Journal of the American Heart Association

ORIGINAL RESEARCH

# Value of Periprocedural Electrophysiology Testing During Transcatheter Aortic Valve Replacement for Risk Stratification of Patients With New-Onset Left Bundle-Branch Block

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**BACKGROUND:** Despite being the most frequent complication following transcatheter aortic valve replacement (TAVR), optimal management of left bundle-branch block (LBBB) remains unknown. Electrophysiology study has been proposed for risk stratification. However, the optimal timing of electrophysiology study remains unknown. We aimed to investigate the temporal dynamics of atrioventricular conduction in patients with new-onset LBBB after TAVR by performing serial electrophysiology study and to deduce a treatment strategy.

**METHODS AND RESULTS:** We assessed consecutive patients undergoing TAVR via His-ventricular interval measurement prevalve and postvalve deployment and the day after TAVR. Infranodal conduction delay was defined as a His-ventricular interval >55 milliseconds. Among 107 patients undergoing TAVR, 53 patients (50%) experienced new-onset LBBB postvalve deployment and infranodal conduction delay was noted in 24 of 53 patients intraprocedurally (45%). LBBB resolved the day after TAVR in 35 patients (66%). In patients with new-onset LBBB postvalve deployment and no infrahisian conduction delay intraprocedurally, the His-ventricular interval did not prolong in any patient to >55 milliseconds the following day. Overall, 4 patients (7.5%) with new-onset LBBB after TAVR were found to have persistent infrahisian conduction delay 24 hours after TAVR. During 30-day follow-up, 1 patient (1.1%) with new LBBB and a normal His-ventricular interval after TAVR developed new high-grade atrioventricular block.

**CONCLUSIONS:** Among patients with new-onset LBBB postvalve deployment, infrahisian conduction delay can safely be excluded intraprocedurally, suggesting that early intracardiac intraprocedural conduction studies may be of value in these patients.

**Key Words:** atrioventricular conduction disease ■ cardiac pacemaker ■ electrophysiological testing

Transcatheter aortic valve replacement (TAVR) has become a well-established treatment option for patients with symptomatic aortic stenosis with an intermediate to high surgical risk[1,2] and has been expanded to include strata with incrementally lower surgical risk.[3] The occurrence of left bundle-branch block (LBBB) post-TAVR remains the most frequent complication of the procedure and has been shown to be associated with

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Supplemental Material is available at https://www.ahajournals.org/doi/suppl/10.1161/JAHA.122.026239

For Sources of Funding and Disclosures, see page 10.



*JAHA* is available at: www.ahajournals.org/journal/jaha

## CLINICAL PERSPECTIVE

### What Is New?

- Early intracardiac conduction studies after transcatheter aortic valve replacement allow early risk stratification of patients with new-onset left bundle-branch block, thereby obviating the need for unnecessary prolonged temporary pacemaker placement and prolonged monitoring.

### What Are the Clinical Implications?

- Early intraprocedural His-ventricular measurements might have the potential to streamline the risk stratification process in this challenging subgroup with the urgent trend towards shorter length of hospital stay without compromising safety.
- Future prospective randomized studies are warranted to validate the proposed electrophysiology-tailored management strategy using early intracardiac conduction studies.

### Nonstandard Abbreviations and Acronyms

| | |
|---|---|
| **AVB** | atrioventricular block |
| **EPS** | electrophysiology study |
| **ESC** | European Society of Cardiology |
| **HV** | His-ventricular |
| **HAVB** | high-grade atrioventricular block |
| **PM** | pacemaker |
| **TAVR** | transcatheter aortic valve replacement |

a substantial rate of high-grade atrioventricular block (HAVB; 5%–34%)[4–6] and syncope (16%) during the first year after TAVR compared with <1% in patients without LBBB.[7,8] Despite being the most frequent complication after TAVR, optimal management of new LBBB remains unknown. Guidance was consolidated in an expert consensus algorithm in 2019[9] and 2020.[10] An algorithm strategy was proposed suggesting temporary cardiac pacemaker (PM) placement in all patients with LBBB for 24 to 48 hours and either using electrophysiology study (EPS) for risk stratification or prophylactic PM placement in patients with persisting dynamic PR or QRS changes 48 hours after TAVR.[9,10] Similarly, in the new European Society of Cardiology (ESC) guidelines for cardiac pacing, ambulatory monitoring or EPS is recommended in patients with new LBBB with QRS ≥150 milliseconds or PR ≥240 milliseconds after TAVR with a class IIa indication.[11]

Performing EPS, most approaches stratify patients with LBBB after TAVR regarding the risk of development of HAVB based on predefined His-ventricular (HV) interval cutoffs such as >55 milliseconds,[12] ≥65 milliseconds,[13] or ≥70 milliseconds.[11] Since periprocedural data are lacking, the optimal timing of the EPS, however, is not known. In most studies, EPS was performed 24 to 48 hours after TAVR.[12–17] The new ESC guidelines for cardiac pacing state that EPS should be performed ≥3 days after the procedure and after the conduction abnormalities have stabilized.[11] It is unclear whether EPS immediately after TAVR would yield similar results. To reduce the length of hospital stay after TAVR, there is a clinical need for strategies to timely assess injury to the cardiac conduction system for improved risk stratification.

Thus, our aim was to describe the temporal dynamics of infranodal conduction delay and investigate the value of periprocedural EPS during TAVR for risk stratification for the development of HAVB in patients with new-onset LBBB. We hypothesized that an early intraprocedural EPS may be useful for risk stratification of patients with new-onset LBBB after TAVR.

## METHODS

### Study Design and Patient Population

We analyzed data collected from consecutive patients in the prospective Swiss TAVR (SwissTAVI Registry: Prospective, National, Multi-Center Registry of Patients Undergoing Transcatheter Aortic Valve Implantation) registry (NCT01368250) for the period from June 2020 to June 2021 treated at our institution. Written informed consent was obtained from all patients and the study was approved by the local ethics committee. All patients included in the present analysis underwent TAVR with an intraprocedural limited EPS pre-TAVR and immediately post-TAVR (prevalve deployment and postvalve deployment) and, if LBBB persisted, an additional invasive EPS was performed the day following TAVR. Exclusion criteria included patients with previously implanted PM, periprocedural death, or when the TAVR procedure was aborted. Valve types included in our study were self-expandable Evolut R and Evolut R Pro (Medtronic), Acurate NEO (Boston Scientific), balloon-expandable Sapien 3 (Edwards Life Science), or mechanically expandable Lotus Edge (Boston Scientific Inc.).

### Transcatheter Aortic Valve Replacement

TAVR procedures were performed as previously described.[12] Briefly, transthoracic echocardiography, coronary angiography, and ECG-triggered multislice computed tomography scan of the aorta were performed for procedural planning. The implantation of the valve was performed according to the recommendations of the manufacturer. During the procedure, a temporary PM using a quadripolar catheter (CRD

5F catheter, St. Jude Medical) was positioned in the right ventricular apex. After implantation, patients were transferred to the intensive care unit overnight. In all patients with LBBB after TAVR, the temporary PM was left in place and programmed to ventricular-ventricular-inhibited pacing 30 beats per minute. Continuous rhythm monitoring by telemetry was performed in all patients for 72 hours after TAVR.

## ECG Assessment

The 12-lead ECGs obtained with a standard ECG recorder (Schiller) before and during hospital stay were analyzed. Each ECG recording was assessed for rhythm and conduction disturbance with a sweep speed of 25 mm/s and standard augmentation of 10 mm/mV. First-degree atrioventricular block (AVB) was defined as a PR interval ≥200 milliseconds. LBBB was defined using conventional criteria with a QRS duration ≥120 milliseconds, an R wave peak delay in lead V5/V6 of >60 milliseconds, and an rS or QS in lead V1 and V2.[14] The automatically calculated PR interval and QRS duration by the ECG recorder were included in the analysis. To improve the accuracy of the measurements, each ECG was manually reviewed, and corrected if necessary.

## Electrophysiology Study

In all patients, a limited EPS was performed intraprocedurally prevalve deployment and postvalve deployment and in case of persistent LBBB for 24 hours additionally the following day after TAVR. In brief, intracardiac measurements were obtained using a portable electrophysiological system (Cardiotek EP Tracer 70, Medtronic) in combination with the quadripolar diagnostic catheter (CRD 5F catheter, St. Jude Medical) used as a temporary PM wire during TAVR. After withdrawal of the catheter from the ventricle to the His position, HV interval was measured over 3 consecutive beats using the electronic calipers with a sweep speed of 100 mm/s. This was performed immediately before implantation (prevalve deployment) as well as after verification of the proper placement of the valve based on the invasive hemodynamic measurements (postvalve deployment). All measurements were performed by the interventional cardiologist (R.J., G.F., and C.K.) implanting the TAVR. All HV measurements were additionally ready by an electrophysiologic physician (P.B., M.K.). Patients with and without LBBB pattern postvalve deployment were stratified into the LBBB and non-LBBB group, respectively. In patients with persistent LBBB the day after TAVR, an EPS was performed in the electrophysiology laboratory (Axiom Sensis EP System, Siemens). For both acquisitions, PR and QRS duration were obtained in patients in sinus rhythm simultaneously. Differences in atrioventricular nodal conduction were calculated for AH, HV, and PR interval and QRS duration between the measurements prevalve and postvalve deployment as well as the day after TAVR. Pacemaker implantation was performed in patients with persistent LBBB and prolonged HV interval >55 milliseconds the day after TAVR. In patients with right bundle-branch block (RBBB) and prolonged HV interval >55 milliseconds, decision to implant a pacemaker was left at the discretion of the treating physician.

## Follow-Up

Follow-up was scheduled 1 month after TAVR and included physical examination, 12-lead ECG, transthoracic echocardiography, and PM interrogation. No need for pacing was defined as <1% ventricular pacing and intrinsic 1:1 atrioventricular conduction with the device programmed to ventricular-ventricular-inhibited pacing 30 beats per minute.[12]

## Statistical Analysis

Continuous variables are presented as mean and SD or median (interquartile range) and categorical variables as numbers and percentages. *t* Test was used for continuous, normally distributed variables and the Wilcoxon test for skewed variables. Categorical variables were compared using chi-square or Fisher exact test as appropriate. All statistical analyses were performed using R version 4.0.2 (R Foundation for Statistical Computing) and SPSS Statistics for Windows version 25.0 (IBM).

## Data Availability Statement

The data underlying this article will be shared on reasonable request by the corresponding author.

# RESULTS

## Baseline Data

Among 138 patients undergoing TAVR, 12 patients were excluded according to predefined criteria (previously implanted PM [n=7], periprocedural death [n=3], or aborted TAVR procedure [n=2]). Among 126 patients undergoing EPS before TAVR, HV measurements were not possible in 19 patients after TAVR (10 patients with periprocedural HAVB requiring immediate PM implantation and 9 patients with unsuccessful measurements), leaving 107 patients in the final cohort for analysis as depicted in Figure 1. Further details regarding excluded patients are provided in Tables S1 and S2. Reasons for unsuccessful measurements were the presence of accelerated junctional rhythm in 2 patients, atrial fibrillation (AF) in 1 patient, transient third-degree AVB in 3 patients, and “other” in 3 patients (logistical reasons

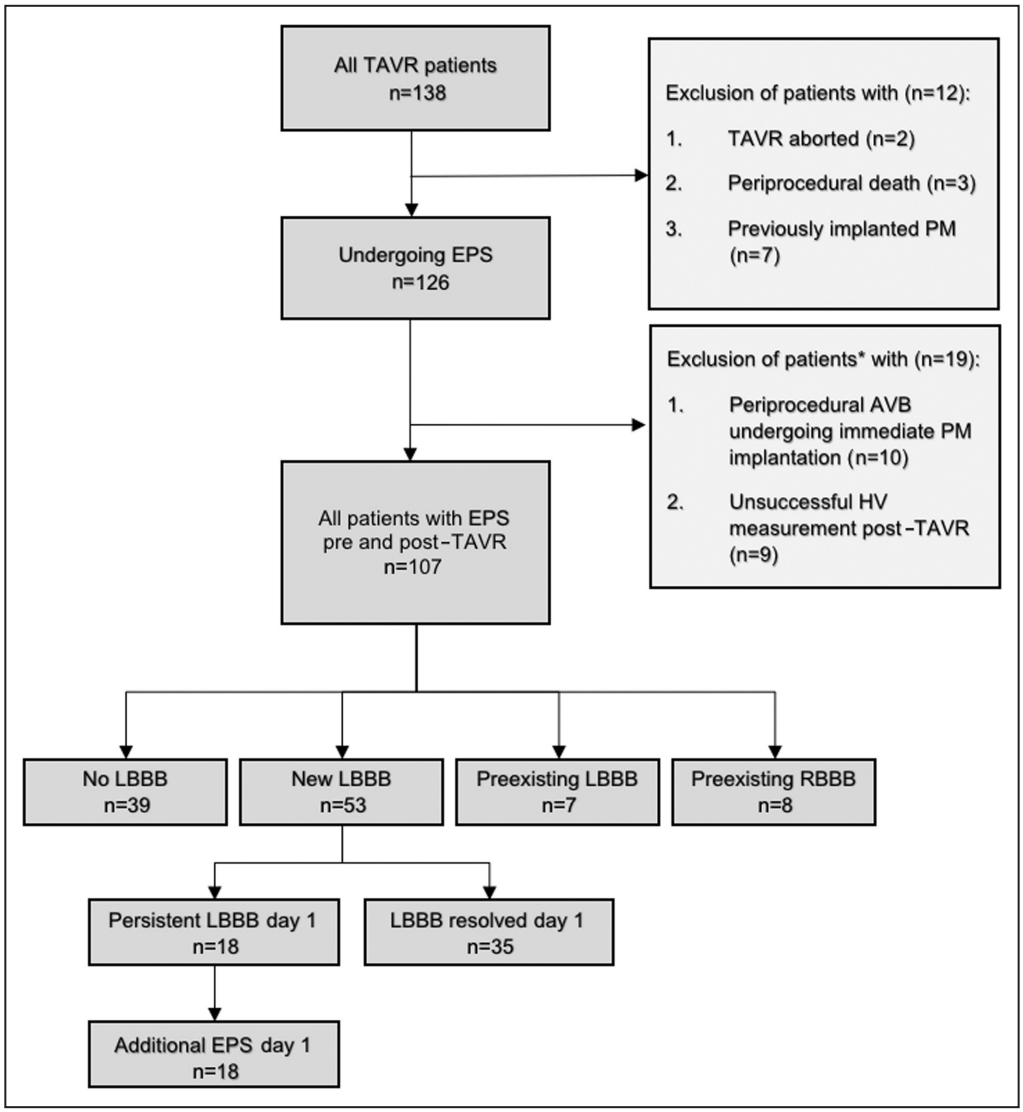


**Figure 1. Flowchart of the total cohort.**
*Further details regarding excluded patients are provided in Tables S1 and S2. AVB indicates atrioventricular block; EPS, electrophysiology study; HV, His-ventricular; LBBB, left bundle-branch block; PM, cardiac pacemaker; RBBB, right bundle-branch block; SR, sinus rhythm; and TAVR, transcatheter aortic valve replacement.

with the portable electrophysiological system). To assess the temporal dynamics of infranodal conduction delay after TAVR in patients with new-onset LBBB, we analyzed patients with preexisting LBBB (n=7 [6.5%]) and RBBB (n=8 [7.5%]) separately. Results of the EPS prevalve deployment and postvalve deployment and the day after TAVR for patients with preexisting LBBB and RBBB are shown in Table S3 and S4.

## Patients With New-Onset LBBB

Among the remaining 92 patients undergoing EPS prevalve and postvalve deployment, 53 (58%) developed new-onset LBBB directly after TAVR. The median age was 80 years (interquartile range, 77–85 years) and 47% of patients were women (Table 1). Sinus rhythm was present in 70 patients (76%) and first-degree atrioventricular delay was observed in 24 patients (26%). The demographic and preprocedural echocardiographic parameters were comparable between patients with LBBB and non-LBBB after TAVR. The valve types used are listed in Table 1.

## Atrioventricular Conduction Dynamics Using Surface ECG

The PR interval and the QRS duration were calculated from the surface ECG prevalve deployment and postvalve deployment as well as 24 hours after TAVR (Table 2).

**Table 1. Clinical and Procedural Characteristics**

| Parameter | Overall (N=92) | Non-LBBB (n=39) | LBBB (n=53) | *P* value |
|---|---|---|---|---|
| Women | 43 (47) | 16 (41) | 27 (51) | 0.465 |
| Age, y | 80 (77–85) | 81 (77–85) | 80 (77–85) | 0.608 |
| Body surface area, $m^2$ | 2 (2–2) | 2 (2–2) | 2 (2–2) | 0.275 |
| BMI | 29 (24–35) | 29 (24–35) | 28 (25–35) | 0.915 |
| Hypertension | 74 (84) | 29 (83) | 45 (85) | 1 |
| CAD | 44 (51) | 22 (63) | 22 (42) | 0.097 |
| Diabetes | 22 (25) | 8 (23) | 14 (26) | 0.9 |
| Dyslipidemia | 45 (52) | 18 (51) | 27 (52) | 1 |
| Prior myocardial infarction | 14 (16) | 7 (20) | 7 (13) | 0.579 |
| Prior stroke | 6 (7) | 3 (9) | 3 (6) | 0.922 |
| NYHA class | | | | 0.468 |
| I | 5 (6) | 2 (6) | 3 (7) | |
| II | 41 (53) | 17 (55) | 24 (52) | |
| III | 25 (32) | 9 (29) | 16 (35) | |
| IV | 4 (5) | 3 (10) | 1 (2) | |
| Preprocedural echocardiography | | | | |
| Aortic valve area, $cm^2$ | 1 (1–1) | 1 (1–1) | 1 (1–1) | 0.589 |
| DP max, mm Hg | 72 (69–88) | 74 (70–86) | 72 (68–90) | 0.899 |
| DP mean, mm Hg | 43 (37–52) | 42 (37–50) | 44 (39–52) | 0.264 |
| LVEF, % | 60 (55–63) | 59 (45–62) | 60 (56–64) | 0.108 |
| Valve type | | | | |
| Balloon-expandable | | | | |
| Sapien 3 | 14 (15) | 6 (15) | 8 (15) | 1 |
| Self-expandable | | | | |
| Evolut R/Pro | 36 (39) | 14 (36) | 22 (42) | 0.742 |
| Acurate Neo | 40 (43) | 19 (49) | 21 (40) | 0.511 |
| Mechanical-expandable | | | | |
| Lotus | 2 (2) | 0 (0) | 2 (3) | 0.604 |

Data are presented as median (interquartile range) for continuous variables and number (percentage) for categorical variables. BMI indicates body mass index; CAD, coronary artery disease; DP max, maximum transvalvular pressure gradient; DP mean, mean transvalvular pressure gradient; LBBB, left bundle-branch block; LVEF, left ventricular ejection fraction; and NYHA, New York Heart Association.

## Atrioventricular Conduction Dynamics

Temporal dynamics of atrioventricular conduction of the 92 patients studied using EPS prevalve and postvalve deployment intraprocedurally are summarized in Table 3. The 18 patients in whom new-onset LBBB persisted the day after TAVR (20%) were studied for a third time 24 hours after TAVR. The temporal dynamics of atrioventricular conduction are presented for all 3 HV measurements in Figure 2. Temporal dynamics of atrioventricular conduction for these patients with persistent new-onset LBBB the following day are presented in Table S5.

## Prolonged HV Interval

Among 92 patients undergoing TAVR and prevalve and postvalve deployment EPS, 53 patients (58%) had LBBB (Figure 3) Among these, the HV interval was prolonged (>55 milliseconds) postvalve deployment in 24 patients (45%). None of the 8 patients with persistent LBBB (28%) and normal HV postvalve deployment showed an abnormal HV interval the day after TAVR. In the 10 patients with persistent LBBB (42%) and abnormal HV interval postvalve deployment, the HV interval normalized in 6 patients (60%) and remained abnormal the day after TAVR in 4 patients (40%). In these 4 patients with persisting LBBB and prolonged HV interval, a dual-chamber PM was implanted (Table S6). There were no complications related to placement of the His catheter in our patient collective.

## Follow-Up

Thirty-day follow-up was complete in 97% of patients. New-onset complete AVB occurred in 1 patient (1.1%). In this case, a PM was implanted 8 days after TAVR for HAVB. The patient was a 67-year-old woman with permanent AF and a mechanically expandable Lotus

**Table 2. ECG Findings Before and After TAVR**

| | Overall (N=92) | Non-LBBB (n=39) | LBBB (n=53) | *P* value |
|---|---|---|---|---|
| Prevalve deployment EPS | | | | |
| PR interval, ms | 193 (175–210) | 192 (180–212) | 196 (170–209) | 0.949 |
| QRS duration, ms | 103 (94–112) | 96 (90–112) | 104 (99–113) | 0.037 |
| QT duration, ms | 430 (411–460) | 434 (410–455) | 429 (412–460) | 0.962 |
| RR interval, ms | 1027 (892–1143) | 1044 (889–1147) | 1023 (906–1095) | 0.816 |
| AH interval, ms | 110 (93–126) | 116 (92–125) | 108 (94–126) | 0.525 |
| HV interval, ms | 43 (38–50) | 42 (38–52) | 44 (38–48) | 0.852 |
| Postvalve deployment EPS | | | | |
| PR interval, ms | 204 (186–229) | 194 (186–229) | 208 (190–229) | 0.39 |
| QRS duration, ms | 136 (112–160) | 107 (98–116) | 154 (140–168) | <0.001 |
| QT duration, ms | 459 (418–486) | 429 (404–458) | 473 (442–494) | <0.001 |
| RR interval, ms | 936 (835–1066) | 940 (827–1077) | 923 (863–1048) | 0.837 |
| AH inverval, ms | 117 (94–134) | 118 (104–135) | 114 (88–130) | 0.164 |
| HV interval, ms | 50 (43–57) | 48 (42–53) | 54 (47–59) | 0.009 |
| Day 1 post-TAVR EPS | | | | |
| PR interval, ms | 183 (164–198) | 186 (170–200) | 177 (161–197) | 0.256 |
| QRS duration, ms | 101 (92–122) | 98 (92–111) | 106 (92–140) | 0.077 |
| QT duration, ms | 415 (391–446) | 402 (389–434) | 422 (394–447) | 0.2 |
| RR interval, ms | 832 (758–908) | 820 (740–896) | 844 (770–908) | 0.65 |
| AH interval, ms | 88 (79–127) | NA | 88 (79–127) | NA |
| HV interval, ms | 49 (42–54) | NA | 49 (42–54) | NA |

Data are presented as median (interquartile range) for continuous variables. ΔPR could not be measured in 20 patients because of atrial fibrillation in either ECG. EPS indicates electrophysiology study; HV, His-ventricular; LBBB, left bundle-branch block; NA, not available; and TAVR, transcatheter aortic valve replacement.

valve was implanted. There was new-onset LBBB with a QRS duration of 152 milliseconds (Δ 52 milliseconds) and an HV interval after TAVR of 36 milliseconds and the day following TAVR of 42 milliseconds (both measurements in AF). Among the other 18 patients with persistent LBBB the day after TAVR, 16 patients (89%) showed persistent LBBB at discharge. A 12-lead ECG was available at 30-day follow-up in 15 patients (83%). LBBB persisted in 9 patients (60%) and resolved in 6 patients (40%) at 30-day follow-up visit. Patients with PM implanted because of LBBB and prolonged HV interval the day after TAVR showed a need for pacing of >1% in 2 of 4 patients (50%, Table S7). All-cause mortality was 1.9% during 30-day follow-up, with 2 patients dying (1 with aortic dissection after 7 days and 1 with heart failure 4 days after TAVR).

**Table 3. ECG Changes Before and After TAVR**

| | Overall (N=92) | Non-LBBB (n=39) | LBBB (n=53) | *P* value |
|---|---|---|---|---|
| Prevalve and postvalve deployment EPS | | | | |
| PR Δ interval, ms | 10 (3–25) | 8 (1–18) | 15 (4–26) | 0.125 |
| QRS Δ duration, ms | 24 (5–55) | 3 (1–10) | 50 (34–65) | <0.001 |
| AH interval Δ, ms | 72 (46–92) | 75 (60–92) | 68 (40–88) | 0.229 |
| HV interval Δ, ms | 4 (0–11) | 0 (–2 to 4) | 7 (3–14) | <0.001 |
| Postvalve deployment EPS and day 1 post-TAVR EPS | | | | |
| PR Δ interval, ms | –22 (–34 to –11) | –16 (–34 to 2) | –25 (–38 to –16) | 0.027 |
| QRS Δ duration, ms | –18 (–47 to –5) | –5 (–14 to 0) | –30 (–54 to –16) | <0.001 |
| AH interval Δ, ms | –18 (–29 to –7) | NA | –18 (–29 to –7) | NA |
| HV interval Δ, ms | –4 (–9 to 2) | NA | –4 (–9 to 2) | NA |

Data are presented as median (interquartile range) for continuous variables and number (percentage) for categorical variables. ΔPR could not be measured in 20 patients because of atrial fibrillation in either ECG. EPS indicates electrophysiology study; HV, His-ventricular; LBBB, left bundle-branch block; NA, not available; and TAVR, transcatheter aortic valve replacement.

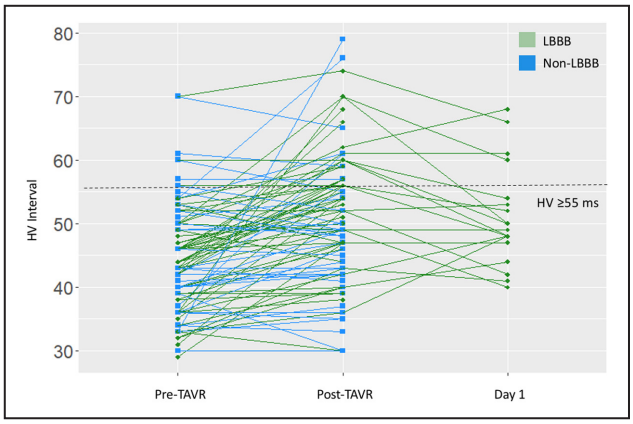


**Figure 2. Temporal dynamics of atrioventricular conduction for all three His-ventricular (HV) measurements.**
LBBB indicates left bundle-branch block; and TAVR, transcatheter aortic valve replacement.

## HV Interval ≥70 milliseconds According to 2021 ESC Guidelines

Among 53 patients with new-onset LBBB postvalve deployment, 5 patients (9.4%) were found to have an HV interval ≥70 milliseconds. Among 18 patients with persistent, new-onset LBBB the following day, no patients were found to have an HV interval ≥70 milliseconds.

## Validation of an Early Electrophysiology-Tailored Strategy

The patient flowchart using the current clinical strategy with and without an early electrophysiology-tailored strategy including the measurements of the EPS are shown in Figure 3 (gray flowchart and red flowchart, respectively). In brief, by using early EPS in patients with LBBB after TAVR, development of HAVB during 30-day follow-up can be ruled out, with a negative predictive value of 97% (95% CI, 84%–99%). By applying an early electrophysiology-tailored strategy overnight, temporary pacemaker placement could be omitted in 55% of patients with new-onset LBBB after TAVR.

# DISCUSSION

Electrophysiology testing for risk stratification of patients with new-onset LBBB after TAVR for HAVB has recently been proposed as a valuable strategy. However, the optimal timing of the measurement is unclear. The main findings of our study are as follows: first, intraprocedural EPS during TAVR is feasible in 92% of patients via a quadripolar catheter used as a temporary PM wire during TAVR and a mobile/portable electrophysiology recording system. Second, EPS prevalve deployment does not add diagnostic value and is not necessary. Third, while new-onset LBBB immediately after TAVR is common and occurred in 58% of patients, it included a significant number of patients with transient LBBB. New-onset LBBB was associated with infrahisian conduction delay (as defined as an HV interval >55 milliseconds) in 45% of patients, but LBBB resolved the following day in 59% of patients. The rate of persistent new-onset LBBB the following day was 18%, which is in the range of previous other studies. Fourth, in patients with persistent new-onset LBBB the day after TAVR, infrahisian conduction delay was rare and was noted in 4 patients 24 hours after TAVR (22% of patients with LBBB, 4.3% overall). Fifth, in patients with new-onset LBBB after TAVR and no infrahisian conduction delay postvalve deployment, the HV interval did not prolong in any case to >55 milliseconds the following day. Sixth, patients with new-onset LBBB after TAVR and normal HV interval postvalve deployment have a low rate of HAVB during 30 days of follow-up (0.9%). In fact, only 1 patient with new-onset LBBB and normal HV interval after TAVR (36 milliseconds) and the following day (40 milliseconds) experienced a higher degree of AVB requiring PM implantation. Of note, these measurements were taken during AF. Finally, and probably most importantly for clinical practice, postvalve deployment HV measurement allows early risk stratification of patients with new-onset LBBB. Depending on the institutional protocol, it allows for reducing the need for temporary PM wires in 55% of patients and narrows the number of patients at risk considered for prolonged monitoring or additional EPS to 11% (10 of 92 patients).

Several studies have assessed EPS results before and after TAVR.[12–17] However, the available studies are small, with differences in valve types and EPS timing. In addition, compared with most prior studies, the implanting techniques and valve types used evolved over the past couple of years towards higher implantation depth with potentially less impact on the conduction system. Rivard et al[13] showed a strong association of the postprocedural HV interval with HAVB. In their study, an HV interval ≥65 milliseconds predicted HAVB with 83.3% sensitivity and 81.6% specificity and 82% negative predictive value and 62% positive predictive value. In addition, they proposed that a ≥13-ms increase in HV interval may assist in decision-making regarding the need for a PM. The need for an EPS before and after TAVR may reduce the feasibility of this approach. The use of the absolute HV interval value as a single measure after the procedure allows simplification of risk stratification. Similarly, we recently showed, with an HV interval cutoff >55 milliseconds measured the day after TAVR in patients with LBBB, a 67% sensitivity and 84% specificity and 90% negative predictive value and 53% positive predictive value.[12] Tovia-Brodie et al[16] implanted PMs in post-TAVR patients with LBBB and an HV interval ≥75 milliseconds. EPS was performed after a median of 6 days (range, 2–210 days). Rogers et

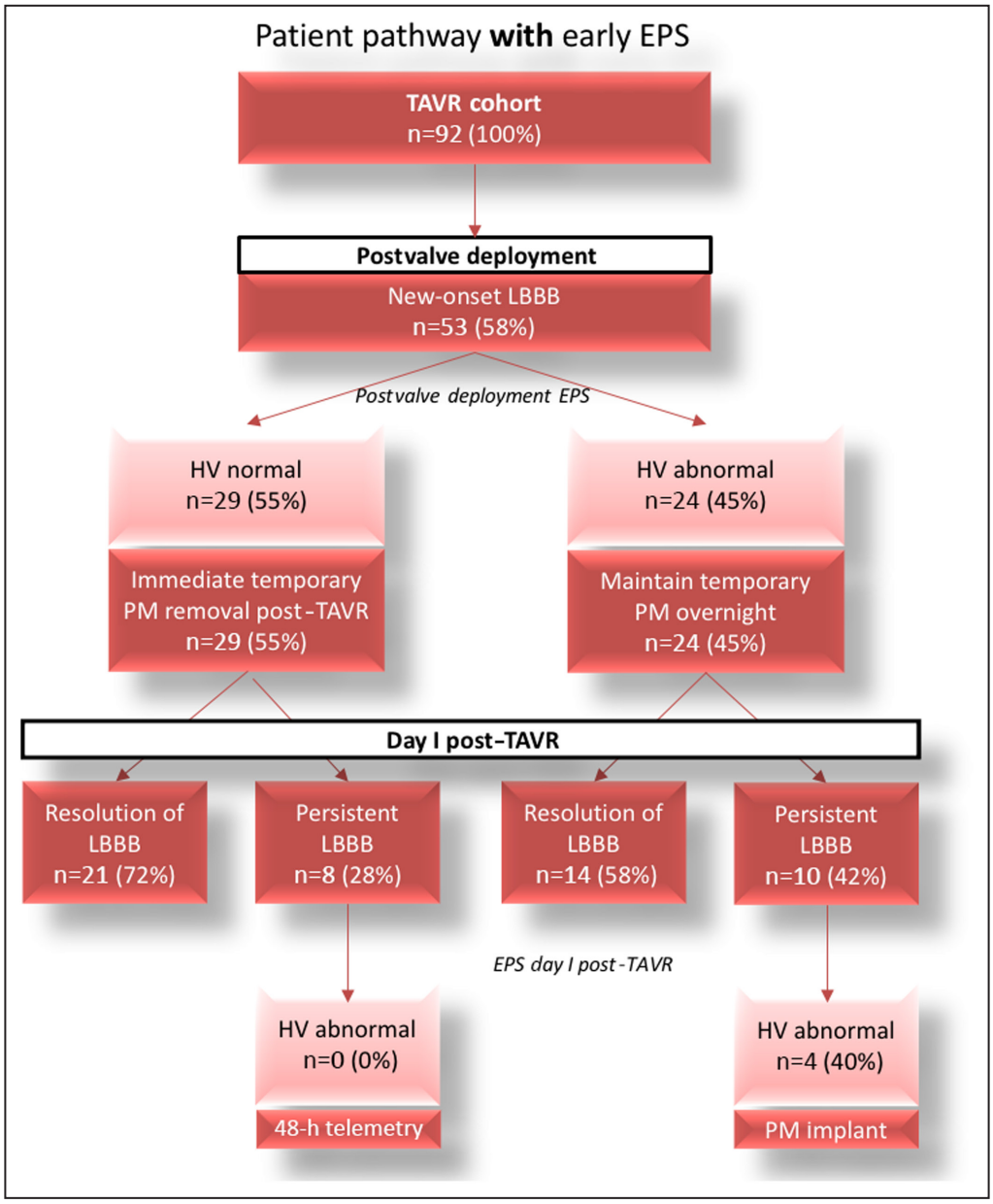


**Figure 3. Electrophysiology study (EPS)–guided strategy.**
HV indicates His ventricular; LBBB, left bundle-branch block; PM, cardiac pacemaker; and TAVR, transcatheter aortic valve replacement.

al[17] used a cutoff for PM implantation of ≥100 milliseconds based on older data outside of the TAVR population. While the study by Tovia-Brodie et al[16] assessed mortality and pacemaker need in a control population of 55 patients, the study by Rogers et al[17] provided no control group for comparison, meaning that outcomes without pacing are unknown.

Using early HV measurements postvalve deployment for risk stratification of patients with new-onset LBBB after TAVR differs in 3 ways from the proposed risk stratification algorithm by the new ESC guidelines[11]: first, according to the ESC guidelines, EPS is recommended in patients with new-onset LBBB with QRS ≥150 milliseconds or PR ≥240 milliseconds. When applying these criteria in our cohort, EPS would have been indicated in 9 of 92 patients (9.8%), thereby identifying all 4 patients with infranodal conduction delay (>55 milliseconds). While in the ESC guidelines no specific recommendations for the need for temporary PM wires based on the surface ECG are provided, the 2020 expert consensus[10] recommends placement of temporary PM wires in patients with new-onset LBBB with an increase in PR or QRS ≥20 milliseconds. When applying these criteria in our cohort, a temporary PM would

have been indicated in 47 of 92 patients (51%) Second, the ESC guidelines recommend using a cutoff for the HV interval ≥70 milliseconds to consider PM implantation. While our decision to proceed to PM implantation with a cutoff for the HV interval of 55 milliseconds seems to be prophylactic, the PM implantation rate overall was only 4.7% in this study and dependency at 30-day follow-up in these patients was 40%. When using a cutoff of 70 milliseconds, no patient would have received a PM in this cohort. Prospective studies using a cutoff for the HV interval of 70 milliseconds are warranted. Third, the ESC guidelines recommend assessing patients ≥3 days postprocedurally after conduction abnormalities have stabilized. In this study, in patients with new-onset LBBB and no infrahisian conduction delay postvalve deployment, the HV interval did not prolong in any case to >55 milliseconds the following day. In addition, the occurrence of late conduction disturbances within 30 days in patients with LBBB after TAVR was rare, with only 1 patient requiring PM implantation during follow-up. Similarly, others have observed a low rate of delayed AVB (≥48 hours after TAVR) in patients with LBBB.[18,19] Ream et al[20] reported that although AVB developed ≥48 hours post-TAVR in 18 (12%) of 150 consecutive patients, it occurred in only 1 patient between days 14 and 30. Interestingly, of those with delayed heart block, only 5 had symptoms, and there were no deaths. In addition, the greatest risk factor for developing delayed HAVB was baseline RBBB (26-fold risk), and new-onset LBBB was not predictive of delayed HAVB. Thus, most conduction disturbances occur during the TAVR procedure or within hours after the procedure. Further research is needed regarding the role of continuation of radial force caused by the prosthesis over a time period exceeding the TAVR procedure, thereby possibly causing delayed AVB, and whether this potential mechanism might be more relevant in patients with (preexisting) RBBB than LBBB.[14,21] Thus, in the setting of new-onset LBBB, it might not be necessary to wait ≥3 days for risk stratification.

Regarding the risk stratification algorithm proposed by the 2020 expert consensus,[10] EPS or PM placement is recommended in patients with new, progressive, or preexisting conduction disturbances that change postprocedure with suggested cutoffs. In addition, ambulatory event monitoring for at least 14 days is suggested for any patient with a PR or QRS interval that is new or extended by ≥10%.

The aforementioned differential features may help physicians and institutions in the selection of their preferred triage algorithm. Early intraprocedural HV measurements might have the potential to streamline the risk stratification process in this challenging subgroup with the urgent trend towards shorter length of hospital stay without compromising safety. The safety of our approach might be increased by only performing HV measurements for risk stratification taken during sinus rhythm. These results, however, should be considered hypotheses generating to guide future studies potentially evaluating such a streamlined workflow prospectively in a randomized fashion.

## Limitations

Several limitations of the present study merit consideration. First, only patients with LBBB the following day received a third EPS. Therefore, it is unknown whether our findings can be extrapolated to patients with other conduction disturbances such as patients with RBBB. Second, we neither assessed the value of a drug challenge, eg using procainamide, flecainide, or ajmaline during EPS after TAVR, nor the value of a functional assessment of the conduction system by means of dynamic atrial pacing, a marker previously described to predict delayed AVB.[22] While this approach might as well be used for risk stratification immediately at the end of TAVR, compared with measurement of the HV interval, it has several disadvantages. While atrioventricular Wenkebach cannot be assessed in patients in AF, HV measurements are feasible although prone to be inaccurate. Atrioventricular Wenkebach is affected by variations in autonomic tone and thus by the type of anesthesia used. In addition, atrioventricular Wenkebach should not be mistaken as an indicator of infranodal disease since it occurs as a result of slowing at the AH level. Third, we did not assess the impact of procedural characteristics such as the implantation depth or oversizing of the prosthetic valves on conduction intervals. Fourth, TAVR has become a minimalist procedure over time, and a significant proportion of centers do not implant a temporary pacing wire during the procedure. Instead, the left ventricular guidewire is used for rapid pacing if needed and, thus, despite the 2019 expert consensus, some centers do not leave the temporary pacemaker wire in place overnight for patients with an isolated new-onset LBBB, which may limit the impact of the proposed strategy. Fifth, temporary pacemaker placement via a jugular venous approach is recommend by the 2020 expert consensus, since it allows early mobilization and lower risk of complications. While our proposed workflow requires an additional femoral access for measurement of HV interval, potentially slightly prolonging the procedure time, temporary pacemaker placement, if needed, might still be placed via the jugular venous approach.

# CONCLUSIONS

Among patients with new-onset LBBB post-TAVR, infrahisian conduction delay can safely be excluded intraprocedurally immediately after the implantation of the valve using limited EPS. This suggests that early

intracardiac conduction studies may be of value in patients with new-onset LBBB after TAVR. However, further studies are needed to confirm these findings.

## ARTICLE INFORMATION

Received March 24, 2022; accepted June 23, 2022.

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### Sources of Funding

None.

### Disclosures

Patrick Badertscher has received research funding from the "University of Basel," the "Stiftung für Herzschrittmacher und Elektrophysiologie," the "Freiwillige Akademische Gesellschaft Basel," and Johnson&Johnson, all outside the submitted work. Sven Knecht has received funding from the "Stiftung für Herzschrittmacher und Elektrophysiologie." Christian Sticherling is a member of the Medtronic Advisory Board Europe and Boston Scientific Advisory Board Europe and received educational grants from Biosense Webster and Biotronik, a research grant from the European Union's FP7 program and Biosense Webster, and lecture and consulting fees from Abbott, Medtronic, Biosense-Webster, Boston Scientific, Microport, and Biotronik, all outside the submitted work. Michael Kühne reports personal fees from Bayer, Böhringer Ingelheim, Pfizer BMS, Daiichi Sankyo, Medtronic, Biotronik, Boston Scientific, Johnson&Johnson, and Roche; and grants from Bayer, Pfizer, Boston Scientific, BMS, Biotronik, and Daiichi Sankyo, all outside the submitted work. Beat Schaer is on the speakers' bureau for Medtronic. The remaining authors have no disclosures to report.

### Supplemental Material

Tables S1–S7

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# Supplemental Material

**Table S1. Patients undergoing directly PM implantation after TAVI for complete AV block.**

| | | | | Pre-TAVI measurements | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Age** | **Sex** | **Valve type** | **Rhythm** | **PR** | **QRS** | **Morphology** | **AH** | **HV** |
| 1 | 74 | M | Evolut R/Pro | SR | 230 | 107 | IVCD | | |
| 2 | 85 | M | Evolut R/Pro | SR | 231 | 135 | RBBB | | |
| 3 | 81 | M | Acurate Neo | SR | 190 | 134 | RBBB | | |
| 4 | 74 | F | Sapien S3 | SR | 200 | 112 | normal | 99 | 47 |
| 5 | 89 | M | Acurate Neo | AF | | 142 | RBBB | | 49 |
| 6 | 85 | M | Evolut R/Pro | SR | 265 | 134 | RBBB | 177 | 49 |
| 7 | 75 | F | Evolut R/Pro | SR | 216 | 90 | normal | 130 | 50 |
| 8 | 78 | M | Acurate Neo | SR | 245 | 171 | RBBB | 119 | 53 |
| 9 | 85 | M | Acurate Neo | SR | 247 | 236 | LBBB | 129 | 56 |
| 10 | 80 | M | Evolut R/Pro | SR | 149 | 82 | normal | 76 | 47 |

M = male, F = femal, SR = sinus rhythm, AF = atrial fibrillation, IVCD = intraventricular conduction delay, RBBB = right bundle branch block, LBBB = left bundle branch block, PR, QRS, AH and HV measurements in ms.

**Table S2. Patients excluded from analysis with missing HV measurements post valve deployment.**

| | | | | Pre-TAVI measurements | | | | | | Post TAVI | EP Study Day 1 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Age | Sex | Valve | R* | PR | QRS | Morphology | AH | HV | Reason not possibe | Morphology | R* | PR | QRS | HV | FU 30d |
| 1 | 83 | F | Acurate Neo | SR | 176 | 84 | 0 | 120 | 27 | JR | Normal | SR | 137 | 86 | | No events |
| 2 | 91 | M | Evolut R/Pro | AF | | 100 | 0 | | 35 | AF | LBBB | AF | | 157 | 68 | PM after TAVI |
| 3 | 55 | F | Lotus | SR | 148 | 102 | 0 | 70 | 43 | Transient CHB | LBBB | SR | 146 | 150 | 40 | Persisting LBBB, No events |
| 4 | 83 | M | Evolut R/Pro | SR | 143 | 90 | 0 | 73 | 44 | Transient CHB | RBBB | SR | 122 | 161 | | No events |
| 5 | 72 | F | Evolut R/Pro | SR | 192 | 62 | 0 | 123 | 44 | n/a | LBBB | SR | 215 | 138 | 41 | LBBB resolved, no Events |
| 6 | 90 | M | Evolut R/Pro | SR | 205 | 99 | 0 | 153 | 46 | Transient CHB | Normal | SR | 247 | 112 | | No events |
| 7 | 87 | M | Evolut R/Pro | SR | 172 | 80 | 0 | 99 | 50 | JR | Normal | SR | 192 | 97 | | No events |
| 8 | 80 | M | Valve in Valve (Evolut R/Pro in Sapien 3) | SR | 225 | 133 | RBBB | 123 | 70 | n/a | RBBB | SR | 249 | 127 | | No events |
| 9 | 79 | F | Evolut R/Pro | SR | 208 | 114 | 0 | 142 | | n/a | LBBB | SR | 238 | 132 | 63 | PM after TAVI |

M = male, F = femal, R* = rhythm, SR = sinus rhythm, AF = atrial fibrillation, IVCD = intraventricular conduction delay, JR = junctional rhythm, RBBB = right bundle branch block, LBBB = left bundle branch block, d = day, PR, QRS, AH and HV measurements in ms.

**Table S3. Patients with preexisting LBBB.**

| | | | | Pre-TAVI measurements | | | | | Post TAVI | | | | EP Study Day 1 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Age** | **Sex** | **Valve** | **R*** | **PR** | **QRS** | **AH** | **HV** | **PR** | **QRS** | **AH** | **HV** | **PR** | **QRS** | **AH** | **HV** | **FU 30d** |
| 1 | 87 | F | Edwards Sapien | SR | 189 | 163 | 107 | 53 | 217 | 169 | 112 | 59 | 204 | 154 | | 53 | No events |
| 2 | 81 | M | Evolut R/Pro | SR | 216 | 159 | 72 | 53 | 228 | 163 | 142 | 60 | 201 | 160 | | 49 | No events |
| 3 | 86 | F | Accurate Neo | SR | 140 | 143 | 60 | 33 | 176 | 146 | 106 | 36 | 199 | 140 | 126 | 36 | No events |
| 4 | 88 | M | Accurate Neo | SR | 266 | 163 | 137 | 52 | 362 | 167 | 163 | 53 | 274 | 148 | 142 | 52 | No events |
| 5 | 89 | F | Evolut R/Pro | SR | 187 | 100 | | 50 | 216 | 176 | | 60 | 198 | 161 | 96 | 48 | No events |
| 6 | 70 | M | Accurate Neo | SR | 260 | 136 | 155 | 49 | 337 | 149 | 164 | 86 | 294 | 161 | 134 | 71 | PM after EPS |
| 7 | 76 | M | Evolut R/Pro | AF | | 120 | 136 | 41 | | 117 | 150 | 42 | | 98 | | | No events |

M = male, F = female, R* = rhythm, SR = sinus rhythm, AF = atrial fibrillation, LBBB = left bundle branch block, PR, QRS, AH and HV measurements in ms.

**Table S4. Patients with preexisting RBBB.**

| | | | | Pre-TAVI measurements | | | | | Post TAVI | | | | EP Study Day 1 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Age** | **Sex** | **Valve** | **R*** | **PR** | **QRS** | **AH** | **HV** | **PR** | **QRS** | **AH** | **HV** | **PR** | **QRS** | **AH** | **HV** | **FU 30d** |
| 1 | 78 | M | Evolut R/Pro | AF | | 172 | | 60 | | 186 | | 56 | | 150 | | | No events |
| 2 | 86 | M | Accurate Neo | SR | 286 | 162 | 160 | 59 | 312 | 170 | 200 | 58 | 232 | 150 | | | No events |
| 3 | 83 | M | Evolut R/Pro | SR | 224 | 136 | 129 | 54 | 220 | 135 | 116 | 53 | 198 | 161 | | | No events |
| 4 | 80 | F | Accurate Neo | SR | 203 | 166 | 112 | 52 | 218 | 164 | 122 | 54 | 202 | 152 | | | No events |
| 5 | 80 | M | Accurate Neo | SR | 146 | 152 | 65 | 49 | 150 | 134 | 86 | 44 | 159 | 126 | | | No events |
| 6 | 88 | M | Accurate Neo | SR | 143 | 149 | 80 | 49 | 183 | 143 | 113 | 49 | 169 | 142 | | | No events |
| 7 | 80 | M | Accurate Neo | SR | 179 | 134 | 120 | 46 | 195 | 143 | 129 | 48 | 198 | 147 | | | No events |
| 8 | 87 | F | Accurate Neo | SR | 230 | 159 | 135 | 44 | 263 | 166 | 131 | 71 | 221 | 150 | | | 26 days post TAVI AV block III, PM implant |

M = male, F = female, R* = rhythm, SR = sinus rhythm, AF = atrial fibrillation, RBBB = right bundle branch block, PR, QRS, AH and HV measurements in ms.

**Table S5. ECG Findings pre- and post-valve deployment and Day 1 post TAVR in patients with persistent LBBB Day I.**

| | Overall (n=92) | Non-LBBB (n=69) | LBBB (n=18) | p-value |
|---|---|---|---|---|
| **Pre- and post-valve deployment EPS** | | | | |
| PR Delta interval, ms | 10 [3, 25] | 9 [3, 21] | 16 [4, 38] | 0.395 |
| QRS Delta duration, ms | 24 [5, 55] | 20 [2, 43] | 63 [54, 66] | <0.001 |
| AH interval Delta, ms | 72 [46, 92] | 74 [47, 92] | 52 [40, 84] | 0.41 |
| HV interval Delta, ms | 4 [0, 11] | 4 [0, 10] | 7 [3, 17] | 0.087 |
| **Post-valve deployment EPS and Day 1 post TAVR EPS** | | | | |
| PR Delta interval, ms | -22 [-34, -11] | -22 [-36, -10] | -22 [-27, -20] | 1 |
| QRS Delta duration, ms | -18 [-47, -5] | -25 [-51, -5] | -14 [-19, -6] | 0.121 |
| AH interval Delta, ms | -18 [-29, -7] | NA [NA, NA] | -18 [-29, -7] | NA |
| HV interval Delta, ms | -4 [-9, 2] | -18 [-18, -18] | -4 [-8, 4] | 0.209 |

Data are presented as median and interquartile range (IQR) for continuous variables. LBBB - left bundle branch block; TAVR – transfemoral aortic valve replacement.

**Table S6. PR intervals and delta PR for the 4 patients with persistent LBBB and a prolonged HV interval.**

| Pre-valve deployment | Post-valve deployment | Delta PR | Day I | Delta PR | Day I |
|---|---|---|---|---|---|
| **PR** | **PR** | **Pre vs. Post** | **PR** | **Post vs. Day I** | **HV** |
| 182 | 232 | 50 | 212 | -20 | 66 |
| 232 | 276 | 44 | 275 | -1 | 68 |
| AF | AF | - | AF | - | 61 |
| 278 | 292 | 14 | 290 | -2 | 60 |

All measurements are in ms.

**Table S7. HV dynamics for patients receiving pacemaker therapy due to HV prolongation in the setting of new-onset left bundle branch block.**

| Pre-valve deployment | Post-valve deployment | Day I | VP% |
|---|---|---|---|
| **HV** | **HV** | **HV** | |
| 70 | 74 | 66 | 0 |
| 50 | 62 | 68 | 27 |
| 46 | 61 | 61 | 10 |
| 50 | 70 | 60 | 1 |

All measurements are in ms. VP = ventricular pacing burden.