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# Cardiovascular Revascularization Medicine



## Impact of baseline and newly acquired conduction disorders on need for permanent pacemakers with 3 consecutive generations of self-expanding transcatheter aortic heart valves

Herbert G. Kroon, Lennart van Gils, Francesca Ziviello, Maarten van Wiechen, Joris Ooms, Zouhair Rahhab, Nahid El Faquir, Anne-Marie Maugenest, Isabella Kardys, Joost Daemen, Peter P. de Jaegere, Nicolas M. Van Mieghem\*

Department of Cardiology, Thoraxcenter, Erasmus Medical Center, Rotterdam, the Netherlands

### ARTICLE INFO

#### Article history:

Received 18 September 2020

Received in revised form 11 December 2020

Accepted 22 January 2021

Available online xxxxx

#### Keywords:

Transcatheter aortic valve replacement

Aortic valve stenosis

Pacemaker

Conduction dynamics

Early discharge

### ABSTRACT

**Introduction:** We aimed to compare conduction dynamics and need for permanent pacemaker implantation (PPI) after CoreValve, Evolut R and PRO (transcatheter aortic valve replacement (TAVR)).

**Methods:** Patients were stratified based on conduction at baseline; Cohort A had normal conduction, Cohort B had conduction abnormalities including atrioventricular (AV)-block, fascicular block or complete bundle branch block. Three different dynamic QRS-patterns were defined: stable QRS-duration, transient QRS-prolongation and persistent QRS-prolongation. We performed multivariable regression analysis to estimate the effect of the three separate transcatheter heart valves (THV's) on need for PPI at 30 days.

**Results:** TAVR was performed with CoreValve (N = 113), Evolut R (N = 157) or Evolut PRO (N = 92). Conduction dynamics were similar between the different THVs. Overall, Evolut R and PRO showed a tendency towards less PPI compared to CoreValve (17% vs. 19% vs. 27%, P = 0.08), which was driven by a lower PPI rate in Cohort A (6% vs. 11% vs. 25%, P = 0.002). Need for PPI was restricted to patients with persistent QRS-prolongation in Cohort A (26/106) but did not correlate with conduction dynamics in Cohort B. In multivariable logistic regression analysis the use of Evolut R (OR 0.38, 95% CI 0.19–0.78, P = 0.008) and PRO (OR 0.41, 95% CI 0.19–0.91, P-value = 0.028) were independently associated with less need for PPI.

**Conclusion:** The newer generations Evolut R and PRO were associated with less PPI compared to CoreValve. Acquired persistent conduction abnormalities predicted PPI after TAVR only in patients with normal conduction at baseline. Our findings may help identify eligible patients for early discharge after Evolut R/PRO TAVR.

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### 1. Introduction

Recently, studies have confirmed non-inferiority of transcatheter aortic valve replacement (TAVR) in patients at low risk for surgery [1,2]. Still, conduction abnormalities and need for permanent pacemaker implantation (PPI) remain frequent after TAVR because of device protrusion into the left ventricular outflow tract and consequent pressure onto the atrioventricular (AV) node and His bundle [3,4]. PPI is

**Abbreviations:** TAVR, Transcatheter aortic valve replacement; PPI, Permanent pacemaker implantation; THV, Transcatheter heart valve; ECG, Electrocardiogram; SEV, Self-expanding valve; AV, Atrioventricular; STS, Society of Thoracic Surgeons; AV1B, 1st degree atrioventricular block; LBBB, Left bundle branch block; RBBB, Right bundle branch block; LVOT, Left ventricular outflow tract; AF, Atrial fibrillation.

\* Corresponding author at: Department of Interventional Cardiology, Thoraxcenter, ErasmusMC, Room Nt-645, Dr. Molewaterplein 40, 3015 GD Rotterdam, the Netherlands.  
E-mail address: [n.vanmieghem@erasmusmc.nl](mailto:n.vanmieghem@erasmusmc.nl) (N.M. Van Mieghem).

more frequent with the self-expanding compared to balloon-expandable transcatheter heart valve (THV) [3–7]. The 2nd generation Evolut R THV (Medtronic Inc., Minneapolis, USA) introduced partial recapturability and repositionability to optimize implantation depth and limit paravalvular leakage and need for PPI and three consecutive studies reported <20% PPI rates in their initial clinical experience with Evolut R THV [8–10]. The Evolut PRO is the latest iteration adding a pericardial wrap to further minimize paravalvular leakage [11]. With trends of shorter length of hospital stay and expanding TAVR indications towards younger and lower risk patients, a cautious approach towards conduction dynamics post-TAVR is paramount. Several studies reported safety and feasibility of early discharge protocols. Patients with no newly acquired persistent conduction disturbances after TAVR seemed suitable for safe early discharge with no risk for late conduction issues [12,13]. These studies included 1st generation mechanically expanded, balloon expandable and self-expanding THV's and lacks confirmation

<https://doi.org/10.1016/j.carrev.2021.01.025>

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Please cite this article as: H.G. Kroon, L. van Gils, F. Ziviello, et al., Impact of baseline and newly acquired conduction disorders on need for permanent pacemakers with 3 consecutive generations of self-expanding transcatheter aortic heart valves, *Cardiovascular Revascularization Medicine*, <https://doi.org/10.1016/j.carrev.2021.01.025>

in newer generations of self-expanding valves (SEV's). In this study we aimed to compare conduction dynamics and need for PPI after TAVR among 3 consecutive generations of self-expanding THV's.

## 2. Methods

All consecutive patients who underwent transfemoral or transsubclavian TAVR with 3 generations of self-expanding THV's for severe aortic valve stenosis (AS) between January 2012 and December 2018 in our center were entered in a dedicated prospective database. All patients provided written informed consent for the TAVR procedure and subsequent data analysis for research purposes. This present study was complementary with the Declaration of Helsinki and approved by the Erasmus University Medical Center Rotterdam Institutional Review Board. Patients with a pacemaker at baseline, who died within 72 h post TAVR or who had no electrocardiogram (ECG) data during their admission were excluded from the analysis.

### 2.1. Electrocardiogram analysis and conduction dynamics

The methodology of ECG analysis has been previously described in detail [13]. In short, twelve-lead electrocardiograms were collected at baseline the day before TAVR and daily afterwards up to discharge, as well as at the one-month follow-up visit in the outpatient clinic. Patients were stratified based on conduction at baseline into Cohort A with normal conduction and Cohort B with any conduction abnormality (any degree AV-block, fascicular block or complete bundle branch block). Dedicated clinical researchers (HK, LVG) analyzed all ECGs and an experienced interventional cardiologist (NVM) was consulted in case of discrepancy. Only ECGs without temporary pacemaker intrusion were analyzed for rhythm, conduction times, and the presence of atrioventricular block or bundle branch block. We analyzed the ECG with the longest QRS-duration, when multiple ECG's were present.

Conduction dynamics after TAVR were divided into three QRS-patterns, as previously described by our group [13]:

1. Stable QRS-pattern: QRS-prolongation after TAVR  $\leq 20$  ms OR more than 20 ms but never exceeding a total QRS-duration of 120 ms throughout the admission.
2. Transient QRS-prolongation: QRS-prolongation  $> 20$  ms post-TAVR, but recovery within 20 ms before discharge.
3. Persistent QRS-prolongation: QRS-prolongation  $> 20$  ms after TAVR which persisted at least up to discharge.

Patients who developed a new bundle branch block after TAVR were specifically classified as transient or persistent QRS-prolongation depending on whether it resolved before discharge or not.

### 2.2. Outcomes

The primary outcome for this study was the need for PPI. The requirement for a permanent pacemaker was per treating physician's decision and in compliance with the European Society of Cardiology guidelines on cardiac pacing and cardiac resynchronization therapy.

### 2.3. Data analysis

Continuous variables were presented as mean ( $\pm$ SD) or median (interquartile range) and categorical variables as n (%). The distribution of continuous variables was examined for normality through histograms and Q-Q plots. To compare continuous variables between the three different transcatheter heart valve designs one-way ANOVA and the non-parametric Kruskal-Wallis test was performed, according to the distribution of the variables. For categorical variables the Pearson  $\chi^2$  test or the Fisher exact test as appropriate was performed. For ensuing pairwise comparisons, the Bonferroni correction was used to account for multiple testing. Cumulative pacemaker-free survival analysis was

performed using the Kaplan-Meier method, with date of the TAVR procedure as initial time of follow-up ( $t = 0$ ). A log-rank test was applied to compare between-group differences. Additionally, we performed multivariable logistic regression to estimate the effect of the three separate THV's on need for PPI at 30 days after TAVR. In this analysis we entered THV type and added baseline covariates, based on selection of those covariates that displayed a difference with a p-value less than 0.10 in univariate analysis. When limited number of events were present we chose those covariates that had a p-value less than 0.10 and are known risk factors for need for permanent pacemaker (i.e. male gender, depth of implantation, RBBB at baseline). All statistical analyses were performed with SPSS version 24.0 (IBM Corporation, New York, United States of America). A two-sided value of  $p < 0.05$  was considered statistically significant.

## 3. Results

A total of 362 (54% male) patients who underwent TAVR with CoreValve (N = 113), Evolut R (N = 157) or Evolut PRO (N = 92) THV-design were included in the analysis after exclusion of cases with an alternative access approach (Direct Aortic, N = 1), mortality within 72 h after the index procedure (N = 5), a pacemaker at baseline (N = 37) or missing ECG data (N = 1). The overall median age and Society of Thoracic Surgeons (STS) predicted risk of mortality were 80 [73–84] years and 4.2% [2.8–6.3], respectively. TAVR was performed through the transfemoral route in the majority (90%) of cases. All baseline characteristics are displayed in Table 1. Half of all patients (59%) had no conduction disturbances at baseline (Cohort A), while the remainder presented with some kind of conduction abnormality, most frequently a 1st degree atrioventricular block (AV1B, 74/362, 20%) or a left bundle branch block (LBBB, 35/362, 10%) as displayed in Supplementary Table 1.

### 3.1. Conduction dynamics with the three consecutive generations of SEV's regardless of baseline conduction

Patients who underwent TAVR with Evolut R or PRO were treated more often through a transfemoral route (CoreValve 84% vs. Evolut R 89% vs. Evolut PRO 97%,  $P = 0.001$ , Table 1). Implantation depth was similar for the 3 different THV's ( $7.1 \pm 3.2$  mm vs.  $7.0 \pm 3.3$  mm vs.  $7.2 \pm 2.6$  mm,  $P = 0.87$ ). Predilatation occurred more often with Corevalve (80% vs. 8% vs. 12%), but post-dilatation less (28% vs. 42% vs. 41%). No significant differences were observed in prevalence of (functional) bicuspid valves and calcification level in the left ventricular out flow tract (LVOT) or annulus. Patients who underwent TAVR with CoreValve had more often a LBBB at baseline (16% vs. 7% vs. 7%,  $P = 0.03$ ), but presence of right bundle branch block (RBBB) was similar between three valves. The occurrence of new conduction disturbances during the index procedure did not differ significantly between the three self-expanding valves. However, thereafter new onset atrial fibrillation (AF) appeared more frequent with CoreValve (14% vs. 5% vs. 3%,  $P = 0.004$ ) and new permanent RBBB was more frequent with Evolut PRO (0% vs. 1% vs. 7%,  $P = 0.001$ ). Need for PPI tended to occur more often with CoreValve (27% vs. 17% vs. 19%,  $P = 0.08$ , Table 2). Importantly, only three patients who underwent CoreValve TAVR with a LBBB at baseline were in need for PPI. Kaplan Meier curves for the pacemaker-free survival probability for the three transcatheter heart valves are displayed in Supplementary Fig. 1 (Log-Rank test  $P = 0.073$ ). In multivariable logistic regression analysis the use of Evolut R (OR 0.38, 95% CI 0.19–0.78,  $P = 0.008$ ) and PRO (OR 0.41, 95% CI 0.19–0.91,  $P$ -value = 0.028) were independently associated with less need for PPI, also when corrected for depth of implantation, conduction disturbances at baseline and male gender (Table 3). Univariate analysis is displayed in Supplementary Table 2. Prevalence of the three predefined conduction patterns did not differ between the three THV-designs. However, CoreValve patients with persistent

**Table 1**  
Baseline characteristics between three self-expanding valves regardless of baseline conduction status.

	CoreValve (N = 113)	Evolut R (N = 157)	Evolut Pro (N = 92)	P-value
<b>Baseline characteristics</b>				
Male gender	67 (59%)	85 (54%)	42 (46%)	0.15
Age in years	81 [75–84]	79 [73–84]	80 [74–85]	0.29
STS-score (%)	4.3 [3.1–5.7]	4.2 [2.7–6.3]	4.3 [2.5–6.5]	0.85
Creatinin on baseline (umol/L)	95 [75–128]	98 [76–117]	90 [74–117]	0.54
Body mass index (kg/m2)	27 ± 4	27 ± 5	27 ± 5	0.82
Ischemic heart disease	52 (46%)	70 (45%)	31 (34%)	0.15
History of AVR/TAVR	5 (4%)	14 (9%)	7 (8%)	0.36
Diabetes mellitus	35 (31%)	43 (27%)	29 (32%)	0.73
Hypertension	84 (74%)	118 (76%)	71 (77%)	0.89
History of atrial fibrillation	28 (25%)	46 (29%)	22 (24%)	0.57
History of stroke	21 (19%)	17 (11%)	14 (15%)	0.19
Peripheral arterial disease	41 (36%)	79 (51%)‡	27 (29%)‡	0.002
NYHA class ≥3	82 (75%)*	91 (60%)*	62 (68%)*	0.04
Bicuspid valve (functional)	9 (8%)	10 (7%)	7 (8%)	0.91
Moderate or severe annulus calcification (Rosenhek)	90 (80%)	125 (82%)	77 (84%)	0.76
Moderate or severe LVOT calcification	20 (18%)	22 (15%)	14 (15%)	0.82
<b>Baseline conduction disturbances (alone or in combination)</b>				
RBBB	7 (6%)	15 (10%)	11 (12%)	0.35
LBBB	18 (16%)	11 (7%)	6 (7%)	0.03
UIVD	3 (3%)	3 (2%)	3 (3%)	0.80
AV1B	25 (22%)	28 (18%)	21 (23%)	0.56
LAFB	15 (13%)	12 (8%)	4 (4%)	0.07
LFPB	1 (1%)	1 (1%)	0 (0%)	0.68
<b>Procedural details</b>				
Femoral access	95 (84%)†	140 (89%)	89 (97%)†	0.001
Depth of implantation (mm)	7.1 ± 3.2	7.0 ± 3.3	7.2 ± 2.6	0.87
Pre-dilatation	90 (80%)*†	12 (8%)*	11 (12%)†	<0.001
Post-dilatation	32 (28%)*	66 (42%)*	38 (41%)	0.05
If Evolut R/PRO, repositioning used?	–	54 (36%) Range 1–4	17 (19%) Range 1–4	<0.001
Valve in valve during procedure	7 (6%)	6 (4%)	4 (4%)	0.65
Number of valves implanted	1, range 1–3	1, range 1–3	1, range 1–2	0.28

Categorical variables are shown as n (%). Continuous variables are displayed as mean ± SD, median [interquartile range] or median, range. Abbreviations: STS = Society of Thoracic Surgeons, AVR = aortic valve replacement, TAVR = transcatheter aortic valve replacement, NYHA = New York Heart Association, LVOT = left ventricular outflow tract, RBBB = right bundle branch block, LBBB = left bundle branch block, UIVD = unspecific intraventricular conduction delay, AV1B = 1st degree atrioventricular block, LAFB = left anterior fascicular block, LFPB = left posterior fascicular block.  
\* (CoreValve vs. Evolut R), † (CoreValve vs. Evolut PRO), ‡ (Evolut R vs. Evolut PRO) means P < 0.05 for pairwise comparisons with Bonferroni correction.

QRS-prolongation required a permanent pacemaker twice as often compared to the others (50% vs. 24% vs. 23%, P = 0.006).

### 3.2. Conduction dynamics between the THV-designs in Cohort A

In patients with normal conduction at baseline patient demographics were comparable between the three THV-designs (N = 214, Supplementary Table 3). Patients treated with CoreValve were more often male (53% vs. 48% vs. 30%, P = 0.03), had higher creatinine levels (97 vs. 91 vs. 81 umol/L, P = 0.03) and more often underwent pre-dilatation before valve deployment (80% vs. 8% vs. 14%, P < 0.0005). The appearance of per-procedural conduction disturbances did not differ significantly, while new permanent RBBB occurred more often with Evolut PRO compared to CoreValve and Evolut R (9% vs. 0% vs. 1%, P = 0.005). Implantation of CoreValve resulted in higher rates of PPI

**Table 2**  
Conduction dynamics after TAVR and need for permanent pacemaker.

	CoreValve (N = 113)	Evolut R (N = 157)	Evolut Pro (N = 92)	P-value
<b>Clinical outcomes</b>				
Permanent pacemaker post TAVR	31 (27%)	26 (17%)	17 (19%)	0.08
Due to AV3B	20 (65%)	23 (89%)	14 (82%)	
Due to AV2B (Mobitz II)	3 (10%)	1 (4%)	3 (18%)	
AF with bradycardia	3 (10%)	0 (0%)	0 (0%)	
Sick sinus syndrome	3 (10%)	0 (0%)	0 (0%)	
Other	2 (7%)	2 (8%)	0 (0%)	
Mortality at 30 days	6 (5%)	3 (2%)	1 (1%)	0.13
<b>New conduction disturbances</b>				
Per-procedural AV3B	23 (20%)	29 (19%)	15 (17%)	0.78
Per-procedural LBBB	63 (56%)	87 (55%)	51 (55%)	1.00
Per-procedural RBBB	2 (2%)	2 (1%)	0 (0%)	0.47
Temporary LBBB	36 (32%)	40 (26%)	30 (33%)	0.38
Permanent LBBB	34 (30%)	51 (33%)	29 (32%)	0.92
Temporary RBBB	4 (4%)	10 (6%)	2 (2%)	0.26
Permanent RBBB	0 (0%)†	1 (1%)‡	6 (7%)‡†	0.001
Temporary AV2B/AV3B	8 (7%)	10 (6%)	13 (14%)	0.09
Permanent AV2B/AV3B	19 (17%)	20 (13%)	11 (12%)	0.53
AV1B	22 (20%)	29 (19%)	15 (17%)	0.84
AF	16 (14%)†*	8 (5%)*	3 (3%)‡	0.004

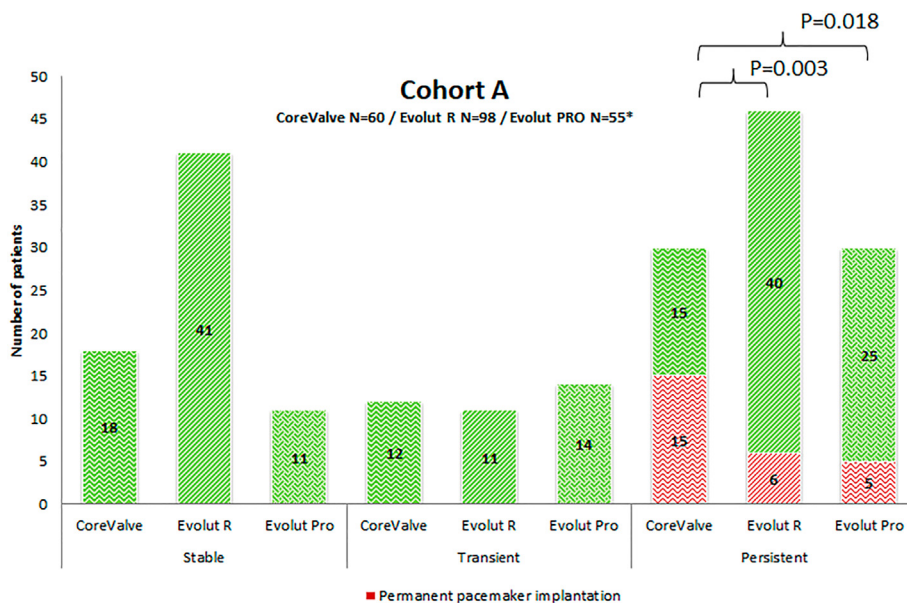
Categorical variables are shown as n (%). Continuous variables are displayed as mean ± SD, median [interquartile range] or median, range. Abbreviations: AV3B = 3rd degree atrioventricular block, AV2B = 2nd degree atrioventricular block, AF = Atrial fibrillation, LBBB = left bundle branch block, RBBB = right bundle branch block, AV1B = 1st degree atrioventricular block.  
\* (CoreValve vs. Evolut R), † (CoreValve vs. Evolut PRO), ‡ (Evolut R vs. Evolut PRO) means P < 0.05 for pairwise comparisons with Bonferroni correction.

compared to Evolut R and PRO (25% vs. 6% vs. 11%, P = 0.002). The stable QRS-pattern was most frequently associated with Evolut R (CoreValve 30% vs. Evolut R 42% vs. Evolut PRO 21%, P = 0.029). The different conduction patterns correlated highly with the need for PPI in patients with normal baseline conduction. Only patients with persistent QRS-prolongation required PPI in cohort A, but less frequent with Evolut R and PRO (50% vs. 13% vs. 17%, P = 0.001 overall, Fig. 1). Of note, one patient with stable QRS-duration needed a permanent pacemaker after discharge, when she was brought in the emergency room with hyperkalemia and this was not considered as a QRS-pattern-related pacemaker. In patients with transient QRS-prolongation the QRS-width reached its maximum the same day of the procedure in 60% of patients, the next day in 73% and the 2nd day in 78% of patients, cumulatively. All patients with transient prolongation reached their maximum QRS-prolongation within 6 days after TAVR.

**Table 3**  
Multivariable logistic regression analysis on need for permanent pacemaker implantation.

	Need for Permanent Pacemaker Implantation OR (95% CI)	P-value
Male gender	0.75 (0.39–1.46)	0.40
Creatinin on baseline (umol/L)	1.002 (0.998–1.007)	0.28
RBBB at baseline	13.68 (5.42–34.58)	<0.005
AV1B at baseline	3.51 (1.75–7.02)	<0.005
LAFB at baseline	1.21 (0.44–3.30)	0.71
<b>Valve type</b>		
CoreValve	1.00 (reference)	–
Evolut R	0.38 (0.19–0.78)	0.008
Evolut PRO	0.41 (0.19–0.91)	0.028
Depth of implantation (mm)	1.22 (1.10–1.35)	<0.005

Variables are shown as odds ratio OR (95% confidence interval). Abbreviations: RBBB = Right Bundle Branch Block; AV1B = First Degree Atrioventricular Block; LAFB = Left Anterior Fascicular Block.



**Fig. 1.** Need for permanent pacemaker implantation related to conduction patterns post-TAVR between the THV-designs in Cohort A. Each column represents the total number of patients with in red the number of patients who were in need of permanent pacemaker implantation. \* One patient in Cohort A with stable QRS-duration required a permanent pacemaker after discharge due to a total AV-block when she suffered of hyperkalemia, which was not considered a device-related pacemaker for the QRS-patterns analysis. This pacemaker was included in the overall analysis. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

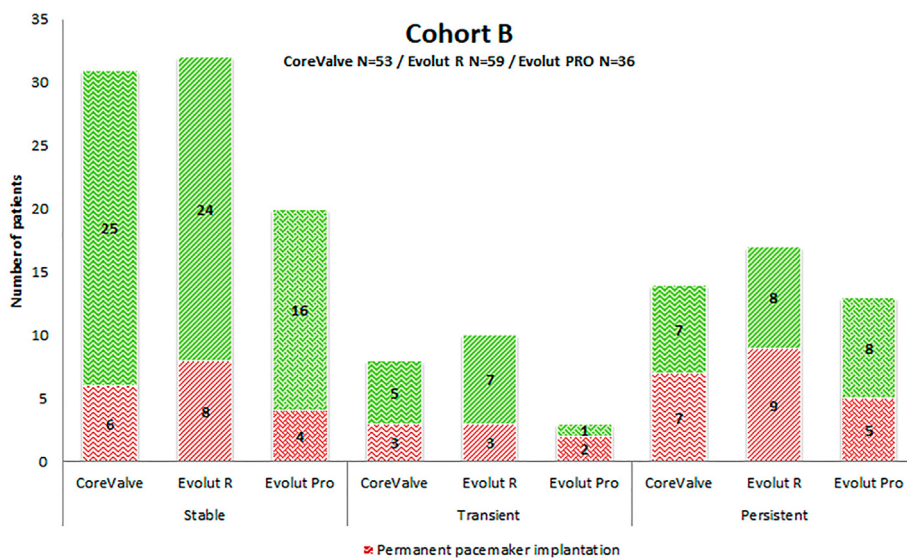
3.3. Conduction dynamics between the THV-designs in Cohort B

Patients with abnormal conduction at baseline who underwent TAVR with CoreValve had more pre-dilatation (79% vs. 7% vs. 8%,  $P < 0.001$ ) and less often transfemoral access (79% vs. 88% vs. 97%,  $P = 0.04$ ). No significant differences with regards to baseline conduction abnormalities, prevalence of (functional) bicuspid valves and LVOT/annular calcifications were observed. Also, the occurrence of per-procedural conduction disturbances between the three self-expanding THVs were similar. Patients with CoreValve more often developed atrial fibrillation after TAVR compared to those treated with Evolut PRO. An equal number of patients required PPI ( $\approx 30\%$

with all THV-designs,  $P = 0.90$ , Supplementary Table 4) in Cohort B. Median recovery of transient QRS-prolongation was within 24 h post TAVR in all groups. Conduction patterns did not predict need for PPI with all three THV's in Cohort B (Fig. 2).

4. Discussion

Our study demonstrates that Evolut R and PRO are associated with less need for PPI compared to CoreValve, particularly in patients with normal conduction at baseline. Baseline conduction status and changing QRS-patterns after TAVR have implications for a permanent pacemaker. No PPI is required when QRS-width is normal at baseline and not



**Fig. 2.** Need for permanent pacemaker implantation related to conduction patterns post-TAVR between the THV-designs in Cohort B. Each column represents the total number of patients with in red the number of patients who were in need of permanent pacemaker implantation. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

permanently affected after TAVR. Patients with normal baseline conduction and acquired permanent conduction abnormalities are at risk for PPI, more so after Corevalve.

#### 4.1. Conduction dynamics in perspective of conduction status at baseline

Overall, Evolut R and PRO were associated with a tendency towards less PPI compared to Corevalve (17% vs. 19% vs. 27%,  $P = 0.08$ ). These lower pacemaker rates of 17% and 19% are comparable with numbers currently reported in the literature for the newest generations of Medtronic SEV's. Pacemaker rates vary from 12 to 20% for the Evolut R and PRO and 25–30% with CoreValve [8–11,14–17]. Also, in multivariable logistic regression analysis Evolut R and PRO seemed associated with less need for PPI compared to CoreValve, when correcting for depth of implantation, male gender and baseline conduction abnormalities. The most important finding in this analysis is that patients without baseline conduction disturbances and no newly acquired persistent QRS-prolongation never needed a PPI regardless of the generation of self-expanding THV. Previous studies mainly reported on the impact of baseline variables to predict PPI post-TAVR like gender, baseline conduction status and THV-design [3–7]. We correlated baseline conduction status to periprocedural conduction dynamics in predicting the risk of PPI after TAVR. Also, Toggweiler et al. reported the predictive value of the ECG after TAVR and suggested that patients with no conduction disturbances post-TAVR never required PPI [12]. Patients who developed a conduction disorder required extensive monitoring until the 12 lead ECG was stable for 48 h after the index procedure [12]. We refined this notion by adding dynamic QRS-patterns post-TAVR to predict the need for PPI. Our findings may further elaborate on prior conclusions because patients without baseline conduction abnormalities and no or transient acquired QRS-prolongation never needed PPI. Only patients with newly acquired persistent conduction disorders were at risk for a pacemaker. Those findings are in line with the recent study conducted by our group in 300 patients treated with self-expanding (1st generation), balloon expandable and mechanically expanded THVs [13]. Similarly, patients with normal conduction at baseline and no newly acquired persistent QRS-prolongation never required PPI. The present study reinforces the importance of baseline conduction status and peri-procedural conduction dynamics in predicting the need for PPI with exclusively SEV THVs.

TAVR with Evolut R and PRO in patients with no conduction disturbances at baseline resulted in lower pacemaker rates (6% and 11%) as compared to 25% with Corevalve. For all THV-designs the QRS-patterns predicted the need for PPI in patients with normal conduction at baseline. Patients were at risk for PPI if they acquired a persistent QRS-prolongation. Of note, persistent prolongation could be distinguished from transient prolongation within 1 day post-TAVR in approximately three-quarters of patients. In early TAVR experience there was a relationship between the occurrence of conduction disorders and balloon pre-dilatation [18]. However, it remains questionable whether less pre-dilatation in patients treated with the latest generations SEV's could explain the lower PPI rate. Conversely, post-dilatation was performed more frequently with the newer generations compared to CoreValve. Also, in our study population, pre- and post-dilatation were not associated with need for PPI.

Evolut R introduced partial repositionability and recapturability to optimize valve deployment and implantation depth [19]. Of note we did not find different implantation depths with the 3 THV designs. Evolut R also featured a more consistent and homogeneous distribution of the radial force which together with the redesigned inflow portion may have less impact pressure on the left ventricular outflow tract [19]. Its successor, the 3rd generation Evolut PRO was built on the same principles and added an outer pericardial wrap to minimize paravalvular leakage. Subsequent device iterations, increased TAVR experience, a trend for treating patients at lower risk for surgery and procedure modifications may have increased overall safety as well.

Decision making regarding PPI after TAVR may have changed over time. Still, high grade atrioventricular blocks remained the principle indication for PPI with all three valve types. Our findings may help identify patients with SEV TAVR who could be eligible for safe early discharge without the risk for (late) conduction disorders and need for PPI provided there was normal conduction at baseline. The QRS-patterns did not correlate with need for PPI in patients with baseline conduction abnormalities. Those patients therefore require telemetry monitoring for a longer time to rule out progression to potentially lethal high-grade atrioventricular block.

#### 4.2. Study limitations

This was a single-center, observational study with inherent time bias. Growing TAVR experience among operators and treating physicians may have affected conduction dynamics (through mature implantation technique) and refined decision making related to permanent pacemakers. Over time the relative proportion of alternative (non-transfemoral) access and balloon valvuloplasty prior to TAVR declined. The non-randomized, observational aspect of this study including the implantation of the THV's in different time periods preclude any definite conclusions. Our findings should be interpreted as hypothesis generating. Although decision for a permanent pacemaker was at the treating physician's discretion, indications consisted predominantly of high degree atrioventricular block and thus were according to the current European Society of Cardiology guidelines on cardiac pacing. At our center the temporary pacemaker is left in situ less than 1 day after the procedure. A permanent pacemaker was implanted when a patient was pacemaker dependent 24 h after the index procedure. This may have prevented resolution of conduction disorders before the decision to proceed with PPI. Overall, analyzable ECG's (without pacemaker interference) were present for 68% of total hospitalized days at our center and referral centers. Percentage of missing ECG's was lower with the newer Evolut R and PRO valve, which may have resulted in underestimation of the prevalence of high degree atrioventricular block in the CoreValve cohort. Incompleteness of present ECG's reflects the retrospective analysis of current clinical practice, however missing ECG's were equally distributed between our three predefined conduction patterns. Therefore we think that our predefined conduction patterns are valid. Our study with daily ECG's after TAVR represents one of the most extensive samples of conduction times reported to date.

## 5. Conclusion

Newer generation Evolut R and PRO were associated with less PPI than Corevalve in present study. Acquired persistent QRS-prolongation predicted PPI after TAVR only in patients with normal conduction at baseline, and this finding was valid regardless of the generation of SEV that was used. Our findings may help identify eligible patients for early discharge after Evolut R/PRO TAVR.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.carrev.2021.01.025>.

#### Funding or grants

None.

#### CRediT authorship contribution statement

**Herbert G. Kroon:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft. **Lennart van Gils:** Conceptualization, Methodology, Investigation, Writing – review & editing. **Francesca Ziviello:** Conceptualization, Investigation, Methodology, Writing – review & editing. **Maarten van Wiechen:** Conceptualization, Investigation, Methodology, Writing –

review & editing. **Joris Ooms**: Conceptualization, Investigation, Methodology, Writing – review & editing. **Zouhair Rahhab**: Conceptualization, Investigation, Methodology, Writing – review & editing. **Nahid El Faquir**: Conceptualization, Investigation, Methodology, Writing – review & editing. **Anne-Marie Maugenest**: Conceptualization, Data curation, Investigation, Methodology, Resources, Software, Writing – review & editing. **Isabella Kardys**: Conceptualization, Data curation, Formal analysis, Methodology, Supervision, Validation, Writing – review & editing. **Joost Daemen**: Conceptualization, Investigation, Methodology, Writing – review & editing. **Peter P. de Jaegere**: Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Writing – review & editing. **Nicolas M. Van Mieghem**: Conceptualization, Investigation, Methodology, Project administration, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

#### Declaration of competing interest

HK: no conflicts of interest to declare.

LVG: no conflicts of interest to declare.

MVW: no conflicts of interest to declare.

JO: no conflicts of interest to declare.

FZ: no conflicts of interest to declare.

ZR: no conflicts of interest to declare.

NEF: no conflicts of interest to declare.

AM: no conflicts of interest to declare.

IK: no conflicts of interest to declare.

JD: no conflicts of interest to declare.

PDJ: is proctor for Boston Scientific.

NVM has received research grants from Medtronic, Boston scientific, Edwards Lifesciences, Abbott, PulseCath. He is advisor to PulseCath, Ancora, Boston Scientific, Medtronic.

#### Acknowledgements

None.

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