

**CLINICAL INVESTIGATIONS**

# Temporal trends in transcatheter aortic valve implantation, 2008–2014: patient characteristics, procedural issues, and clinical outcome

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**Background:** About a decade past the first transcatheter aortic valve implantation (TAVI), data are limited regarding temporal trends accompanying its evolution from novel technology to mainstream therapy. We evaluated these trends in a large multicenter TAVI registry.

**Hypothesis:** TAVI is changing and improving with time.

**Methods:** Patients who underwent TAVI between January 2008 and December 2014 at 3 high-volume Israeli centers were divided into 5 time quintiles according to procedure date. Outcomes were analyzed and reported according to Valve Academic Research Consortium-2.

**Results:** A total of 1285 patients were studied (43% male; mean age,  $83 \pm 3$  years; mean Society of Thoracic Surgeons [STS] score,  $5.5 \pm 3.6$ ). Over time, there was a shift toward treating patients at lower STS score, increased use of conscious sedation and transfemoral approach, and decreased use of balloon predilatation. The balloon-expandable to self-expandable valve utilization ratio decreased, the valve-in-valve experience increased from 4% to 17% of all TAVI volume, and length of hospital stay was halved ( $P = 0.006$ ). Kaplan-Meier survival curves showed gradual decrease in mortality risk ( $P = 0.031$ ), but there was no significant 1-year mortality decrease by multivariable analysis. Each year increment was associated with an adjusted 20%, 15%, and 12% decrease in new pacemaker obligation ( $P = 0.004$ ), new pacemaker obligation or left bundle branch block ( $P = 0.008$ ), and in-hospital infections ( $P = 0.082$ ), respectively.

**Conclusions:** Temporal trends accompanying TAVI evolution include its utilization in lower-risk patients, procedural simplification, improved overall survival, decreased pacemaker obligation, and shorter hospital stay.

**KEYWORDS**

Valvular heart disease, Cardiac, catheterization/diagnostic interventional, Aortic disease

## 1 | INTRODUCTION

More than a decade past the first transcatheter aortic valve implantation (TAVI), the procedure is widely accepted by the medical community and is endorsed by European and American guidelines, as well as the US Food and Drug Administration, indicating TAVI as the intervention of choice in “inoperable” severe aortic stenosis patients and as an alternative to surgery in high-risk patients.<sup>1,2</sup> With >150 000 worldwide procedures performed and growing at a rate of 40% annually,<sup>3</sup> little is known about the temporal trends for TAVI

regarding patient characteristics, technical issues, and outcomes accompanying its evolution from novel technology to mainstream therapy. Therefore, the present study aimed to evaluate TAVI temporal trends in a large multicenter Israeli registry.

## 2 | METHODS

Consecutive patients with severe symptomatic aortic stenosis who underwent TAVI between January 2008 and December 2014 at

1 of 3 tertiary medical centers in Israel were included in the analysis (Rabin Medical Center, Petah Tikva:  $n = 328$  [25.5%]; Sheba Medical Center, Tel Hashomer:  $n = 375$  [29.2%]; and Sourasky Medical Center, Tel Aviv:  $n = 582$  [45.3%]). The study was approved by the institutional review board at each of the participating centers.

Severe aortic stenosis was defined by echocardiography as a valvular orifice area  $<1.0 \text{ cm}^2$  or  $<0.6 \text{ cm}^2/\text{m}^2$  and/or a mean transaortic valvular gradient  $>40 \text{ mm Hg}$  and/or jet velocity  $>4.0 \text{ m/s}$ . All patients underwent a rigorous assessment process that included history-taking, physical examination, physical performance measures, cognitive assessments, laboratory tests, and calculation of the Society of Thoracic Surgeons (STS) score predicted risk of mortality (STS-PROM). Eligibility for TAVI was established based on the consensus of a multidisciplinary heart team and even if the calculated STS score was low, if patients were deemed as high surgical risk based on other factors and comorbidities or frailty measures not included in the standardized risk scores. The number of operators per center remained stable throughout the study period. All endpoints were defined and collected using the Valve Academic Research Consortium-2 (VARC-2) consensus definitions and pooled into a dedicated multicenter database.<sup>4</sup>

## 2.1 | Study population

For the purpose of this study, patients were divided into 5 time quintiles according to their procedural date (Q1: 2008–2010, 260 patients; Q2: 2011, 251 patients; Q3: 2012, 266 patients; Q4: 2013, 261 patients; and Q5: 2014, 248 patients).

The selection of the transcatheter valve was at the discretion of the heart team. Patients underwent TAVI via the transfemoral, transapical, transaxillary, or direct aortic access routes. The transfemoral access was the default approach in all centers unless there were anatomic limitations that led to selection of an alternative access. Similarly, the decision on other technical issues, such as whether to perform the procedure under conscious sedation or general anesthesia, was according to the planned implantation approach and at the discretion of the interventional team in each center.

Prespecified clinical and laboratory data were collected for all patients at baseline prior to the procedure, immediately postprocedure, during the index hospitalization, and during long-term follow-up. Collected data included patient medical history, electrocardiography, echocardiography, catheterization laboratory studies, laboratory tests, and clinical outcomes. In-hospital outcomes were collected according to the VARC-2 document.<sup>4</sup>

## 2.2 | Statistical analysis

Categorical data are reported as frequency and percentages, and comparison between groups was performed using the  $\chi^2$  test or the Fisher exact test, as appropriate. Continuous variables are presented as mean  $\pm$  SD or median and interquartile range, and comparisons were performed with the 2-sample *t* test or the 2-sample Wilcoxon rank-sum (Mann-Whitney) test. The probability of all-cause mortality by TAVI procedure year was graphically displayed according to the Kaplan-Meier method, with comparison of instantaneous risk by the log-rank

test. Univariate Cox regression analysis was used to evaluate the association between calendar year (assessed both as a categorical and as a continuous variable) and mortality with follow-up censored at 1 year. The best subsets regression procedure was used to identify significant variables to be included in the multivariable regression models. Multivariable Cox regression analysis was used to evaluate the association between calendar year and mortality with follow-up censored at 1 year, adjusting for the following variables: age, sex, left ventricular ejection fraction, STS-PROM, transaortic gradients at baseline, and history of valve replacement surgery, diabetes mellitus, chronic obstructive pulmonary disease, percutaneous coronary intervention, and atrial fibrillation. Separate multivariable models were constructed using logistic regression analysis for the following endpoints: new permanent pacemaker (PPM) implantation, new PPM implantation or left bundle branch block (LBBB), in-hospital infections, and hospital admission days. Data were registered in an electronic file and analyzed using SAS software version 9.4 (SAS Institute, Inc., Cary, North Carolina). A 2-tailed *P* value  $<0.05$  was considered statistically significant.

## 3 | RESULTS

Between January 2008 and December 2014, a total of 1285 TAVI procedures were performed in the 3 medical centers collaborating in this study. Annual implantation rate increased during the first years (2008–2010) and remained roughly constant thereafter (251–266 TAVI procedures per year during 2010–2014).

### 3.1 | Patient characteristics

The mean age of the total study population was  $82 \pm 7$  years; 57% were female. Patients' mean STS-PROM score was  $5.5 \pm 3.6$ , and mean aortic valve area was  $0.7 \pm 0.16 \text{ cm}^2$ . Most patients (80%) were severely symptomatic (New York Heart Association class III/IV), 39% had depressed left ventricular function (left ventricular ejection fraction  $<40\%$ ), and 17% were adjudged frail. Over the 5 timeframes, there were no temporal trends regarding patient age, sex, and most of the comorbidities (Table 1). Conversely, throughout the study period, the proportion of high-risk patients gradually decreased along with an increase in the proportion of intermediate- and low-risk patients based on the STS-PROM (mean STS:  $6.7 \pm 4.9$  in 2008–2010 and  $4.8 \pm 2.8$  in 2014; *P* for trend  $<0.001$ ). The STS score risk-classification proportions over time are presented in Supporting Information, Figure 1, in the online version of this article. There was also an increase in the prevalence of atrial fibrillation and PPM and a decrease in the prevalence of peripheral vascular disease and chronic obstructive pulmonary disease between the earlier and more recent TAVI periods. There was a clear temporal trend in the direction of higher mean aortic valve area ( $0.64 \pm 0.16 \text{ cm}^2$  in 2008–2010 to  $0.74 \pm 0.19 \text{ cm}^2$  in 2014; *P*  $< 0.001$ ) and heterogeneity among some other variables, but without any recognized unidirectional temporal pattern (Table 1).

### 3.2 | Procedural characteristics

Regarding procedural characteristics stratified in consort with TAVI calendar year-group (Figure 1; also see Supporting Information, Table 1,

**TABLE 1** Baseline characteristics of patients stratified according to TAVI time quintile

Characteristic	Total, N = 1285	Q1: 2008–2010, n = 260	Q2: 2011, n = 251	Q3: 2012, n = 266	Q4: 2013, n = 261	Q5: 2014, n = 248	P Value
Age, y	82 ± 7	83 ± 7	83 ± 8	82 ± 7	82 ± 7	82 ± 8	0.165
Male sex	43	40	39	40	50	46	0.031
STS score	5.5 ± 3.6	6.7 ± 4.9	5.4 ± 3.4	5.1 ± 3.5	5.4 ± 3.9	4.8 ± 2.8	<0.001
DM	36	36	29	34	37	42	0.039
HTN	88	83	89	91	89	87	0.096
Dyslipidemia	81	80	79	78	85	82	0.380
PVD	12	14	16	10	9	10	0.079
COPD	19	25	20	18	19	14	0.049
Current smoker	6	5	9	5	7	3	0.122
“Porcelain” aorta	5	5	6	5	3	6	0.821
AF	31	30	25	32	30	38	0.044
CAD	51	52	51	48	56	48	0.283
MI	18	17	16	19	24	13	0.025
PCI	33	31	34	30	41	31	0.090
CABG	20	26	16	18	21	18	0.026
PPM	10	7	6	8	14	11	0.019
ICD	1	2	1	2	2	1	0.837
CKD	25	27	23	25	27	23	0.672
Hgb, g/dL	12 ± 1	12 ± 2	12 ± 1	12 ± 2	12 ± 2	12 ± 2	0.801
Frailty	17	28	10	11	15	24	<0.001
NYHA class							
II	16	14	17	13	22	18	0.002
III	56	62	57	63	46	54	
IV	24	20	24	22	31	26	
Mean aortic valve area, cm <sup>2</sup>	0.7 ± 0.16	0.64 ± 0.16	0.69 ± 0.19	0.70 ± 0.20	0.71 ± 0.19	0.74 ± 0.19	<0.001
Mean aortic valve gradient, mm Hg	47 ± 16	47 ± 16	48 ± 15	48 ± 17	48 ± 16	46 ± 18	0.311
Peak aortic valve gradient, mm Hg	76 ± 23	77 ± 24	78 ± 24	76 ± 23	77 ± 24	72 ± 22	0.073
LVEF <50%	39	48	36	37	32	39	0.065

Abbreviations: AF, atrial fibrillation; CABG, coronary artery bypass grafting surgery; CAD, coronary artery disease; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; Hgb, hemoglobin; HTN, hypertension; ICD, implantable cardioverter-defibrillator; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NYHA, New York Heart Association; PCI, percutaneous coronary intervention; PPM, permanent pacemaker; PVD, peripheral vascular disease; Q, quintile; SD, standard deviation; STS, Society of Thoracic Surgeons; TAVI, transcatheter aortic valve implantation.

Categorical variables are presented as % and continuous variables are presented as mean ± SD.

in the online version of this article), there was a clear drift toward more frequent practice of conscious sedation (85% in 2014 vs 41% in 2008–2010;  $P < 0.001$ ) and transfemoral approach (91.1% in 2014 vs 80% in 2008–2010;  $P < 0.001$ ), and less implementation of balloon predilatation, which decreased from ~95% to ~55% of cases ( $P < 0.001$ ). The use of balloon-expandable devices was lowest in 2008–2010, peaked to 40% in 2012, and decreased again to ~30% in 2014. Additionally, valve-in-valve experience increased significantly in the most recent cohort and constituted 17% of all TAVI volume, compared with 4% in early years ( $P < 0.001$ ).

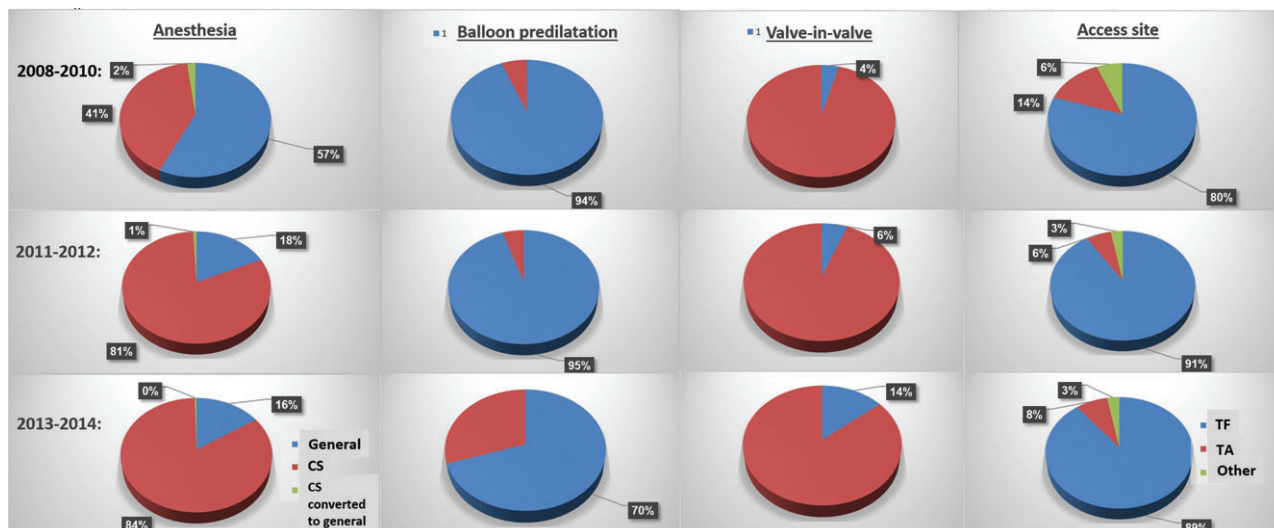
### 3.3 | Prosthetic valve function

Figure 2 summarizes the in-hospital procedural complications and outcomes according to procedure calendar year. There were no remarkable temporal trends in prosthetic valve function: TAVI time period did not influence the success rate of device implantation,

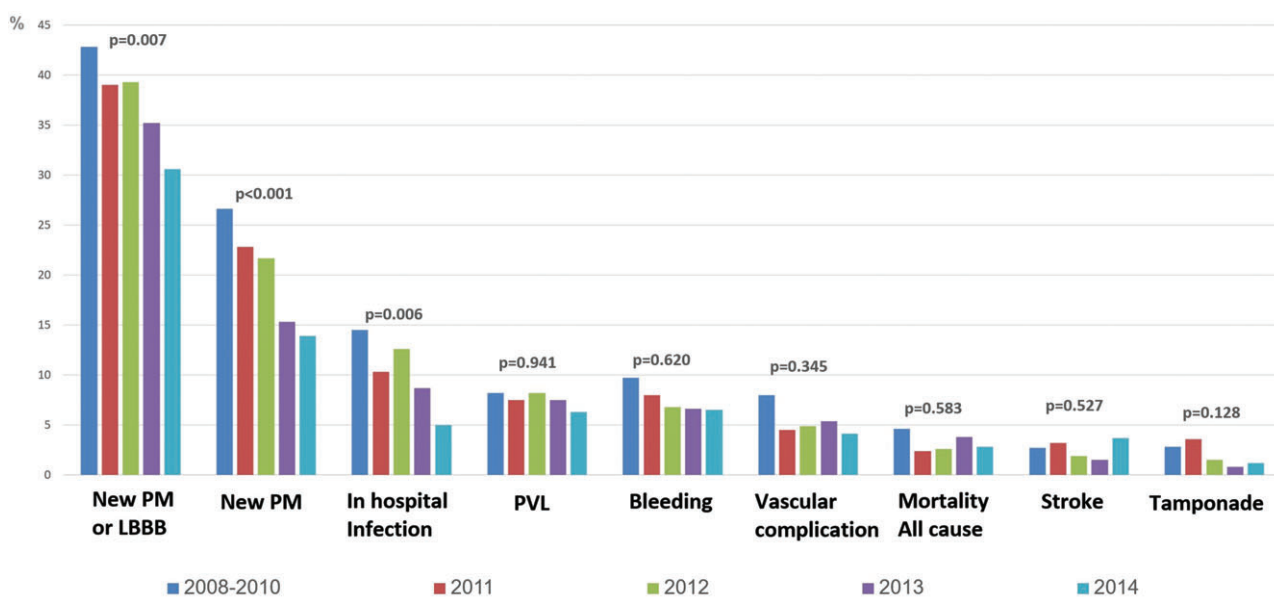
which overall was excellent and reached 94.5% (complete procedural and in-hospital outcomes description is presented in Supporting Information, Table 2, in the online version of this article). Notably, device success low tide appeared in 2012, together with the apex in utilization of balloon-expandable devices. The incidence of postprocedural > moderate paravalvular leak remained quite persistent over the course of the study and stood at approximately 6% to 8% ( $P = 0.941$ ). Although the differences were without clinically substantial change, postprocedural transaortic gradients significantly decreased over time ( $10 \pm 5$  mm Hg in 2008–2010 vs  $8.5 \pm 3.5$  mm Hg in 2014;  $P = 0.042$ ).

### 3.4 | Clinical endpoints

There was a low event rate with no apparent temporal trend in peri-procedural myocardial infarction (MI), stroke, and tamponade, as well as in the rate of major vascular complications, which was 8% in



**FIGURE 1** Temporal trends in procedural characteristics. Presented in blue are (left to right) anesthesia, balloon predilatation, valve-in-valve TAVI, and access site. For simplification, the 2011–2012 and 2013–2014 calendar-year cohorts were joined. Abbreviations: CS, conscious sedation; TA, transapical; TAVI, transcatheter aortic valve implantation; TF, transfemoral.



**FIGURE 2** In-hospital procedural complications by TAVI annual cohort. PVL is defined as  $\geq$  moderate; bleeding is defined as major or life-threatening; vascular complications are defined as major, all using the VARC-2 consensus definitions. Abbreviations: LBBB, left bundle branch block; PM, pacemaker; PVL, paravalvular leak; TAVI, transcatheter aortic valve implantation; VARC-2, Valve Academic Research Consortium-2.

2008–2010, decreased to 4.5% in 2011, and remained constant thereafter (4.1%–5.4%;  $P = 0.345$ ). On the other hand, moving from the initial to the last time cohort, there was a witnessed shift regarding several other outcome measurements. To begin with, the new PPM insertion rate decreased from 25% in 2008–2010 to 12% in 2014 ( $P < 0.001$ ), and multivariable analyses (Table 2) demonstrated that each upturn in calendar year was associated with 20% reduction in need for new PPM (odds ratio [OR]: 0.81, 95% confidence interval [CI]: 0.67–0.94,  $P = 0.004$ ) and 15% reduction in need for new PPM or LBBB (OR: 0.85, 95% CI: 0.75–0.96,  $P = 0.008$ ). Other factors that were associated with increased need for new PPM include history of right bundle branch block and utilization of self-expandable or large

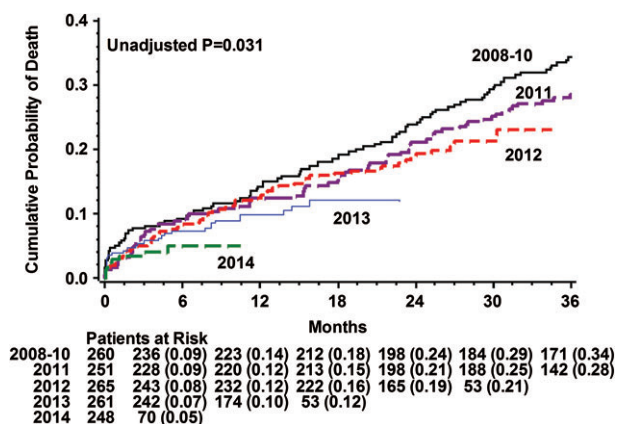
device. Likewise, there was a consistent reduction in the rate of in-hospital infections (14.5% [2008–2010] to 5% [2014];  $P = 0.006$ ), and multivariable analyses demonstrated each calendar year to be associated with 12% fewer infections (OR: 0.88, 95% CI: 0.76–1.02,  $P = 0.082$ ). Correspondingly, in-hospital admission days were halved from 12.5 ( $\pm 38$ ) days in the 2008–2010 cohort to 6.6 ( $\pm 12$ ) days in the 2014 cohort ( $P < 0.001$ ). Finally, Kaplan-Meier curves showed an inverse relationship between procedure year and cumulative mortality risk (Figure 3). By multivariate analysis (see Supporting Information, Table 3, in the online version of this article), there was no significant mortality decrease (hazard ratio per calendar-year increment: 0.96, 95% CI: 0.83–1.10,  $P = 0.576$ ).

**TABLE 2** Multivariate analysis: Risk of new PM implantation by TAVI year

	OR	95% CI	P Value
TAVI calendar year as a continuous measure			
Per 1-year increment	0.81	0.70-0.94	0.004
TAVI period categorized by quintiles			
Q1: 2008–2010	Ref		
Q2: 2011	0.54	0.28-1.02	0.057
Q3: 2012	0.69	0.37-1.26	0.221
Q4: 2013	0.23	0.10-0.50	<0.001
Q5: 2014	0.50	0.26-0.97	0.039

Abbreviations: AF, atrial fibrillation; CI, confidence interval; COPD, chronic obstructive pulmonary disease; DM, diabetes mellitus; LVEF, left ventricular ejection fraction; OR, odds ratio; PCI, percutaneous coronary intervention; PM, pacemaker; Q, quintile; Ref, reference; STS, Society of Thoracic Surgeons; TAVI, transcatheter aortic valve implantation.

Adjusted for age, sex, LVEF, STS score, DM, AF, COPD, baseline mean transaortic gradient, and history of PCI and mitral valve replacement.

**FIGURE 3** Kaplan-Meier survival curves of TAVI patients for each of the 5 time quintiles. Abbreviations: TAVI, transcatheter aortic valve implantation.

## 4 | 4 DISCUSSION

In this multicenter Israeli TAVI registry, we report on the temporal trends accompanying the vigorous era of TAVI evolution from preliminary technique to conventional therapy. Our findings show several temporal trends that deserve emphasis: (1) a shift to a lower-risk patient population; (2) adoption of less-invasive operative techniques (ie, more practice of conscious sedation, less employment of balloon predilatation, and further restriction to transfemoral access); (3) a decrease in adverse events, such as need for new PPM, LBBB, and in-hospital infections; (4) a shorter hospital stay; and (5) an increase in overall survival rate.

### 4.1 | Patient characteristics

We found that TAVI is being applied in lower-risk patients. This shifting paradigm is broadly reported both in clinical practice and in clinical trials in Europe<sup>5-9</sup> and in the United States.<sup>10-16</sup> Although the mean STS score of patients in the early cohort (2008–2010) was already within the customary intermediate STS risk range, all patients

were deemed as inoperable/high surgical risk based on other comorbidities and/or technical issues (ie, porcelain aorta, hostile chest) not captured by the STS score. A prominent element was the considerably higher proportion of patients in the early 2008–2010 cohort that were judged to be frail, in comparison to the more recent (2011–2014) cohorts: 28% vs 15% ( $P < 0.001$ ). Contemporary data demonstrate that compared with surgery, lower-risk patients do very well with TAVI,<sup>15-19</sup> with the recent Placement of Aortic Transcatheter Valves (PARTNER) IIA and PARTNER IIS3i studies providing (along with the soon-to-be-reported Safety and Efficacy Study of the Medtronic CoreValve System in the Treatment of Severe, Symptomatic Aortic Stenosis in Intermediate-Risk Subjects Who Need Aortic Valve Replacement [SURTAVI] trial) more robust answers to this issue. Refinement in technology, patient selection, and operator techniques, together with long-term durability appreciation, are expected to further expand the percutaneous approach to lower-risk patients.

### 4.2 | Procedural characteristics

The extent of valve-in-valve procedures increased significantly to constitute 17% of all TAVI volume at the end of the study. This emerging alternative for patients with a failed bioprosthetic valve at high risk for revision surgery has been explored as safe and very effective procedure,<sup>20</sup> and its frequency will most probably increase even further in the near future. One of the medical centers participating in the current study performs the highest number of valve-in-valve interventions in our country, and thus explains the high degree of valve-in-valve TAVI exhibited. We encountered an accelerated practice of using conscious sedation over the years. Despite this, there was a temporal decrease in the need to urgently convert from conscious sedation to general anesthesia during the procedures (from 2% to 0.5%;  $P < 0.001$ )—a finding that should strengthen the comfort operators feel with light anesthesia. There was a decrease in the nonfemoral approach and in use of balloon predilatation, which in sum indicates a drift on the road to more restrained, minimal procedures. Thanks to the recent advances in technology and smaller catheter platform available, procedural simplification is becoming consolidated and most certainly has some effect on outcomes, which is the next subject to be discussed.

### 4.3 | Clinical outcomes

Post-TAVI conduction abnormalities result primarily from mechanical compression by the device on the specialized adjacent conduction system. The key risk factors for this complication are CoreValve device utilization and baseline right bundle branch block, but it may also depend on other procedural factors. We found that each calendar-year increment was associated with an adjusted 20% reduction in the need for a new PPM ( $P < 0.001$ ), along with an equal balloon-expandable to self-expandable valve utilization ratio during those periods after adjusting for baseline conduction abnormalities. Consistently, each year increment was associated with an adjusted 15% reduction in requirement for a new PPM or LBBB. Holmes et al assessed the temporal trends among 26 414 patients who underwent TAVI from 2012 through 2014 in the US Transcatheter Valve Therapy (TVT) registry.<sup>14</sup> The investigators found that the most common periprocedural cardiac complication was a

need for a new PPM, which actually increased from 7.5% in 2012 to 2013 to 10.5% in 2014 ( $P$  for trend  $<0.001$ ). This contrasting trend can be explained by the fact that the CoreValve prosthesis has been included in the US registry only since 2013. The device, which has been associated with a higher incidence of conduction-system abnormalities,<sup>21</sup> most likely confounded the calendar-year influence. Indeed, we also found CoreValve implantation to be an independent risk for new PPM; but, on the contrary, the CoreValve 2008 to 2014 utilization rate remained fairly steady in the practice of the 3 participating medical centers; hence, the mechanism behind the decrease seen in conduction abnormalities most probably relates to some modifications in procedural technique, such as the decrease in balloon predilatation (see Supporting Information, Table 1, in the online version of this article) and perhaps more accurate valve sizing and positioning associated with more frequent use of preprocedural computed tomography, operator learning curve, and the appreciation that higher implantation may be optimal.<sup>22-24</sup> In line with our findings, a recent report on the temporal trends from the UK TAVI registry<sup>25</sup> did not show differences in the total need for PPM or a new LBBB, but it did find a reduction from ~30% (2007–2008) to ~15% (2012) in PPM requirement with CoreValve implantation ( $P < 0.001$ ). Although the impact of PM implantation on mortality has not been demonstrated, lowering this risk would be preferable, especially in younger patients,<sup>3</sup> as it will decrease PM-associated complications and may affect the TAVI cost-effectiveness profile, as PPM implantation accounts for the largest attributable cost for TAVI in the United States.<sup>26</sup>

The event rates for periprocedural stroke, MI, tamponade, major vascular complications, and in-hospital mortality were all small, and no temporal trends were identified. Similar periprocedural stroke rate and temporal consistent were reported in other studies,<sup>14,27,28</sup> although the TVT did demonstrate a statistically significant (but numerically/clinically very small) reduction in periprocedural MI.<sup>14</sup> Although other studies did find a temporal decrease in the rate of vascular complications,<sup>14,22,27</sup> we did not. An important consideration on the subject of vascular complications is that smaller catheter sheaths allow the pursuit after higher degree of transfemoral access, so that peripheral vasculatures that were inaccessible 5 years ago are now being accessed, instead of referring patients to alternative approaches associated with inferior results.<sup>29</sup> We sampled a subgroup of 375 transfemoral-access TAVI patients and calculated the patients with index femoral artery minimal diameter  $<6.5$  mm (which is associated with increased vascular complications).<sup>29,30</sup> We found such patients to account for 4.5% during 2008 to 2010 and 20% during 2014. This may imply that operators choose for themselves and their patients undergo some risk for a vascular complication “penalty” rate in favor of higher adherence to transfemoral access.

We found no temporal trend with regard to post-TAVI paravalvular leak ( $>$  moderate) risk, with incidence of 8.2% in 2008 to 2010 and 6.3% in 2014 ( $P = 0.941$ ). Paravalvular leak was somewhat lower over time in the TVT registry, but without clinically substantial change (from 5.5% to 4.8%). This may feel disappointing, as paravalvular leak is associated with poor outcome<sup>15,21</sup> and represents to some the Achilles heel of TAVI. Nevertheless, keeping in mind that 99% of the valves in this registry were first-generation transcatheter valves, the degree of regurgitation may change over time with the current

shift toward second-generation devices, as was already demonstrated in many recent reports.<sup>15,16,31</sup>

An additional observation was the temporal reduction in in-hospital infections and length of stay. The mean hospital stay went down from 12.5 ( $\pm 38$ ) to 6.6 ( $\pm 12$ ) days during the study ( $P < 0.001$ ). Shorter hospital stay has important implications on patient comfort and rehabilitation, as well as on cost-effectiveness. Moreover, it may serve as a good short-term surrogate indicator for the combined temporal trends in TAVI: lower-risk patients undergoing more restrained procedures with lower complication rates.

Finally, we found a significant temporal trend in survival, with improved long-term survival as the procedure calendar year advanced. There was no significant difference between the cohorts in short-term mortality rate (see Supporting Information, Table 2, in the online version of this article), and the long-term survival variance lost its significance once we adjusted for age, multiple comorbidities, and STS score (see Supporting Information, Table 3, in the online version of this article). The same findings were demonstrated in the UK TAVI registry and by others,<sup>25,27</sup> and they most likely reflect the fact that the shift in mortality is mainly driven from patient selection rather than from technical/procedural matters, as these would be expected to be projected during/early after the intervention and to be consistent after correcting for the former covariates. Nevertheless, it is possible that our study was underpowered to expose such procedural-driven mortality trends because the short-term mortality event rate was very low, so larger studies are needed to examine this issue.

#### 4.4 | Study limitations

This is a retrospective study, which carries the concern of unmeasured confounding variables and/or possible missing reported outcomes. Study results can be influenced by differences in disease assessment and documentation patterns at participating institutions. The event rates of some outcome measures (eg, stroke, MI, tamponade, in-hospital mortality) were small, and our study probably was underpowered to detect any temporal changes in these. Importantly, our aim was to define temporal trends and associations, and no cause-and-effect suppositions can be drawn.

## 5 | CONCLUSION

Temporal trends accompanying the evolution of TAVI include its increasing utilization in a lower-risk population, increased practice of conscious sedation, and adherence to the transfemoral access. Over time, TAVI patients require a shorter hospital stay and are experiencing lower rates of NPP, LBBB, and in-hospital infections. Post-TAVI survival is increasing.

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## SUPPORTING INFORMATION

Additional Supporting Information may be found online in the supporting information tab for this article.

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