum timing and duration of AECG monitoring for patients undergoing TAVR.

PPMI has increased significantly (7). In addition, the incidence and clinical impact of new-onset tachyarrhythmias following TAVR have been less studied, especially those events occurring after hospital discharge. Atrial fibrillation (AF) has been the most frequently documented arrhythmia during the initial TAVR hospitalization (8). However, silent AF episodes may be present before and after TAVR index hospitalization. The prompt identification of AF may lead to important therapeutic changes (anticoagulation treatment) with potential clinical benefits, particularly considering the high cardioembolic risk of the TAVR population and the poor prognosis of patients with ischemic cerebrovascular events after TAVR (9,10).

Ambulatory electrocardiogram (AECG) monitoring is a well-known tool to detect arrhythmic events in multiple clinical settings (11), and its use has been recently implemented in the TAVR field, leading to important insights regarding the occurrence and clinical impact of bradyarrhythmic and tachyarrhythmic events before and after the periprocedural period (**Table 1**) (12–20). The aim of this review was to provide an up-to-date overview on the current status, clinical implications, and future perspectives of AECG monitoring in the context of TAVR.

AMBULATORY RHYTHM MONITORING

AECG monitoring has gained importance during recent years and is widely used in different clinical settings (21). The purpose of AECG monitoring is to detect and properly categorize rhythm abnormalities occurring during daily life, either silent or symptomatic (palpitations, syncope, dizziness, chest pain, or shortness of breath) (22). A summary of the established clinical indications of AECG monitoring is depicted in **Table 2**.

Since the advent of the Holter monitor more than 50 years ago, there has been a progressive development focusing on the quality of electrocardiogram (ECG) signals and ECG monitoring duration. Nowadays, multiple AECG monitoring technologies are available and can be classified according to their main characteristics, mode of action, and monitoring duration (**Figure 1, Table 3**) (2). Ambulatory external electrocardiogram monitoring technology includes standard Holter, event monitors (including smartphone-based technologies), patch-type monitors, external loop recorders, and mobile cardiovascular telemetry (MCT) monitoring. MCT monitoring devices (often single-lead electrogram devices embedded in a patch, necklace, or chest belt) allow real-time streaming (transmission of a loop or single-event electrogram) to a reading 24-h center, with nearly immediate capacity to warn the patient and responsible physician if a life-threatening event occurs. On the other hand, the development of smartphone technologies for AF screening has also opened new perspectives in the field (23). Finally, implantable cardiac monitor (ICM) recorders are also available and allow long-term recording, which is known to increase the diagnostic capacity compared with conventional external recorders in case of unexplained syncope and for the detection of AF episodes (24,25). A summary of the characteristics of current AECG monitoring technologies is shown in **Table 3** (2).

AMBULATORY RHYTHM MONITORING BEFORE TAVR

The main advantage of AECG monitoring before the TAVR procedure would be the ability for early detection of significant arrhythmic disorders that may lead to a change in the clinical management before and/or after TAVR (e.g., anticoagulation management, need for PPMI), potentially lowering complications and length of hospital stay. To date, 3 studies with different types and duration of AECG monitoring (from 24 h to 14 days) have been published, including a total of 582 patients (**Table 4**) (12,19,20). Overall, AECG monitoring showed the presence of arrhythmic

ABBREVIATIONS AND ACRONYMS

AECG = ambulatory electrocardiogram
AF = atrial fibrillation
AVB = atrioventricular block
CD = conduction disturbance
CHB = complete heart block
HAVB = high-degree atrioventricular block
ICM = implantable cardiac monitor
MCT = mobile cardiovascular telemetry
NOAF = new-onset atrial fibrillation
PPMI = permanent pacemaker implantation

TABLE 1 Studies Using Ambulatory ECG Monitoring in the Context of TAVR

First Author, Year (Ref. #)	n	AECG Monitoring Device	Time of Monitoring	Duration of Monitoring	Population	Reported Arrhythmic Events
Urena et al., 2015 (12)	435	In-hospital telemetry and Holter monitors*	Pre-procedural	24 h	All TAVR patients	All arrhythmic events
Tempio et al., 2015 (13)	146	Standard 24-h Holter	Pre- and post-procedural	24 h	All TAVR patients without PPMI	Ventricular arrhythmias
Jørgensen et al., 2017 (14)	27	Implantable cardiac monitor (Reveal, Medtronic, Minneapolis, Minnesota)	Post-procedural	Up to 3 yrs	All TAVR patients without baseline AF	AF
Rodés-Cabau et al., 2018 (15)	103	Implantable cardiac monitor (Reveal, Medtronic)	Post-procedural	Up to 3 yrs	New-onset persistent LBBB patients	All arrhythmic events
Ream et al., 2019 (16)	118	Mobile cardiac telemetry (Biotel ACT EX, BioTelemetry, Malvern, Pennsylvania)	Post-procedural	30 days	All TAVR patients without PPMI	Bradyarrhythmic events
Tian et al., 2019 (17)	127	Mobile cardiac telemetry (BodyGuardian, Preventice Solutions, Inc., Eagan, Minnesota)	Post-procedural	30 days	All TAVR patients without PPMI	Bradyarrhythmic events
Skaf et al., 2020 (18)	54	Mobile cardiac telemetry (BodyGuardian, Preventice Solutions, Inc.)	Post-procedural	30 days	All TAVR patients without PPMI presenting new ECG-CDs after the procedure	All arrhythmic events
Winter et al., 2020 (19)	41/23	Mobile cardiac telemetry (Pocket-ECG; m-Health Solutions, Hamilton, Ontario, Canada)	Pre- and post-procedural	14 days	All TAVR patients without PPMI	All arrhythmic events
Asmarats et al., 2020 (20)	106	Patch ECG recorder (CardioSTAT, Icentia, Quebec City, Quebec, Canada)	Pre-procedural	7 days	All TAVR candidates without previous PPMI	All arrhythmic events

*The study from Urena et al. (12) used continuous ECG monitoring 24 h prior to the TAVR procedure in most patients.

AECG = ambulatory electrocardiogram monitoring; AF = atrial fibrillation; ECG = electrocardiogram; ECG-CD = electrocardiographic conduction disturbance; LBBB = left bundle branch block; PPMI = permanent pacemaker implantation; TAVR = transcatheter aortic valve replacement.

events in ~15% of patients (60% bradyarrhythmias, severe bradycardia or HAVB; 40% NOAF), most of them (~95%) asymptomatic.

BRADYARRHYTHMIC EVENTS. HAVB/CHB episodes before TAVR occurred in 3% (1.9% to 3.2%) of the patients, leading to PPMI in 56% of them (12,19,20). Moreover, severe bradycardia (defined as heart rate <40 beats/min) occurred in 6% of patients (12,20). Whereas the relatively low number of patients included in the studies precluded the identification of independent predictors of severe bradyarrhythmic events, Asmarats et al. (20) showed a higher rate of bradyarrhythmic events in patients with either first-degree AVB ($p = 0.047$) or RBBB ($p = 0.008$) at baseline.

TACHYARRHYTHMIC EVENTS. Overall, new-onset atrial fibrillation (NOAF) or atrial tachycardia (AT) pre-TAVR was detected in 6% of patients (12,19,20). These findings led to changes in medical treatment in two-thirds of the patients, and 42% of them received additional antiarrhythmic or rate control therapy (12,20). Of note, Urena et al. (12) showed that the occurrence of AF/AT during the 24-h ECG monitoring before the procedure was associated with an increased risk of cerebrovascular events after TAVR (7.1% vs. 0.4%; $p = 0.030$). Finally, nonsustained ventricular tachycardia was found in 11% of patients, with no episodes of sustained ventricular tachycardia (12,19,20).

AMBULATORY RHYTHM MONITORING AFTER TAVR

To date, 6 studies evaluated the use of AECG monitoring after TAVR (**Table 1**) (14–19). The 2 initial publications used an ICM with long-term continuous ECG monitoring (up to 3 years) and reported data either on NOAF events in consecutive TAVR patients (14) or on the global arrhythmic burden (bradyarrhythmic and tachyarrhythmic events) in new-onset LBBB post-TAVR patients (15). The subsequent studies used MCT in the early period after the procedure, with a monitoring period of 2 to 4 weeks and focusing on HAVB/CHB events (16–19).

BRADYARRHYTHMIC EVENTS. The MARE (Ambulatory Electrocardiographic Monitoring for the Detection of High-Degree Atrio-Ventricular Block in Patients With New-onset Persistent Left Bundle Branch Block After Transcatheter Aortic Valve Implantation) study used an ICM (Reveal XT, Reveal LINQ, Medtronic, Minneapolis, Minnesota) in new-onset LBBB post-TAVR patients and provided important insights regarding the incidence of significant bradyarrhythmic events in this challenging group (15,26). Up to 16% of patients had HAVB/CHB episodes at 2-year follow-up (leading to PPMI in 66% of them), most of them occurring in the early phase post-TAVR (50% and 80% within the first and fourth months, respectively, with only 1 event after 12 months) (**Figure 2**) (15,26).

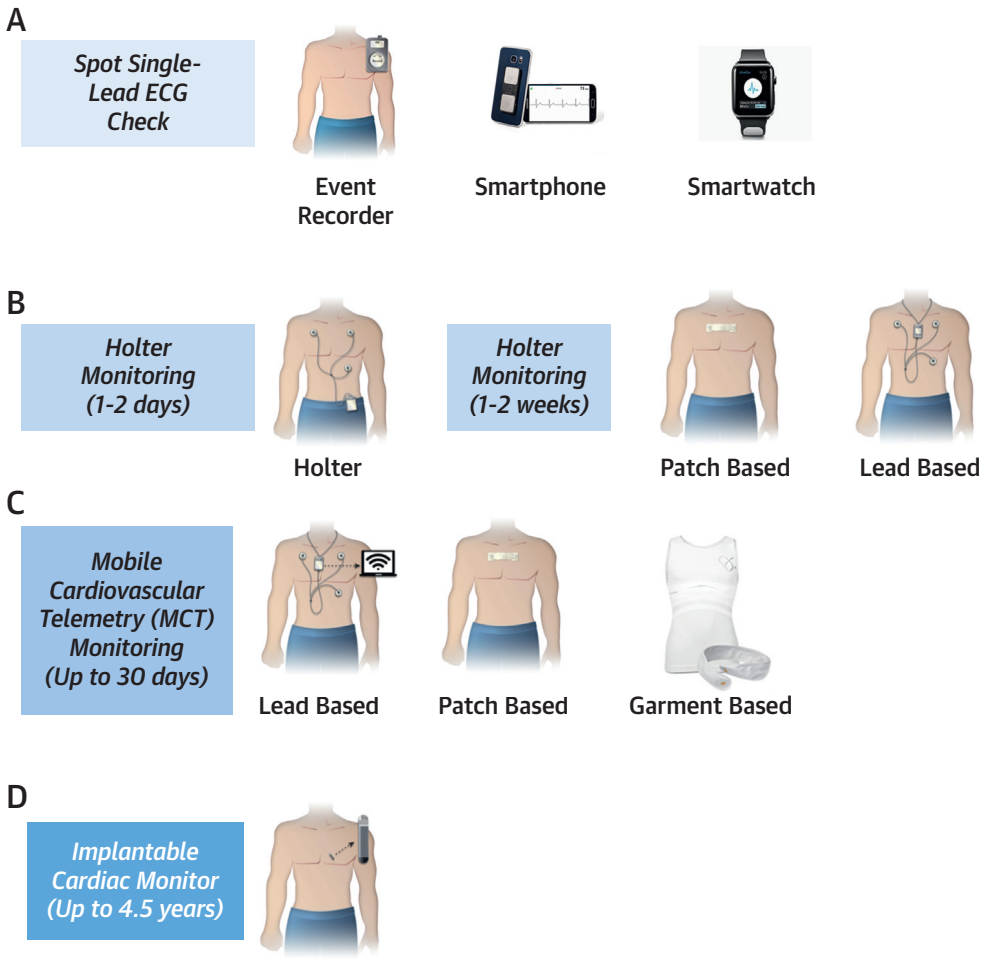
TABLE 2 Indications for Ambulatory Electrocardiographic Monitoring

Diagnosis of unexplained symptoms	Pre-syncope or syncope	
	Recurrent falls	
	Palpitations	
	Cryptogenic stroke	
Prognosis and risk stratification	Ischemic heart disease and post-infarction patients	
	Nonischemic dilated cardiomyopathy	
	Hypertrophic cardiomyopathy	
	Arrhythmogenic right ventricular cardiomyopathy	
	Wolf-Parkinson-White syndrome	
	Inherited primary arrhythmic diseases (e.g., QT syndromes, Brugada, and so on)	
	Sleep apnea	
	Athletes and pre-participation screening	
Holter-based markers of autonomic nervous tone and repolarization	Heart rate variability	
	Heart rate turbulence	
	QT variability	
Pre- and post-treatment arrhythmia assessment	Ventricular arrhythmias	Premature ventricular beats monitoring
		Evaluation of ventricular arrhythmic burden after medical or ablation therapy
	Atrial fibrillation	Study of atrial fibrillation patterns (e.g., paroxysmal vs. persistent, ventricular rate control, duration and burden, and so on)
		Assessment of efficacy of medical or ablation treatment
Drug trials and safety	QT and arrhythmia evaluation	
Patients with cardiac implantable devices	Assess device function	

The main characteristics of the 2 chief studies using MCT monitoring after TAVR (similar sample size exceeding 100 TAVR recipients, comparable inclusion criteria, and equal duration of monitoring) are summarized in **Table 5** (16,17). A total of 245 patients were included. At 30 days of follow-up, episodes of HAVB/CHB leading to PPMI were diagnosed in 9% of the patients (**Figure 2**), the majority (75%) of them asymptomatic. Of note, among the 15 patients with RBBB that were discharged with AECG monitoring, 6 (40%) experienced delayed CHB/HAVB episodes. RBBB was found to be the only independent predictor for delayed HAVB events (odds ratio: 20.46; 95% confidence interval: 2.67 to 158.31; $p = 0.004$) (16). On the other hand, 4% of patients with normal ECG at discharge had CHB/HAVB episodes, which represented 19% of all patients with CHB/HAVB events (**Figure 3**). These results are in contrast to previous publications that established the safety of early discharge in patients without electrocardiographic CDs after TAVR (3,6,27). Because syncope episodes were uncommon among AECG monitoring recipients with delayed HAVB (10% of patients) and no deaths occurred, the presence of transient asymptomatic HAVB episodes without clinical significant consequences may have occurred in those studies with an early discharge strategy not using AECG monitoring systems (3,6,27). In the absence of randomized data, whether the increased sensitivity for the diagnosis of delayed HAVB obtained with AECG monitoring systems in all TAVR recipients translates into a clinically significant benefit remains to be elucidated. Also, the study by Ream et al. (16) showed the presence of delayed HAVB in 3 patients with incomplete LBBB (QRS >110 ms). More studies are needed to know the incidence of major bradyarrhythmic events in patients with intermediate ECG-CDs (e.g., incomplete LBBB, fascicular block). Finally, 9% of patients with new-onset LBBB experienced CHB/HAVB episodes within the first 30 days after discharge (16,17).

TACHYARRHYTHMIC EVENTS. Studies using AECG monitoring after TAVR and reporting tachyarrhythmic events are scarce. The first report using an ICM (Reveal XT) after aortic replacement focused on AF and included patients undergoing SAVR ($n = 27$) or TAVR ($n = 27$) (14). At 3 months of follow-up, the cumulative rate of NOAF in TAVR patients was 81.5% (**Figure 2**) (14). Of note, most (>90%) NOAF events in the TAVR group occurred within the first month after the procedure (**Figure 4**) (14). In the MARE study, close to one-third of TAVR recipients presented NOAF episodes at 2 years of follow-up, and anticoagulation treatment was started in one-fourth of them (26). Two studies using MCT systems after TAVR including a total of 77 patients showed an incidence of NOAF ranging from 0% to 6% (18,19). More data are needed with larger cohorts to know the incidence and clinical implications of late NOAF in this context. Finally, the

FIGURE 1 Types of Ambulatory ECG Monitoring



(A) Event recorder. **(B)** Holter monitoring. **(C)** Mobile cardiovascular telemetry (MCT) monitoring. **(D)** Implantable cardiac monitoring. ECG = electrocardiogram.

presence of ventricular tachyarrhythmias has often been associated with aortic stenosis. However, data regarding its occurrence (especially sustained events) in the TAVR field are limited. Tempio et al. (13) used a 24-h standard Holter in 146 patients before TAVR and at 1 and 12 months following the procedure for the detection of ventricular arrhythmias, showing a decrease in ventricular tachycardia events (all of them nonsustained) over time (from 9.6% before TAVR to 4.8% and 2.1% at 1 and 12 months post-procedure).

CLINICAL PERSPECTIVES

AECG MONITORING BEFORE TAVR. Current available data regarding AECG monitoring before the TAVR procedure revealed the potential clinical benefits of this strategy, because it would identify significant arrhythmic events (severe bradyarrhythmias or AF) in around 10% of TAVR candidates (Table 4).

Bradyarrhythmic events. The prompt identification of severe bradyarrhythmias in selected patients may lead to planned PPMI before TAVR, which otherwise would be have been attributed to a direct complication of the procedure. This strategy may facilitate patients' post-procedural management and reduce periprocedural complications and hospital length of stay. Interestingly, some studies have shown that the presence of calcific aortic stenosis was associated with conduction disturbances irrespective of TAVR, with the deposit of calcium on the

TABLE 3 Ambulatory ECG Monitoring Modalities and Technology

Type of Recorder	Duration of Recording	Modality of Recording	Advantages	Disadvantages
Standard Holter monitor	24–48 h	Continuous single and multilead external recorders.	Ability to record and document single or 3- to 12-lead ECG signal simultaneously.	Frequent noncompliance with symptom logs and event markers. Signal quality issues.
External event recorders/ Smartphone-based recorder	<1 min	Intermittent external patient- or auto-trigger activated post-event recorders.	Records only selected ECG segments of fixed duration after an event is detected by the patient. Immediate alarm generation upon the event detection. Well-tolerated for the patient.	Single-lead devices. Noncontinuous cardiac recording.
Patch ECG recorders	Up to 4 weeks	Continuous single or two lead external recorders without and with wireless data transmission.	Long-term recorder of 28 days or longer. Excellent patient acceptance.	Records a limited ECG from closely spaced electrodes (lack of localization ability of arrhythmia origin). Inconsistent optimal ECG signal quality due to varying body types.
External loop recorders (ELR)	4–8 weeks	Intermittent external patient- or event-activated (auto-triggered) recorders.	Records only selected ECG segments of fixed duration marked as events either automatically or manually by the patient. Immediate alarm generation upon event detection.	Records a single-lead ECG sequence. P waves may not be visible. Requires patients to wear electrodes continuously.
Mobile cardiovascular telemetry monitoring	Real-time streaming to call centers	External real-time continuous cardiac tele-monitoring systems.	Immediate alarm generation.	Frequent electrode changes. Cost.
Implantable cardiac monitors	Up to 4.5 yrs	Intermittent implantable or insertable patient- or auto-trigger activated post-event recorders.	Very long-term recording. Well-tolerated.	Cost.

ECG = electrocardiography.

conduction system and left ventricular dysfunction leading to LBBB and advanced atrioventricular block as possible mechanisms (28,29). Whereas the cost-effectiveness of using AECG monitoring before the procedure in all TAVR patients remains questionable, the high incidence of HAVB/severe bradycardia (up to 47%) in patients with previous ECG abnormalities such as first-degree AVB or RBBB suggest that AECG monitoring would be highly sensitive and of particular value in this group (20). While awaiting additional data, patients with RBBB (especially with associated fascicular block or first-degree AVB) would be appropriate candidates (**Figure 5**). In this context (patients with RBBB at baseline), a PPMI would be recommended in case of documented HAVB/CHB, even if asymptomatic (**Figure 5**). On the other hand, current guidelines do not support PPMI in patients with asymptomatic pauses in the context of sinus node disease or permanent AF (30). Thus, the decision should be individualized in such cases (e.g., need for atrioventricular node inhibitors). A temporal correlation between the arrhythmic event and the presence of symptoms would be needed to consider PPMI (30).

Tachyarrhythmic events. The identification of AF before the TAVR procedure may lead to the initiation of anticoagulation therapy and potentially decrease the rate of post-TAVR cerebrovascular events (31), which remains one of the most worrisome complications due to its high mortality and morbidity (9,10). Unfortunately, no specific predictors of newly diagnosed episodes of AF before the procedure have been identified yet. Also, the minimum AF duration required to initiate anticoagulation in patients with asymptomatic AF episodes detected by AECG monitoring systems remains controversial. Whereas a recent consensus document suggested that the anticoagulation treatment may be recommended if AF episodes lasted >5.5 h (32), this recommendation may not apply to TAVR recipients (an elderly population with frequent comorbidities and high CHA_2DS_2-VASc score [congestive heart failure, hypertension, age ≥75 years, diabetes, previous stroke, vascular disease, age 65 to 74, and female sex]). In addition, previous data suggested an increased risk of stroke (>1%/year) in patients with CHA_2DS_2-VASc score of 3 to 4 with daily AF episodes of >6 min, and in patients with a CHA_2DS_2-VASc score ≥5 even with no AF (33).

While waiting for further studies focusing on pre-TAVR AF, the indication of AECG monitoring may be considered in patients with an elevated clinical suspicion of AF (risk factors for AF and higher CHADs score), such as those with frequent supraventricular ectopic activity, severely dilated left atrium, history of ischemic stroke, or left ventricular dysfunction. In the case of documented AF, we would recommend

TABLE 4 Summary of the Published Studies Using Ambulatory ECG Monitoring Before TAVR

	Urena et al. (12) (n = 435)	Winter et al. (19) (n = 62)*	Asmarats et al. (20) (n = 106)	Overall (N = 582)
Baseline characteristics				
Age, yrs	81 ± 8	84 ± 5	80 ± 8	81 ± 8
Previous AF	169 (38.9)	9 (21.9)	27 (25.5)	205 (35)
STS-PROM score	7.3 ± 5.4	8.9 ± 6.5	4.8 ± 2.7	7.0 ± 5
Mean gradient, mm Hg	45 ± 18	49 ± 18	42 ± 16	45 ± 18
1-AVB	N/A	9 (21.9)	20 (22.5)	N/A
RBBB	N/A	7 (17)	15 (14.2)	N/A
New-onset arrhythmias				
AF	28 (10.5)†	1 (2.6)	6 (7.6)	35 (6)
Severe bradycardia	12 (3.2)	N/A	20 (18.9)	N/A
CHB/HAVB	12 (3.2)	4 (10)	2 (1.9)	18 (3)
AF or bradyarrhythmia	54 (12)	5 (12)	28 (26)	87 (15)
PPMI before TAVR	5 (1)	3 (7)	2 (2)	10 (2)
Nonsustained VT	26 (6)	6 (15)	31 (29)	63 (11)

Values are weighted mean ± SD or n (%). *Non-ECG baseline characteristics form the whole cohort (AECG monitoring pre- and post-procedure). New-onset arrhythmias from pre-TAVR AECG monitoring (n = 41). †Atrial fibrillation or atrial tachycardia.

1-AVB = first-degree atrioventricular block; CHB = complete heart block; HAVB = high-degree atrioventricular block; N/A = not available; RBBB = right bundle branch block; STS-PROM = Society of Thoracic Surgeons Predicted Risk of Mortality; VT = ventricular tachycardia; other abbreviations as in Table 1.

anticoagulation treatment to be initiated in all patients with daily FA burden of >5.5 h. In addition, it may be considered in patients with CHA_2DS_2-VASc score ≥3 and daily episodes of >6 min (Figure 5). Finally, the presence of increased ectopic ventricular activity with frequent complex forms (couplets or nonsustained ventricular tachycardia) occurring before the procedure should raise concerns. Thus, a prompt hospitalization to proceed with TAVR might be considered, irrespective of the ejection fraction.

Type of AECG monitoring. No data exist regarding the most adequate type of AECG monitoring before the TAVR procedure, and the decision will depend on local availability and experience. However, previous data suggested that in-hospital monitoring with ECG telemetry could be applied in all patients before TAVR (at time of hospital admission) given the low economic cost, wide availability, and ability to unmask previously unknown arrhythmic disorders (12). However, longer periods of ECG monitoring (7 to 30 days) before the hospitalization would likely determine an increase in the number of arrhythmic events detected and should be considered (24).

AECG MONITORING AFTER TAVR. The introduction of AECG monitoring after the TAVR procedure may help to partially overcome the current clinical dilemma between a minimalist approach with an early discharge strategy and the risk of missing delayed significant arrhythmic events. In addition, previous data showed very low (or even absent) ventricular pacing rates at follow-up in some PPMI recipients (e.g., transient intraprocedural CHB, new-onset LBBB (34,35). These patients may benefit from AECG monitoring instead of early PPMI after TAVR. The clinical safety of this strategy has been demonstrated with the initial experience using AECG monitoring post-TAVR in all comers and in high-risk patients (e.g., new-onset LBBB), with no reported early deaths (15–19). However, additional data are needed to further determine the subset of patients where AECG monitoring following a TAVR procedure would exhibit the best cost-efficacy ratio.

Bradyarrhythmic events. Although the occurrence of bradyarrhythmias (usually asymptomatic transient HAVB episodes) in patients discharged with a normal ECG post-TAVR may raise concerns (16,17), its incidence was relatively low (4% among all patients discharged with normal ECG) and should be confirmed in future studies. Also, cumulative clinical data with large TAVR cohorts showed that the risk of clinically apparent bradyarrhythmias (associated with syncope, sudden death) in patients with normal ECG after TAVR is negligible (3,6,27). Thus, current evidence does not support the systematic use of AECG monitoring after the procedure in all TAVR recipients. In this direction, a recent scientific expert panel document for the management of CDs after TAVR did not recommend the use of AECG monitoring in those patients without significant ECG changes after the TAVR procedure (2).

The group of patients with baseline RBBB (around 10% of TAVR candidates) represents the group with the highest risk of CDs after TAVR. Prior RBBB has been the most consistent patient-related factor of CHB/HAVB after the procedure (1), with in-hospital PPMI rates of ~40% (36,37). Also, some studies have shown an increased risk of mortality after hospital discharge in this group of patients (36). A recent publication analyzed the timing of the occurrence of CDs in RBBB patients undergoing TAVR (n = 110) (38). The main results showed that almost all CHB/HAVB episodes (98%) occurred within the 3 days following the procedure (only 2% between 3 and 30 days), suggesting that a strategy including a minimum hospitalization period of 3 days may be safe in such patients. However, recent complementary data obtained with AECG monitoring showed an increased risk of delayed events in this group (CHB/HAVB episodes in 40% of them) (16,17). Yet, recent publications

focusing on valve type and valve positioning have shown promising results regarding post-TAVR CDs, including patients with pre-existing RBBB (39,40). Further studies are warranted to shed light on the current controversial management of RBBB patients (including the possibility of prophylactic PPMI in some cases). Meanwhile, the available data suggest that 2 to 4 weeks of AECG monitoring after TAVR may be considered in all patients with baseline RBBB discharged without PPMI (Figure 5).

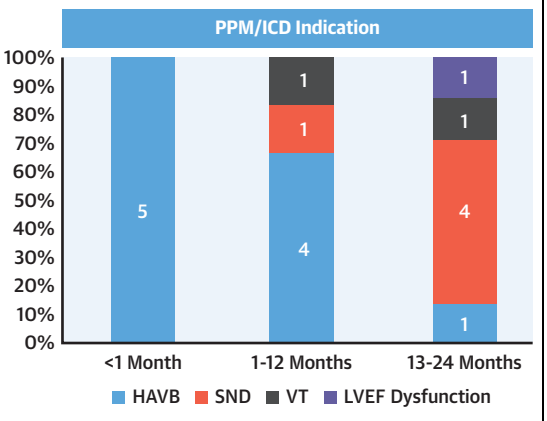
In patients with new-onset LBBB, the results of the MARE study established the safety of AECG monitoring in patients with new-onset persistent LBBB (15). Furthermore, the fact that most of the patients did not require PPMI at follow-up along with the resolution of the LBBB in one-third of them would strongly discourage systematic PPMI in this setting (2,15). The MARE study also showed that PPMI due to HAVB predominated in the early phase after TAVR, with one-half of the events occurring within the first month (26). Based on these results, AECG monitoring for 2 to 4 weeks post-TAVR may be considered in all patients with new-onset persistent LBBB (Figure 5).

The use of AECG monitoring after TAVR in a variety of other clinical scenarios may also be considered. The number of potential combinations of CD types and timings following TAVR is extensive and a case-by-case clinical decision scenario would be required. As an example, patients without RBBB/LBBB presenting dynamic de novo ECG changes (significant [>20 ms/day] and progressive PR and/or QRS enlargement) and without a classic indication for PPMI could also benefit from AECG monitoring (2). Other borderline cases where AECG monitoring may be considered include non-LBBB patients with wide de novo QRS, patients with persistent periprocedural atrioventricular block (present after leaving the catheterization laboratory room) but with early (<24 h) recovery, or patients with equivocal results from an electrophysiological study.

Regarding pacing indications in the context of baseline RBBB, progression of baseline CDs, or new-onset LBBB (Figure 5), a PPMI might be recommended in case of HAVB/CHB events, even if asymptomatic. As discussed in the pre-procedural assessment, there is no established pause duration to consider PPMI (the decision should be individualized in such cases).

Tachyarrhythmic events. Data on AECG post-TAVR for the detection of episodes of AF remain scarce, but an incidence of up to 9% and 16% of AF episodes at 1- and 12-month follow-up has been reported (15).

FIGURE 2 Reason for PPM/ICD Implantation According to Time Period Following TAVR in the MARE Study (<1, 1 to 12, and 13 to 24 Months)



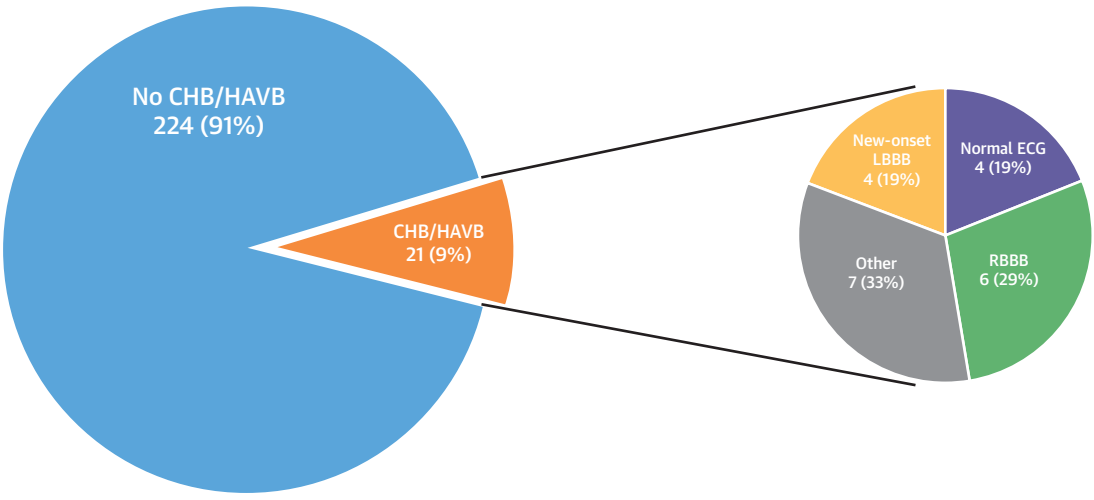
Reproduced with permission from Muntané-Carol et al. (26). HAVB = high-degree atrioventricular block; ICD = implantable cardioverter-defibrillator; LVEF = left ventricular ejection fraction; PPM = permanent pacemaker; SND = sinus node disease; VT = ventricular tachycardia.

TABLE 5 Summary of the Main Published Studies Using Mobile Cardiac Telemetry After TAVR

	Ream et al. (16) (n = 118)	Tian et al. (17) (n = 127)	Overall (n = 245)
Baseline characteristics			
Age, yrs	77 ± 10	81 ± 6	79 ± 8
Female	56 (47)	46 (39)	102 (42)
Previous AF	35 (30)	44 (35)	79 (32)
STS-PROM score, %	N/A	5.9 ± 3	N/A
Mean gradient, mm Hg	N/A	46 ± 14	N/A
Sapien 3 (vs. Evolut R/Pro)	94 (80)	123 (97)	217 (89)
ECG at discharge			
Normal ECG	53 (45)	43 (34)	96 (39)
RBBB	6 (5)	9 (7)	15 (6)
New-onset LBBB	23 (19)	24 (19)	47 (19)
Other	36 (31)	51 (40)	87 (36)
New-onset bradyarrhythmias			
CHB/HAVB			
Overall	12/118 (10)	9/127 (7)	21/245 (9)
Normal ECG	1/53 (2)	3/43 (7)	4/96 (4)
RBBB	4/6 (66)	2/9 (22)	6/15 (40)
New-onset LBBB	1/23 (4)	3/24 (13)	4/47 (9)
Other	6/36 (17)	1/51 (2)	7/87 (8)
Syncope	2/12 (17)	0/9 (0)	2/21 (10)
Death	0 (0)	0 (0)	0 (0)
Sudden death	0 (0)	0 (0)	0 (0)

Values are weighted mean ± SD, n (%), or n/N (%).
Abbreviations as in Tables 1 and 4.

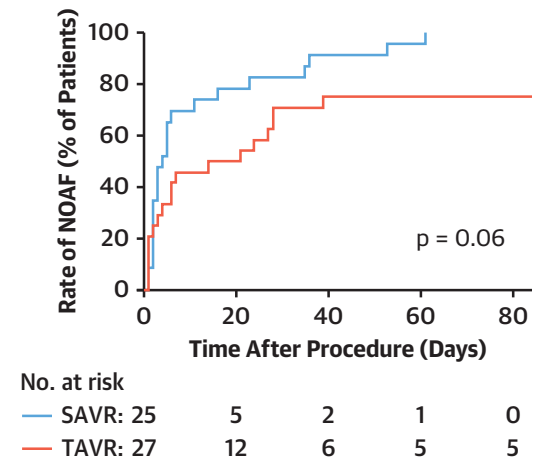
FIGURE 3 Complete or High-Degree Atrioventricular Block After TAVR



Rate of CHB/HAVB after TAVR **(left)** in patients receiving mobile cardiovascular telemetry (MCT) monitoring (16,17). Electrocardiogram characteristics **(right)** at discharge in patients with CHB/HAVB events. CHB = complete heart block; LBBB = left bundle branch block; RBBB = right bundle branch block; other abbreviations as in Figures 1 and 2.

However, no data has been reported to date regarding subgroups of patients at higher risk of NOAF after hospital discharge. Thus, the decision for using AECG monitoring for this purpose should be individualized, and could probably be considered in patients with a high clinical suspicion of AF or in those with very short episodes during the hospitalization to confirm the occurrence of more prolonged late episodes (Figure 5). We recommend anticoagulation treatment to be initiated in all patients with daily FA of >5.5 h. Furthermore, it may be evaluated in patients with CHA_2DS_2-VASc score ≥3 and daily episodes of >6 min (Figure 5).

FIGURE 4 Rate of New-Onset Atrial Fibrillation Over Time After Surgical Aortic Valve Replacement or Transcatheter Aortic Valve Replacement

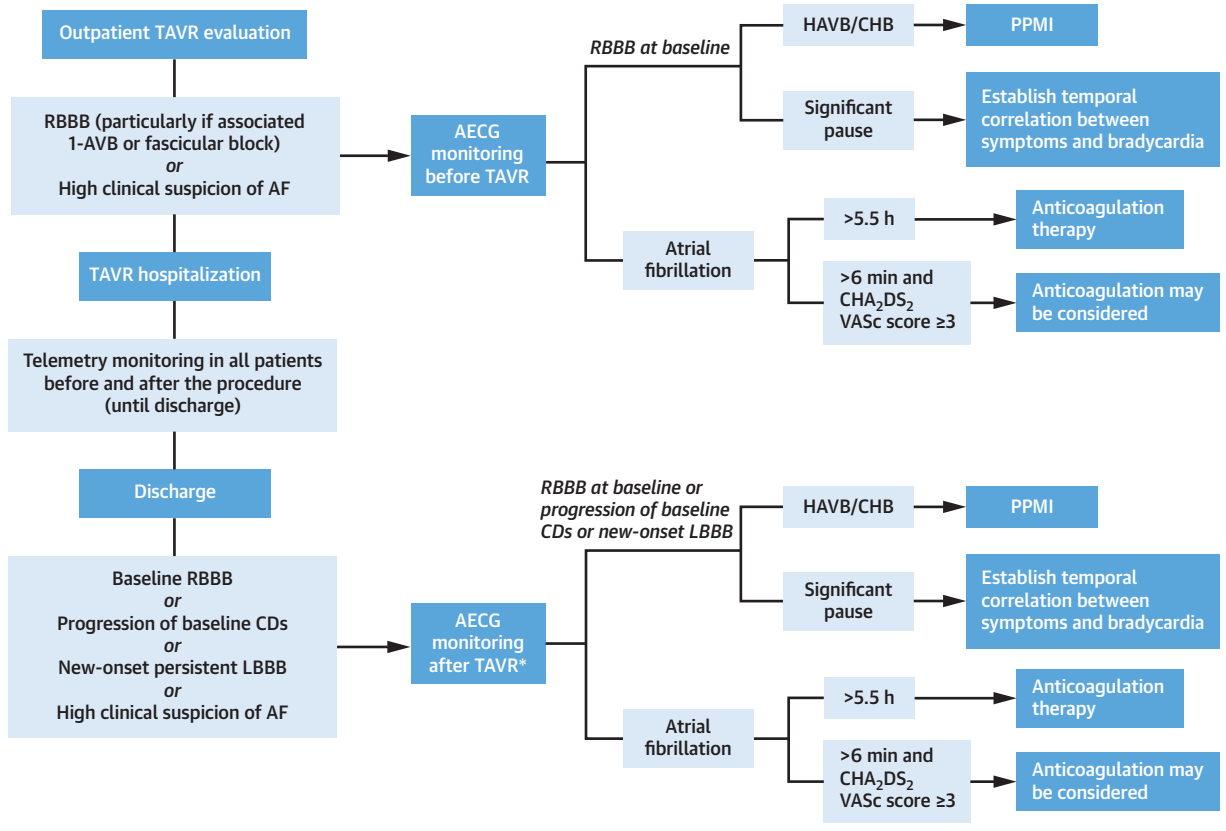


Detection of NOAF over time after SAVR or TAVR in patients that were continuously electrocardiography monitored using an implantable cardiac monitor from time of intervention. Reproduced with permission from Jørgensen et al. (14). NOAF = new-onset atrial fibrillation; SAVR = surgical aortic valve replacement; TAVR = transcatheter aortic valve replacement.

Finally, limited data exist focusing on the ventricular arrhythmic burden after the procedure (13). Further studies are needed to establish the specific role of AECG monitoring for ventricular arrhythmic events in TAVR. Meanwhile, the initiation of medical treatment (e.g., beta-blocker therapy, amiodarone) might be considered in patients with frequent and/or complex nonsustained ventricular events. In case of persistent severe left ventricular dysfunction after TAVR, a consultation with an electrophysiologist might be considered to assess the risk-benefit of implantable cardioverter-defibrillator implantation.

Type of AECG monitoring. The optimal duration of AECG monitoring after TAVR is unknown, as data regarding the timing patterns on the incidence of new-onset arrhythmic events after discharge are limited. The MARE study showed that the risk of new-onset arrhythmic events predominated in the early phase post-procedure (15). The incidence of new arrhythmic events was similar within the first 30 days after TAVR compared with the first and second year after the procedure (26). Also, the study from

FIGURE 5 Global Recommendations for the Use of Ambulatory ECG Monitoring in TAVR



*Ambulatory rhythm monitoring may also be considered in the following cases: dynamic de novo ECG changes (significant [>20 ms per day] and progressive PR and/or QRS enlargement), non-LBBB patients with wide de novo QRS, patients with persistent periprocedural atrioventricular block with early (<24 h) recovery, or patients with equivocal results from an electrophysiological study. 1-AVB = first-degree atrioventricular block; AECG = ambulatory electrocardiogram; AF = atrial fibrillation; CD = conduction disturbance; CHA_2DS_2-VASc = congestive heart failure, hypertension, age ≥75 years, diabetes mellitus, prior stroke, transient ischemic attack, or thromboembolism, vascular disease, age 65–74 years, sex category (female); PPMI = permanent pacemaker implantation; other abbreviations as in Figures 2 to 4.

Jørgensen et al. (14) using ICM after TAVR and focusing on new-onset AF showed that most of the events occurred within the first month (Figure 2). While waiting for more data in the field, the duration of AECG monitoring for 2 to 4 weeks after discharge seems adequate (Figure 5).

The type of AECG monitoring post-TAVR would also be important. The relatively high incidence of life-threatening bradyarrhythmias within the few weeks following the procedure in patients with high-risk features (e.g., baseline RBBB, new-onset LBBB) would favor the use of MCT incorporating alarm systems (Table 1) to implement a rapid intervention and prevent further potential fatal arrhythmic events.

FUTURE PERSPECTIVES

Current data on the clinical use of AECG monitoring in the context of TAVR have provided important insights into the high arrhythmic burden of TAVR recipients beyond the peri-procedural period (Central Illustration). Also, promising preliminary results have been obtained on the clinical impact of AECG monitoring pre- and post-TAVR, with significant therapeutic changes (PPMI, anticoagulation, addition/withdrawal of antiarrhythmic drugs) in a relatively high proportion of patients, particularly in those groups at highest risk (i.e., those with prior or de novo CDs). However, further data would be needed to confirm these findings and provide

TABLE 6 Ongoing Studies Using Ambulatory ECG Monitoring in TAVR Recipients

Study	NCT Number	Study Design and Timing	Intervention	n	Target Population	Main Outcomes
Reveal	NCT02559011	Observational. Prospective. Post-procedure.	Medtronic Reveal ICM implantation.	100	All TAVR patients.	Number of patients with NOAF and CHB. Time frame: up to 12 months.
RECORD	NCT04298593	Observational. Prospective. Post-procedure.	CardioSTAT implantation.	200	All TAVR patients without PPMI.	Incidence and type of arrhythmic events after discharge in TAVR recipients. Time frame: 2 weeks.
LBBB-TAVI	NCT02482844	Observational. Prospective. Post-procedure.	EP study with PPMI if HV interval >70 ms and implantable cardiac monitoring if <70 ms.	200	New-onset LBBB.	Incidence of HAVB/CHB. Time frame: 12 months.
Clinical Monitoring Strategy vs. EP-Guided Algorithmic in LBBB Patients Post-TAVI	NCT03303612	Randomized. Prospective. Post-procedure.	Group 1: EP-based algorithmic approach. Group 2: standard clinical follow-up with transcutaneous cardiac monitoring.	134	New-onset LBBB.	Hospitalization, syncope or death after TAVR. Time frame: 12 months.
Remote ECG Monitoring of TAVI Patients	NCT03810820	Observational Prospective. Pre- and post-procedure.	M-CARDS (MCT) pre- and post-TAVR.	240	All TAVR patients.	New-onset conduction disturbances. Time frame: 30 days.
Brady-TAVR Study	NCT03180073	Observational. Prospective. Pre- and post-procedure	Ziopatch (ECG patch recording).	100	All TAVR patients.	Need for pacemaker.
PAF-TAVI Trial	NCT03991754	Randomized. Observational. Post-procedure.	60-day Holter: 1. Amiodarone group. 2. Nonamiodarone group.	120	All TAVR patients.	Incidence of NOAF.
SMART TAVR	NCT04454177	Observational. Prospective. Post-procedure.	Huawei smart watch.	100	All TAVR patients.	Incidence of conduction disturbances and PPMI implantation.

EP = electrophysiology; HV = His ventricle; ICM = implantable cardiac monitor; LBBB-TAVI = Assessment of the Prognosis of Persistent Left Bundle Branch Block (LBBB) After Transcatheter Aortic Valve Implantation (TAVI) by an Electrophysiological and Remote Monitoring Risk-Adapted Algorithm; M-CARDS = mobile Cardiac Arrhythmia Diagnostics Service; MCT = mobile cardiovascular telemetry; NOAF = new-onset atrial fibrillation; PAF-TAVI = Prevention of New Onset AF After TAVI; Reveal = Assessment of Arrhythmias in Patients Undergoing Transcatheter Aortic Valve Implantation Using a Small Insertable Cardiac Monitoring Device; SMART TAVR = SMART Watch Facilitated Early Discharge in Patients Undergoing Transcatheter Aortic Valve Replacement; other abbreviations as in Tables 1 and 4.

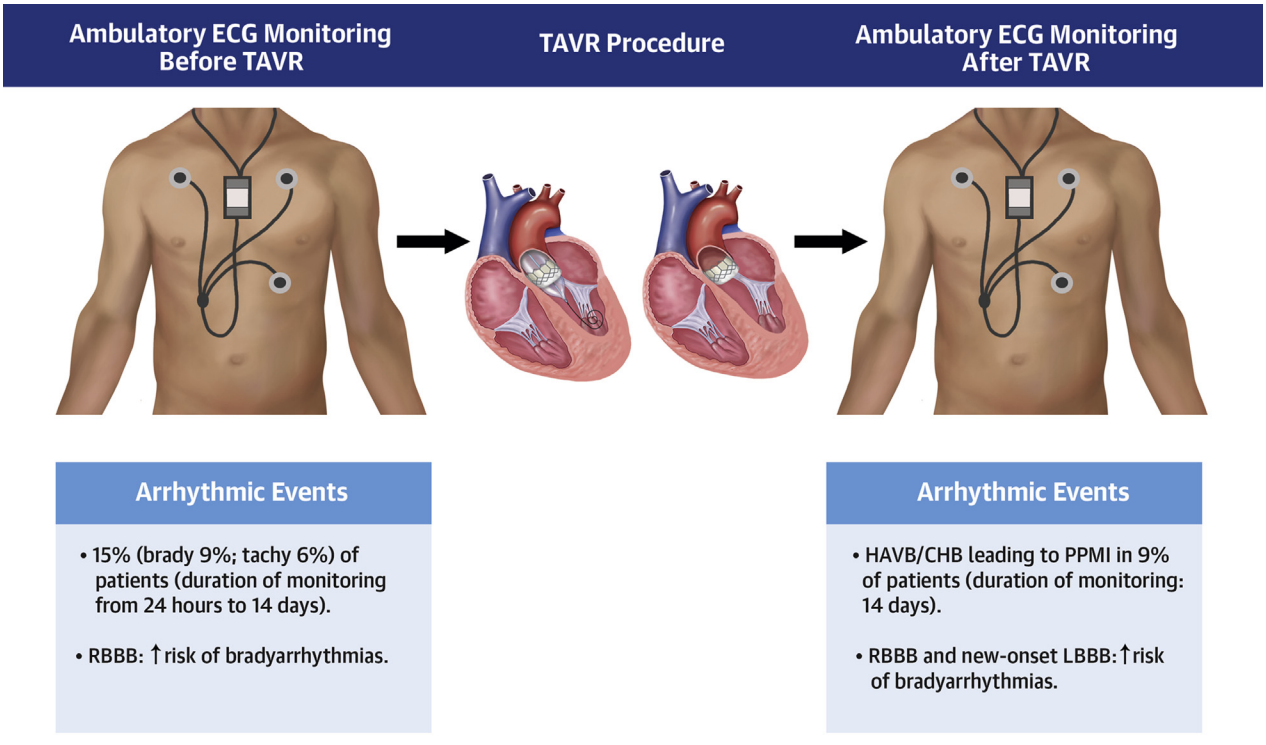
additional evidence on the usefulness and cost-effectiveness of AECG monitoring in TAVR recipients. The main unmet need regarding the management of CDs after TAVR has been the lack of consensus between operators and centers, which has translated into major differences regarding PPMI rates or the use of AECG monitoring. Large-scale observational, prospective studies with a uniform post-procedure management including AECG monitoring are needed to establish robust recommendations. Moreover, randomized studies using AECG (either pre- and post-procedure) are needed to evaluate its clinical (e.g., sudden cardiac death after TAVR, unplanned hospitalization) and economic impact (e.g., length of stay).

Currently, there are multiple ongoing studies with different AECG monitoring systems in the context of TAVR, which are summarized in Table 6. Most studies are focusing on AECG monitoring following TAVR, mainly including all comers or new-onset LBBB patients, and all studies but 2 (randomized) are of observational nature. These upcoming data will help to further define the role of AECG monitoring in this setting.

CONCLUSIONS

AECG monitoring has emerged as a useful tool in the challenging field of arrhythmic disorders before and after TAVR. AECG monitoring studies provided important clinical data regarding the incidence, timing, and type of arrhythmic events beyond the periprocedural TAVR period, and showed the safety and potential clinical usefulness of AECG monitoring systems in this context, particularly in patients with prior RBBB and those with new CDs (LBBB). However, the absence of randomized data, and the relatively low sample size of the studies published to date along with its heterogeneity (different times of monitoring and devices) limit a broader use of AECG monitoring. Further studies with larger cohorts and focusing on the specific subgroups who may benefit from AECG monitoring are needed to establish robust recommendations.

CENTRAL ILLUSTRATION **Ambulatory Electrocardiography Monitoring in Transcatheter Aortic Valve Replacement**



Muntané-Carol, G. et al. J Am Coll Cardiol. 2021;77(10):1344–56.

Summary of the main findings using ambulatory electrocardiography (ECG) monitoring in TAVR. Main results with ambulatory ECG monitoring before TAVR **(left)** using different duration of monitoring (24 h to 14 days) (12,19,20). AECG monitoring after TAVR **(right)** using mobile cardiovascular telemetry monitoring (16,17).
CHB = complete heart block; HAVB = high-degree atrioventricular block; LBBB = left bundle branch block; PPMI = permanent pacemaker implantation; RBBB = right bundle branch block; TAVR = transcatheter aortic valve replacement.

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