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► To cite this version:

Léo Lemarchand, Dominique Boulmier, Guillaume Leurent, M Bedossa, Sam Sharobeem, et al.. Conductive disturbances in the transcatheter aortic valve implantation setting: An appraisal of current knowledge and unmet needs. Archives of cardiovascular diseases, 2023, 10.1016/j.acvd.2023.05.004 . hal-04164924

HAL Id: hal-04164924

<https://hal.science/hal-04164924v1>

Submitted on 21 Jul 2023

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Conductive Disturbances in the transcatheter aortic valve implantation setting: an appraisal of current knowledge and unmet needs.

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Word Count : 5336

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Abstract :

New-onset conduction disturbances (NOCD), including left bundle branch block and permanent pacemaker implantation remain a major issue after transcatheter aortic valve implantation (TAVI). Pre-procedural risk assessment in current practice is most often limited to the evaluation of the baseline electrocardiogram whereas it may benefit from a multimodal approach including ambulatory ECG monitoring and multidetector computed tomography (MDCT). Physicians may encounter equivocal situations during the hospital phase, and the management of the follow-up is not fully defined despite the publication of several experts' consensus and the inclusion of recommendations regarding the role of electrophysiological studies (EPS) and post-procedural monitoring in recent guidelines. This review provides an overview of current knowledge and future perspectives regarding the management of NOCD in the setting of TAVI, from the pre-procedural phase to the long-term follow-up.

Keywords:

Transcatheter Aortic Valve Repair; New-Onset Conduction Disturbances; Left Bundle Branch Block; Permanent Pacemaker Implantation; High-Degree Atrioventricular Block; Calcifications; Membranous Septum; Electrophysiology Study; Right Atrial Pacing; ambulatory monitoring.

Introduction

Transcatheter Aortic Valve Implantation (TAVI) is a reference treatment for severe symptomatic aortic stenosis (AS) among intermediate-to-high risk patients and a valid option among low-risk older patients¹. Its development was made possible by technological enhancements and procedural simplification over the past 20 years², allowing its widespread use in current practice. TAVI has gradually supplanted conventional surgical aortic valve replacement (SAVR) as the treatment of severe and symptomatic AS for the majority of patients^{3,4}. Although this procedure was initially reserved for comorbid patients, some studies have suggested the non-inferiority, and even superiority, of TAVI compared to SAVR in patients at low surgical risk of death^{3,4}. Nevertheless, new-onset conduction disturbances (NOCD) including left bundle branch block (LBBB), and permanent pacemaker implantation (PPI), remain significantly more frequent than after SAVR³ and are currently a major issue in the management of these patients. Furthermore, it has been suggested that NOCD increase the risk of hospitalization for heart failure (HHF) and mortality^{5,6,7}. The occurrence of such complications implies better anticipation, understanding, and ultimately prevention, in an increasingly younger and less comorbid population. This article reviews the current knowledge and unmet needs regarding the management of conduction disturbances in the TAVI setting.

1. Pre-procedural management

The main goal of pre-procedural management is to identify patients suffering from severe bradyarrhythmia, which may prompt pre-emptive PPI and those patients most susceptible of suffering post-TAVI NOCD to plan preventive procedural measures minimizing their occurrence.

a. Electrocardiogram and Monitoring

Several factors have already been demonstrated to predict NOCD and are used in routine practice⁶, such as the presence of PR interval prolongation, left anterior hemiblock, and more importantly right bundle branch block (RBBB) on the baseline electrocardiogram (ECG)⁸⁻¹⁰. In addition, other studies have demonstrated pre-existing severe bradyarrhythmias and/or high-degree atrioventricular blocks (HAVB) in TAVI candidates^{11,12}. In the PARE study¹¹, a 7-day pre-TAVI ambulatory cardiac monitoring was performed in 106 TAVI candidates, showing 20.8% of bradyarrhythmias, especially in case of PR-interval prolongation (30%) and pre-existing RBBB (47%). Urena and al.¹² noted that 5.5% of the patients had bradyarrhythmia during a 24 hours monitoring before TAVI, half of whom presented HAVB and the other half sinus node dysfunction, which may lead to a change in medical treatment or even a PPI. Based on these findings, randomized trials are needed to delineate the indications of, assess the cost-effectiveness and relevance of pre-TAVI monitoring.

b. Multidetector Computed Tomography

i. Calcifications

Anatomically, the atrioventricular node is located on the infero-septal side of the right atrium. It continues with the His bundle which protrudes at the lower part of the membranous septum (MS), and finally divides in the right and left bundle branch. These structures are intimately close to the aortic valve complex and can be damaged by mechanical compression of the conduction pathways (Figure 1a).

Calcifications are little-to-non-compressible structures, inherent to AS, which are involved in the occurrence of NOCD. Multidetector Computed Tomography (MDCT) is a systematically performed examination, which is essential to include in the pre-procedural NOCD risk assessment. In the European Society of Cardiology guidelines¹³, porcelain aorta

and severe mitral annular calcifications are considered to be conducive to the occurrence of NOCD after TAVI^{14,15}. However, these structures do not have a close anatomical relationship with the Device Landing Zone (DLZ), as illustrated in Figure 1b. Indeed, recent studies suggested that high volumes of calcifications in the DLZ, more precisely at the level of the non-coronary cusp (NCC) were associated with a higher rate of PPI (Odds Ratio [OR]= 1.04, 95% CI: 1.02 – 1.06), after third-generation balloon-expandable valve¹⁶. In the same way, Mauri & al.¹⁷ found that calcifications of the left ventricular outflow tract under the left and right coronary cusps (OR = 3.7, 95% CI: 1.3 – 10.6; and OR = 4.7, 95% CI: 1.6 – 14.1; respectively), were independent predictors of NOCD. Nonetheless, these measurements may be time-consuming and require a standardized segmentation. Moreover, relevant and validated cut-offs identifying the most at risk patients are lacking in routine practice.

ii. Membranous Septum Length

A short membranous septum length (MSL), measured from the annular plane to the vertex of the muscular septum, must also be considered as an independent risk factor of NOCD^{17,18}, even if its measurement can be tedious, and subject to significant inter-observer variability. This is why it has not yet been widely adopted in clinical routine¹⁹. Nevertheless, thresholds have been proposed by Jilaihawi²⁰ to distinguish patients at low- (MSL > 5 mm), intermediate- ($2 \leq \text{MSL} \leq 5$ mm), and high-risk (MSL < 2 mm) of NOCD. In this study including 248 patients, MSL was significantly lower in the PPI-group (2.9 ± 1.9 vs. 4.0 ± 2.3 ; $p = 0.026$), and a MSL < 2 mm was a predictor of PPI (33.3% vs. 16.1%). This measure should obviously be interpreted in light of other predictive factors, yet may be used by operators to identify patients, for whom great care should be taken in selecting the prosthesis type and significant efforts made to achieve higher implantation (more aortic position) of the transcatheter heart valve (THV). Indeed, different models including pre-existing CD, volumes of calcifications, and the difference between membranous septum and implantation depth, have been proposed. Maeno & al.¹⁶

found a sensitivity of 94.3% and a specificity of 83.8% for the prediction of NOCD, in the case of pre-existing RBBB, calcifications of the DLZ at the level of the non-coronary cusp associated with an implantation depth > MSL. Similarly, Mauri & al.¹⁷ reported a PPI rate of 87% with this combination compared to 13% in patients with only one risk factor.

2. Peri-procedural Management

During the hospital phase, the main objectives regarding conduction disturbances are to prevent their occurrence and adequately manage patients with NOCD representing equivocal PPI indications. Persistent HAVB post-TAVI do not pose a significant challenge and several algorithms have recently been proposed to manage patients according to the type of observed NOCD^{13,21}. These elements can be found elsewhere and thus will not be discussed thoroughly thereafter. We will rather focus on the actionable procedural aspects, which may influence the occurrence of NOCD and discuss the potential role of electrophysiological studies (EPS). Finally, it is worth underscoring that the appropriateness of some negative chronotropic drugs should be reassessed during this hospital phase.

a. Balloon or self-expandable Valve

NOCD occur more often with self-expandable than with balloon-expandable valves. Two randomized trials have compared these two types of THV^{22,23}. In the CHOICE trial with first-generation devices²², self-expandable valves implantation was associated with a higher rate of PPI at 30-days (17.3% vs 37.6%, $p < 0.01$). Although this difference was less pronounced with newer-generation devices (23.0% vs. 19.2%), non-inferiority of self-expandable valves was not met regarding this aspect in the SOLVE-TAVI trial²³. Therefore, among patients identified as at high-NOCD risk during the pre-procedural evaluation, balloon-expandable valves may be preferred to mitigate the risk of HAVB and PPI.

b. Right or Left Ventricular pacing

TAVI procedures usually require ventricular pacing during the THV deployment. Right ventricular pacing using temporary pacing lead needs additional venous access and may present vascular complications, or cardiac tamponade due to right ventricular perforation. Recently, left ventricular rapid pacing via the stiff guidewire has been identified as a safe alternative to perform THV implantation, with a reduction of procedure duration and fluoroscopy time²⁴. Although additional data is needed, it is nonetheless safe to perform right ventricular temporary pacing in patients at high risk of NOCD (especially those with pre-existent right bundle branch block). Moreover, right ventricular pacing may allow for an evaluation of the atrioventricular conduction as detailed below.

c. Pre and post-dilatation

Pre-dilatation by balloon valvuloplasty may be considered to increase the aortic valve area, facilitate the crossing of the aortic annulus and achieve better deployment of the THV, especially in patients with severely calcified stenosis or during self-expandable valve implantations. Nevertheless, pre-dilatation has been associated with an increased rate of NOCD^{25,26,27}. Bernardi and al.²⁶ found that pre-dilatation was associated with persistent new-onset LBBB (47.7% vs. 35.1%; $p=0.01$). Physiopathologically, it could be explained by a “two-hit model” as proposed by Lange and al.²⁷, where pre-dilatation is the first aggression provoking inflammation and intramural hematoma. In the same study, a larger pre-dilatation balloon (25 mm) was an independent predictor of PPI in the context of CoreValve implantation whereas smaller balloon sizes (18 to 23 mm) were not. Post-dilatation has also been described as a predictor of NOCD¹⁰. However, it is noteworthy that in current practice pre- and post-dilatations are mostly performed in patients with a high volume of calcifications, which inherently predispose to NOCD.

d. Implantation Depth

Jilaihawi proposed a Minimizing Depth According to membranous Septum (MIDAS) approach²⁰, based on an implantation depth $<$ MSL whenever feasible. In this work using self-expandable devices, implantation depth $>$ MSL was an independent predictor of PPI (OR = 8.04, 95%CI: 2.58-25.04; $p < 0.001$). This approach may be considered in patients with MSL $>$ 2mm. For those for whom MSL $<$ 2mm, too high implantation could increase the risk of prosthesis migration/embolization, result in a higher rate of significant paravalvular leak, and restrict access to the coronary arteries during long-term follow-up. Similarly, Schwerg and al.²⁸ have highlighted using the SAPIEN 3 system (Edwards Lifesciences) that a “low implantation” (i.e. a central marker to annulus distance $<$ 2 mm) resulted in a 32% PPI rate compared with only 4% in patients with higher implantation. Achieving a limited implantation depth requires meticulous pre-procedural planning using the dedicated MDCT and a reliable per-procedural assessment before deployment of the device.

The cusp-overlap projection (COP) technique superimposes the right and the left coronary hinge points on the operating view, which offers a better visualization of the NCC, and a reduction of the parallax effect, resulting in a better appreciation of the implantation depth. It complements the conventional three-cusp coplanar (TCC) technique and may allow higher implantation of the THV. In a comparative study using self-expandable valves, Pascual and al.²⁹ found that COP was associated with higher implantation (i.e. lower implantation depth), than the TCC technique, resulting in a lower 30-day PPI rate (12.6% vs 21.2%). However, the rate of new-onset LBBB was numerically higher in the COP group. Furthermore, the difference in implantation depth between these two groups was 0.9 mm when the measurement was performed between the hinge point of the NCC and the lower part of the THV, while the angiographic spatial resolution is about 0.2 mm³⁰. Finally, the difference was not significant with other measurement methods, which overall questions the true influence of the COP technique on the observed reduction of post-TAVI PPI in published studies.

Therefore, the optimal implantation depth should be individualized and result from a compromise between the prevention of NOCD and the preservation of coronary arteries access. Although more data are needed, COP may offer a better appreciation of the relationship between the THV and the anatomical structures involved in the occurrence of CD.

e. Right Atrial Pacing

Rapid Atrial Pacing (RAP) is an important component of routine EPS, which can be performed immediately after TAVI, if a temporary pacemaker has been used, to assess atrio-ventricular conduction. A Wenckebach phenomenon, defined as a progressive PR-interval prolongation followed by a blocked QRS complex, can be searched by incremental RAP with a temporary pacemaker, and indicates an alteration of the atrio-ventricular conduction. Krishnaswamy and al.³¹ showed a higher rate of PPI at 30 days in patients with a Wenckebach phenomenon after an incremental RAP from 70 to 120 bpm (13.1% vs. 1.3%, $p < 0.001$). The presence of a Wenckebach block was identified as an independent predictor of 30 days PPI (OR = 11.19, 95% CI: 2.34 –53.59; $p = 0.003$) while its absence was associated with a 98.7% negative predictive value.

Patients without a Wenckebach phenomenon during RAP following TAVI could thus be reasonably discharged after a short in-hospital follow-up. However, this practice cannot be applied in patients with atrial fibrillation or when a left ventricular rapid pacing via the stiff guidewire is performed, which is increasingly the case in current practice. In addition, the Wenckebach phenomenon is frequently the result of a lengthening of the AH interval, whereas HAVB is usually subsequent to an insult at the infra-hissian level, which increases the HV interval. Consequently, a thorough EPS may be necessary to define the exact nature of post-TAVI conduction disturbances.

f. Electrophysiology Study

According to the European society of cardiology guidelines on cardiac pacing¹³, persistent HAVB (Class I), new alternating Bundle Branch Block (Class I) and pre-existing RBBB associated with NOCD (Class IIa) require PPI before discharge. Regarding other situations, like persistent LBBB > 150 ms and/or PR-interval prolongation > 240 ms, and pre-existing conduction disturbances with prolongation of QRS (> 20 ms) and/or PR-interval (> 20 ms), the choice is left to the physician's discretion between ambulatory ECG monitoring and EPS¹³. The latter allows an invasive exploration of the AH and HV intervals, to determine the location of the block. It must be performed at least 72 hours after the procedure, when NOCD are stabilized. Yet, performing an EPS did not increase the length of hospital stay compared to patients who eventually underwent PPI in a single center report³². Overall, this is a safe procedure^{32,33}, although mechanical injuries to the right bundle branch, leading to PPI have been reported³⁴. Since 2015, some studies³²⁻³⁴ have demonstrated that a post-TAVI HV interval > 65 – 70 ms is a strong predictor of HAVB during follow-up. In contrast, a reassuring EPS in patients with new-onset LBBB even with PR-interval prolongation, may allow a safe hospital discharge with a very low risk of subsequent PPI for HAVB³⁴.

3. Management after discharge

a. New-Onset Left Bundle Branch Block

i. Incidence

Table 1 summarizes the incidences of new-onset LBBB and PPI after TAVI according to the type of valve. According to recent studies using new-generation devices, the incidence of new-onset LBBB can vary from 6% to 77%^{35,36}. This heterogeneity could be explained by different definitions and management strategies across centers, due to a lack of consensus.

In the PARTNER 3 study³, including 496 TAVR procedures using the SAPIEN 3 system, this complication occurred in 22% of patients at 30 days, which was 3-fold higher

compared to conventional SAVR³. Regarding self-expandable valves, the incidence ranges between 8% and 44.2% in recent studies with the EVOLUT R/PRO (Medtronic, Minneapolis, MN, USA)^{37,38,39}. In the SCOPE II trial, Tamburino and al.³⁹ found a lower rate with the ACURATE neo valve (Boston Scientific) than the EVOLUT platform (14 % vs. 19 %). For the PORTICO valve (Abbot Medical), rates were approximately 12%^{40,41}.

Although most studies used the ECG at discharge to report rates of new-onset persistent LBBB, it may be more clinically relevant to assess the persistence of a new-onset LBBB without PPI at 30 days to evaluate the long-term prognosis impact of this NOCD, as 25 to 40% of patients with new-onset LBBB may experience recovery during the first month post-TAVI . Indeed, approximately 40% of the patients with new-onset LBBB had a CD recovery at 1-year follow-up in the PARTNER II study⁶.

ii. Clinical Impact

The clinical impact of NOCD after TAVI is a major issue given the increasing procedural volume and the expansion of indications toward lower-risk patients with a longer life expectancy. Moreover, studying this impact requires a significant number of patients, as well as a prolonged follow-up. Stability or even an increase in the left ventricular ejection fraction (LVEF) has been reported early after the procedure^{5,37}. However, several studies reported a decrease in LVEF among TAVI recipients with new-onset LBBB during long-term follow-up^{5-7,37}, akin to what has been described in patients with idiopathic/degenerative LBBB⁴². This decrease could be significantly greater in patients with episodes of tachyarrhythmias during the follow-up³⁷ as well as in patients with baseline LVEF \leq 50%⁶.

Some studies have highlighted an increased 1-year risk of HHF^{5,43}, as in a large recent meta-analysis (risk ratio=1.35, 95% CI: 1.05-1.72)⁴³. During a 5-years follow-up, Jorgensen

and al.⁵ also highlighted a higher adjusted hazard ratio (HR) for the first HHF (HR=1.47 95% CI: 1.02 – 2.12) and a higher mean number of recurrent HHF (ratio=1.57 95% CI: 1.28–2.07).

Faroux and al.⁴³ also showed higher rates of cardiac deaths (RR = 1.46, 95% CI: 1.20-1.78) and all-cause mortality (RR = 1.32, 95% CI: 1.17-1.49). In another study with a follow-up of 22 ± 18 months, Urena & al.⁷ highlighted a higher risk of sudden cardiac death (SCD) among TAVI recipients with new-onset LBBB when QRS duration > 150 ms and/or with LVEF \leq 40%. Finally, three meta-analyses reported an approximately 2-fold higher rate of PPI associated with new-onset LBBB at mid-term (\approx 1 year) follow-up⁴³⁻⁴⁵. In analogy to the incidence of SCD, this risk seems especially significant in patients with QRS duration > 150 ms and/or a PR interval prolongation > 240 ms⁴. Therefore, this population should be closely monitored.

b. Permanent Pacemaker Implantation

i. Incidence

Regarding new-generation balloon-expandable devices, rates range from 4% to 24%. Importantly, in the PARTNER 3 randomized trial, PPI was performed in only 6.5% of TAVI patients at 30 days, without significant difference with the SAVR group (4.0%)³; while in the Evolut Low Risk study, the implantation of a self-expandable EVOLUT R/Pro was associated with a higher rate (17.4%) than in the surgical group (7.1%)⁴. Recent registries suggested rates ranging from 2.3% to 11.5% for the ACURATE neo prosthesis^{46,47}, and from 9.8% to 28.1% for the PORTICO valve^{40,48}. According to SCOPE I and SCOPE II, new PPI rates after procedures using the ACURATE Neo valve were similar to those using SAPIEN 3, but lower compared with the EVOLUT R/PRO^{38,47}.

ii. Clinical Impact

Data are equivocal regarding long-term outcomes in patients with PPI after TAVI, while the effect of prolonged pacing on LVEF and HHF has been well documented in other settings⁴⁹. In the PARTNER trial, LVEF and left ventricular dimensions were similar at 1-year between the PPI and no PPI group⁵⁰. In contrast, in a single-center Danish registry, with a median follow-up of 2.5 years, new PPI was strongly associated with a decrease of the LVEF⁵. These discrepancies could be explained by longer follow-up or different baseline clinical characteristics depending on the studies, but also by pacing indications and pacing dependency.

If a higher incidence of HHF has been reported by a large meta-analysis of unadjusted data (RR=1.18, 95% CI: 1.03-1.36)⁴³, adjusted results from recent individual studies have been controversial^{5,51}. One of these studies showed a higher cumulative incidence of HHF particularly in the case of ventricular pacing > 40%⁵. Therefore, it is conceivable that among TAVI recipients with a high pacing burden, PPI may exert a significant and independent role in this increased HHF risk

Except for meta-analyses⁴³, there was no consistent evidence of increased mortality by PPI after TAVI in adjusted individual studies^{5,51}. However, the magnitude of PPI effect upon TAVI results might be moderate, thus requiring a significantly greater number of patients, to be apparent. Moreover, the TAVI populations included in previous studies were likely susceptible to non-cardiovascular causes of death, which may act as competing events precluding the demonstration of deleterious consequences of long-term right ventricular pacing.

Data regarding single vs. dual chamber or cardiac resynchronization therapy (CRT) in the context of TAVI are lacking. Whether the systematic implantation of dual-chamber pacemaker offering the opportunity for a more physiologic pacing among patients presenting sinus rhythm is beneficial over the implantation of a simpler “back-up” single-chamber device remains elusive. Indeed, the potential recovery of conduction disturbances over time with an

exceedingly low pacing burden in a significant proportion of patients may favor the latter strategy. Moreover, the implantation of dual-chamber pacemakers may increase the risk of procedural and post-procedural complications (tamponade, pneumothorax, endocarditis...), jeopardizing patients safety and global cost-effectiveness. Algorithms promoting spontaneous atrio-ventricular conduction should be used¹³. CRT indications should follow usual guidelines¹³ although some data outside of the TAVI setting support its use when LVEF is $<50\%$ ⁵². However, considering the frequent improvement of LVEF after treatment of aortic stenosis, and the previously-discussed potential resolution of conduction disturbances leading to low pacing percentage, liberal indications of CRT in the TAVI periprocedural period cannot be advocated at present²¹.

In a recent study, TAVI recipients undergoing PPI during the follow-up were more likely to present new-onset LBBB at discharge (25% vs. 15%, $p=0.007$) and 16.9% of them received CRT while only 1.8% of patients implanted during the index hospitalization received CRT and upgrading was necessary in only 1.6% of patients with a previous pacemaker or implanted during the index hospitalization⁵¹. Overall, in this study, among patients without a permanent pacemaker at discharge, 2.5% of those with new-onset LBBB at discharge received CRT during follow-up compared with only 0.8% of those without ($p=0.08$). These data suggest that post-TAVI new-onset LBBB may convey a particularly deleterious effect, which may require close monitoring or even pre-emptive CRT implantation in some cases. Further studies are necessary to determine the predictors of LVEF deterioration among new-onset LBBB patients and delineate the optimal management of this complication. Furthermore, His/left bundle branch pacing are promising prospects and must be validated by clinical trials. Finally, leadless PPI, especially in patients with a low predicted ventricular pacing rate or with a high infectious risk, may be a viable option.

c. Ambulatory Monitoring

In patients with NOCD but for whom an indication for PPI has not been retained during the hospital phase, it is recommended to perform ambulatory ECG monitoring for 7-30 days (class IIaC and IIbC depending on the underlying NOCD)¹³. Indeed, several studies have looked at the interest of continuous monitoring by implantable loop recorders or wearable heart monitoring patches^{53,54}. In a study including 459 TAVI recipients without a permanent pacemaker who underwent ambulatory ECG monitoring for 14 days post-discharge, Muntane-Carol and al.⁵³ showed that HAVB occurred in 4.6% of the patients, especially among those with pre-existing RBBB (13.2%) or NOCD (8.5%), and within 5 days after discharge. With a longer follow-up of 12 months, using implantable loop recorders, Reiter and al.⁵⁴ found a rate of 11.9% of HAVB, including 8.5% in the first 30 days. The only electrocardiographic predictor of delayed HAVB was PR interval prolongation between the pre and post-procedural ECG (OR =1.04, 95%CI: 1.01-1.09). Ambulatory ECG monitoring was safe in published studies to date.

Overall, these findings suggest that bradyarrhythmia or HAVB mainly occur early after TAVI and could be safely detected by a short period, i.e. ≤ 30 days, of ambulatory ECG monitoring. Additional data are still needed to describe precisely subgroups of patients for whom continuous ambulatory monitoring would be beneficial. The respective role of these ambulatory ECG monitoring strategies and in-hospital EPS among patients without firm PPI indications should also be better defined, which is the subject of the Clinical Monitoring Strategy Versus Electrophysiology-guided Algorithmic Approach With a New LBBB After TAVI (COME-TAVI) study (NCT03303612) and the French Society of Cardiology-supported MONITOR-TAVI study.

Conclusion

Conduction disturbances remain one of the main issues of transcatheter aortic valve implantation with potential deleterious long-term clinical consequences. Preventing the occurrence of post-TAVI conductive disturbances, as well as predicting their evolution during follow-up, requires a holistic approach. During the pre-procedural planning, aside from a careful evaluation of the baseline ECG, MDCT should be exploited, especially by evaluating the degree and location of the device landing zone calcifications, and the membranous septum length. Further efforts are needed to define the exact role of pre-procedural ambulatory ECG monitoring, which appears as a promising tool to pre-emptively identify patients with severe bradyarrhythmia or HAVB. Several procedural aspects, from the valve type choice to the implantation projection, may have an impact on the risk of NOCD and should be taken into account in TAVI recipients. The main post-procedural issue is to identify the patients, who require close follow-up or even PPI while avoiding unnecessary implantations. EPS and ambulatory ECG monitoring have both shown promises in safely identifying patients who will and will not require PPI. However, delineating their respective role in post-TAVI management is still a matter of research.

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Figures legends

Figure 1 – Imaging predictors of post-TAVI conduction disturbances

Figure 1A. Calcifications located in the left ventricular outflow tract and the device landing zone, at the level of the membranous septum (yellow arrow). Figure 1B. Anatomical relationships between device landing zone, left ventricular outflow tract, membranous septum and the conduction pathways

AVN : atrioventricular node; DLZ: device landing zone, LBB : Left Bundle Branch, LVOT: left ventricular outflow tract, MS: membranous septum, RBB : Right Bundle Branch.

Central Illustration. Management of Conduction Disturbances in the setting of transcatheter aortic valve Implantation.

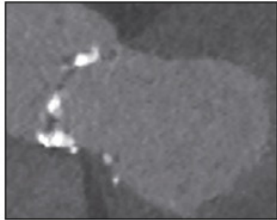
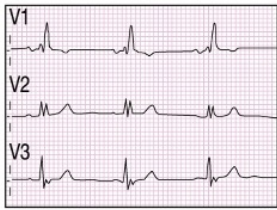
At the pre-procedural stage, RBBB remain the most consistent predictor of HAVB. Imaging data from the pre-procedural computed tomography, such as the length of the membranous septum and the degree of calcifications in the device landing zone may help refine the risk estimation. Moreover, ambulatory ECG monitoring may help identify patients with pre-existing episodes of HAVB, especially among patients with RBBB and/or PR interval prolongation. During the hospital phase, using the cusp-overlap projection is an emerging technique to reduce the prosthesis implantation depth, which is strongly related to the risk of conduction disturbances. Performing RA pacing immediately after valve deployment, from 70 to 120bpm without occurrence of a Wenckebach phenomenon, has also recently demonstrated an excellent negative predictive value for 30-days HAVB. Finally, in case of persistent LBBB > 150ms and/or PR interval prolongation > 240ms, or even in case of significant (>20ms) QRS and/or PR prolongation among patients with pre-existing conduction disturbances, the latest ESC guidelines recommend the use of an electrophysiological study to identify patients at low/high-

risk of HAVB. After hospital discharge, 14 to 30 days ambulatory ECG monitoring is a safe and effective option to identify patients with paroxysmal HAVB requiring PPI. *Data from Asmarats et al¹¹; ⁱConsidering any transcatheter heart valve models; [°]Data from Muntane-Carol et al⁵²; [‡]Data from Reiter et al⁵³.

HAVB: high-degree atrioventricular block, LBBB: left bundle branch block, PPI: permanent pacemaker implantation, RA: right atrial, RBBB: right bundle branch block.

% of Bradyarrhythmias during 7-days monitoring^a:

- 47% for RBBB
- 30% for PR-P



Imaging risk factors of conduction disturbances:

- Short MSL
- Calcifications on DLZ and LVOT

Preprocedural management

TAVI

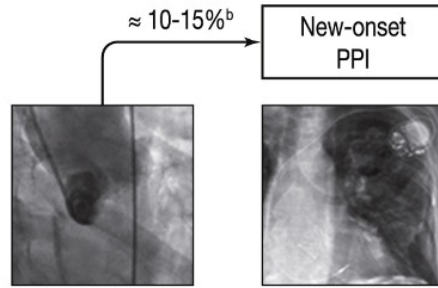
Cusp-overlap projection to optimize implantation height

≈ 20-25%^b

No Wenckebach during RA pacing and/or Negative EPS (HV < 70ms) → low risk of HAVB



Hospital phase



x2 risk (especially if QRS > 150 ms and/or PR > 240 ms)

Persistent LBBB (≈ 60 to 80%)

Recovery (≈ 20 to 40%)

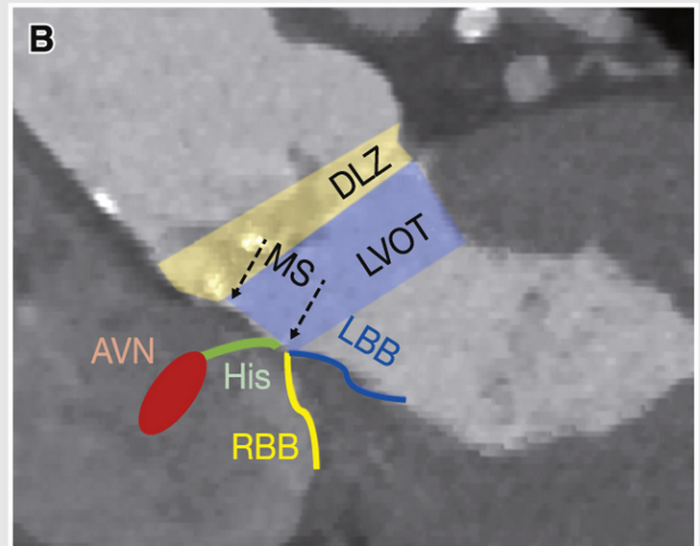
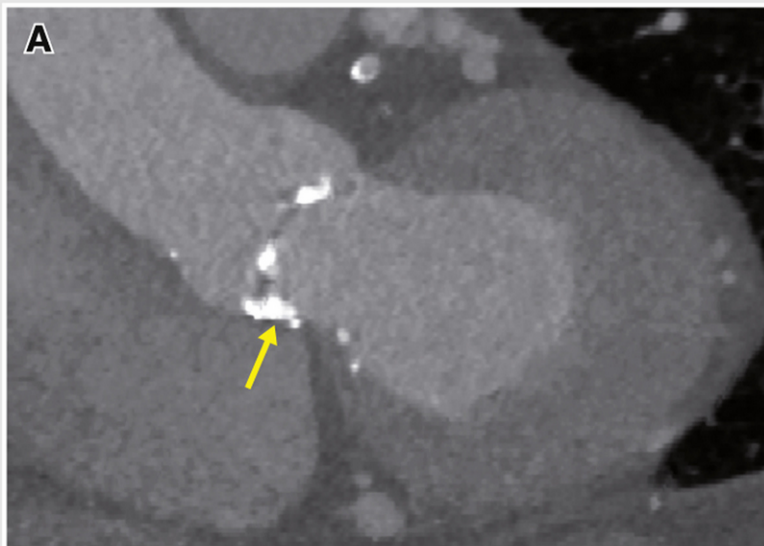
Postprocedural ambulatory monitoring (% of HAVB):

- 4.6% during 14-days follow-up^c
- 8.5% at 30-days and 11.9% at 12-months^d

Early follow-up (< 30-days)

Late follow-up (≥ 30-days)

LVEF	HHF	CV mortality	All-cause mortality
↘	↗	=	↗
↘	↗	↗	↗



TABLES

Table 1 – Incidences of new-onset left bundle branch block and permanent pacemaker implantation after transcatheter aortic valve implantation according to the type of prosthesis from ³⁶.

	Balloon-expandable valves	Self-expandable valves		
	Sapien 3 / Ultra	Evolut R/Pro/Pro+	Acurate Neo	Portico / Navitor
New-onset left bundle branch block	6-29%	8-44%	10-13%	12%
Permanent pacemaker implantation	4-24%	15-31%	2-12%	10-28%