International Journal of Cardiology 293 (2019) 80–83

Contents lists available at ScienceDirect

International Journal of Cardiology

journal homepage: www.elsevier.com/locate/ijcard

Short communication

# Temporal trends in procedural death and need for urgent open surgery during transcatheter aortic valve replacement: A single, high-volume center 10-year experience☆

Alessandra Laricchia [a,b,*], Antonio Mangieri [a,b], Azeem Latib [a,c], Matteo Montorfano [a], Georgios Tzanis [a], Guglielmo Gallone [a], Ottavio Alfieri [d], Antonio Colombo [a,b], Francesco Giannini [a,b]

[a] Interventional Cardiology Unit, San Raffaele Scientific Institute, Milan, Italy
[b] Interventional Cardiology Unit, GVM Care & Research Maria Cecilia Hospital, Cotignola, Ravenna, Italy
[c] Department of Cardiology, Montefiore Medical Centre, New York, USA
[d] Cardiac Surgery Unit, San Raffaele Scientific Institute, Milan, Italy

ARTICLE INFO

*Article history:*
Received 26 March 2019
Received in revised form 14 June 2019
Accepted 21 June 2019
Available online 22 June 2019

*Keywords:*
TAVR
Immediate outcomes
Procedural mortality
Safety

ABSTRACT

*Background:* Despite advancements in the safety of transcatheter aortic valve replacement (TAVR) resulting in progressively wider indications, adverse periprocedural outcomes still raise concern. Real-world outcome data are thus of primary importance to evaluate the procedural risk-benefit trade-off in the continuously changing populations undergoing TAVR.

*Methods:* We retrospectively assessed 1348 consecutive patients undergoing TAVR between 2007 and 2017. The primary endpoint was a composite of procedural mortality and need for conversion to emergent surgery, as defined by the Valve Academic Research Consortium-2 criteria. Temporal trends in baseline characteristics and outcomes were evaluated. The independent outcomes predictors were assessed through multivariate regression analysis.

*Results:* A total of 56 (4.1%) patients experienced the primary endpoint. 47 (3.5%) patients died during hospital stay, 19 (1.4%) within 72 h from the procedure. 17 patients (1.2%) needed an emergent conversion to open surgery, of whom 7 (41.2%) did not survive.

Significant temporal trends of increasing mean age (from 79.4 ± 7.4 to 81 ± 7.5, $p = 0.007$) and decreasing surgical risk (mean STS: from 9 ± 9.5 to 7.1 ± 9.8, $p = 0.010$) were observed. When dichotomized at the median procedural date (year 2014), a significant reduction in the occurrence of the primary endpoint in more recent years was observed (3.0% vs 5.2%, $p = 0.041$). This was the single primary endpoint independent predictor at multivariate analysis.

*Conclusion:* The high-volume 10-year experience in TAVR procedures at our center shows encouraging trends in procedural mortality reduction, which anyhow still occurs at a non-negligible rate, calling for further research to detect and to blunt the determinant of early procedural events.



## 1. Introduction

Since the first transcatheter aortic valve replacement (TAVR) in 2002, this procedure has markedly widened its indications [1–5]. Current European guidelines recommend TAVR for inoperable patients with severe aortic stenosis and for those at intermediate to high surgical risk [6]. Pure aortic regurgitation and bicuspid aortic valves are still under investigation [7–9].

Operator experience, better patient selection and pre-procedural planning, along with technological improvements are all factors involved in TAVR safety and diffusion. However, major procedural complications requiring conversion to open surgery or leading to periprocedural death still occur.

Registries (such as the German experience or the Edwards SAPIEN Aortic Bioprosthesis European Outcome - SOURCE) and metanalysis report as the cumulative incidence of emergent surgery is around 0.7–1.5%, with a trend toward reduction in more recent years [10–12]. However, even if few patients require conversion to emergency surgery, mortality is as high as 50% [13].

☆ All authors take responsibility for all aspects of the reliability and freedom from bias of the data presented and their discussed interpretation.

* Corresponding author at: Interventional Cardiology Unit, GVM Care & Research Maria Cecilia Hospital, Via Madonna di Genova 1, 48033 Cotignola, RA, Italy.
*E-mail address:* alaricchia@gvmnet.it (A. Laricchia).

https://doi.org/10.1016/j.ijcard.2019.06.060
0167-5273/

As a consequence, in order to decrease early adverse events, efforts should be done to understand, predict and manage these complications.

The aim of our study is to analyze temporal trends in the incidence of major procedural complications during 10 years of experience in a single, high volume, center and to identify predictors of in-hospital events leading to death and complications requiring conversion to emergency surgery.

## 2. Methods

We retrospectively analyzed data of patients who underwent TAVR in a single center (Cardiovascular Intervention Unit, San Raffaele Hospital, Milan) between 2007 and 2017. Informed consent for data collection was obtained from each patient and the study conforms to the ethical guidelines of the 1975 Declaration of Helsinki as reflected in a priori approval by the institution's human research committee.

All patients underwent baseline evaluation to establish the diagnosis, assess surgical risk and plan the procedure. Transthoracic echocardiography was performed in all patients while pre-procedural computed tomography (CT) scan was introduced from the second half of 2009 and became routine practice from the second half of 2013. Patients considered eligible for TAVR were discussed by the Heart Team to confirm the indication and plan procedural issues.

TAVR was performed using balloon-expandable, self-expandable and other deployment valves, thorough percutaneous (transfemoral, transaxillary; local anesthesia) or with minimally invasive (transapical, transaortic; general anesthesia) approaches. Device choice was at the operator discretion.

In-hospital events were defined according to the Valve Academy Research Consortium (VARC)-2 criteria [14]. The primary endpoint was a composite of procedural mortality (within 30 days from the procedure) and need for conversion to emergent surgery; secondary endpoints were the individual components of the primary endpoint and immediate procedural mortality (≤72 h post-procedure).

The incidences of post-TAVR complications are presented and causes of adverse events are summarized into three categories: a) heart failure-related (end-stage pump-failure, severe aortic regurgitation, acute myocardial infarction, arrhythmias); b) mechanical complication-related (LV or RV perforation, device embolization, aortic annulus rupture, cardiac tamponade, aortic dissection, aortic and main vessels ruptures, hemorrhagic shock, stroke); c) intensive care-related (sepsis, multi-organ failure, acute mesenteric ischemia, pulmonary embolism; definitions as per reference (15)).

We further analyzed the outcomes stratified by procedure date quartiles to evaluate temporal trends in baseline characteristics and outcomes.

Categorical variables are expressed as number and percentages, continuous variables are expressed as mean ± standard deviation or median and interquartile range as appropriate. Unpaired *t*-test or nonparametric analysis of variance ANOVA was used for comparisons of continuous variables while chi-square test was used for categorical variables. A multivariate regression analysis was performed to assess the independent determinants of the primary endpoints. All the variables with a univariate $p \ll 0.10$ were entered into the model. A two-sided $p$ value $\ll 0.05$ was considered statistically significant. Statistical analyses were performed with SPSS 20.0 software (SPSS Inc., Chicago, Illinois).

**Table 1**
comparison of baseline and procedural characteristics (A), in-hospital outcomes (B) and type of complication (C) among quartiles in which patients were divided according to the date of the procedure; STS: Society of Thoracic Surgeons risk calculator; ES: Euro Score; COPD: chronic obstructive pulmonary disease; CAD: coronary artery disease; CS: cardiac surgery; TAVR: transcatheter aortic valve replacement; BAV: balloon aortic valvuloplasty; EF: ejection fraction; CKD: chronic kidney dysfunction; GFR: glomerular filtration rate; CT: computed tomography; BE: balloon expandable; SE: self-expanding; VARC: valve academy research consortium; ICU: intensive care unit; Primary outcome: composite of conversion to emergent surgery and procedural mortality.

| Variable | Overall | Quartiles (337 patients each) | | | | *p*-Value |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| A: Baseline and procedural characteristics | | | | | | |
| Age, mean ± SD | 80.5 ± 7.8 | 79.4 ± 7.4 | 80.3 ± 8.2 | 81.3 ± 8.2 | 81 ± 7.5 | 0.007 |
| Over 80, n (%) | 776 (57.1%) | 168 (49.9%) | 192 (57%) | 217 (64.4%) | 199 (59.1%) | 0.002 |
| Male, n (%) | 647 (47.6%) | 179 (53.1%) | 158 (46.9%) | 135 (40.1%) | 175 (52%) | 0.002 |
| STS, mean ± SD | 7.7 ± 8.7 | 9 ± 9.5 | 7.8 ± 7.3 | 6.9 ± 7.8 | 7.1 ± 9.8 | 0.010 |
| STS ≫ 8, n (%) | 314 (23.1%) | 116 (34.4%) | 87 (25.8%) | 60 (17.8%) | 51 (15.1%) | 0.000 |
| Log ES, median (IQR) | 16.01 (10–27.4) | 19.9(11.6–32.2) | 10(8–12) | 14.2(9–25) | 14 (9.3–24) | 0.000 |
| Log ES ≫ 20, n (%) | 499 (36.7%) | 167 (49.6%) | 132 (39.2%) | 102 (30.3%) | 98 (29.1%) | 0.000 |
| Hypertension, n (%) | 1068 (79.2%) | 262 (77.7%) | 281 (83.4%) | 267 (79.2%) | 258 (76.5%) | 0.142 |
| Dyslipidemia, n (%) | 658 (48.8%) | 145 (43%) | 183 (54.3%) | 161 (47.8%) | 169 (50.1%) | 0.030 |
| Diabetes, n (%) | 314 (23.3%) | 88 (26.1%) | 81 (24%) | 77 (23%) | 68 (20.2%) | 0.395 |
| Smoke, n (%) | 406 (30.1%) | 127 (37.7%) | 93 (27.6%) | 84 (25%) | 102 (30.3%) | 0.005 |
| COPD, n (%) | 313 (23.2%) | 131 (38.9%) | 57 (17%) | 58 (17.2%) | 67 (20%) | 0.000 |
| Previous CAD, n (%) | 545 (40.4%) | 149 (44.2%) | 142 (42.1%) | 140 (42%) | 114 (34%) | 0.034 |
| Previous CS, n (%) | 322 (23.9%) | 92 (27.3%) | 92 (27.3%) | 70 (21%) | 68 (20.2%) | 0.034 |
| Previous TAVR, n (%) | 19 (1.4%) | 5 (1.5%) | 6 (1.8%) | 4 (1.2%) | 4 (1.2%) | 0.899 |
| Previous BAV, n (%) | 27 (2%) | 7 (2.1%) | 7 (2.1%) | 4 (1.2%) | 9 (2.7%) | 0.588 |
| Valve-in-Valve, n (%) | 85 (6.2%) | 18 (5.3%) | 19 (5.6%) | 24 (7.1%) | 24 (7.1%) | 0.672 |
| EF, mean ± SD | 52.3 ± 12.2 | 51.2 ± 13.1 | 52.9 ± 12.5 | 52.2 ± 11.2 | 53.1 ± 11.9 | 0.177 |
| EF ≤ 35%, n (%) | 172 (12.7%) | 51 (15.1%) | 43 (12.8%) | 36 (10.7%) | 42 (12.5%) | 0.386 |
| Creatinine, mean ± SD | 1.4 ± 1.4 | 1.36 ± 1.2 | 1.7 ± 2.2 | 1.33 ± 0.9 | 1.36 ± 1.1 | 0.003 |
| eGFR, mean ± SD | 49.3 ± 23.9 | 51.5 ± 22.6 | 47.5 ± 25.2 | 48.6 ± 24.5 | 49.5 ± 23.4 | 0.178 |
| CKD, n (%) | 948 (69.8%) | 229 (68%) | 249 (73.9%) | 243 (72.1%) | 227 (67.4%) | 0.338 |
| GFR ≪ 30, n (%) | 282 (20.7%) | 59 (18%) | 88 (26.1%) | 75 (22.3%) | 60 (17.8%) | 0.031 |
| Dialysis, n (%) | 46 (3.4%) | 11 (3.3%) | 14 (4.2%) | 11 (3.3%) | 10 (3%) | 0.865 |
| CT scan, n (%) | 727 (53.5%) | 26 (7.7%) | 110 (32.6%) | 289 (85.8%) | 302 (89.7%) | 0.000 |
| BE, n (%) | 517 (38.1%) | 202 (60%) | 161 (47.8%) | 89 (26.4%) | 65 (19.2%) | 0.000 |
| SE, n (%) | 602 (44.3%) | 135 (40.1%) | 128 (38%) | 124 (36.8%) | 215 (63.8%) | 0.000 |
| Different deploy, n (%) | 225 (16.7%) | 0 | 48 (14.2%) | 123 (36.5%) | 54 (16%) | 0.000 |
| B: In-hospital outcomes | | | | | | |
| VARC-2 success, n (%) | 1259 (93.4%) | 315 (93.5%) | 310 (92%) | 321 (95.2%) | 313 (92.3%) | 0.374 |
| Primary Outcome, n (%) | 56 (4.1%) | 19 (5.6%) | 17 (5%) | 11 (3.3%) | 9 (2.7%) | 0.216 |
| Emergency surgery, n(%) | 17 (1.2%) | 4 (1.2%) | 6 (1.8%) | 3 (0.9%) | 4 (1.2%) | 0.769 |
| ≤72 h mortality, n (%) | 19 (1.4%) | 6 (1.8%) | 4 (1.2%) | 5 (1.5%) | 4 (1.2%) | 0.899 |
| 30 days mortality, n (%) | 47 (3.5%) | 15 (4.4%) | 15(4.4%) | 10 (3%) | 7 (2.1%) | 0.249 |
| C: Type of complication | | | | | | |
| Mechanical, n (%) | 28 (2%) | 9 (2.7%) | 8 (2.4%) | 6 (1.8%) | 5 (1.5%) | 0.692 |
| Heart Failure, n (%) | 14 (1%) | 5 (1.5%) | 3 (0.9%) | 3 (0.9%) | 3 (0.9%) | 0.834 |
| ICU related, n (%) | 15 (1.1%) | 4 (1.2%) | 8 (2.4%) | 2 (0.6%) | 1 (0.3%) | 0.050 |

## 3. Results

During the study period, 1348 patients underwent TAVR in our center, with the number of procedures progressively increasing each year (Supplementary Fig. 1A). Mean age was 80.5 ± 7.8 and patients presented an intermediate to high surgical risk profile (mean log ES 21.3 ± 16.2, std. ES 10.1 ± 4.2, STS 7.8 ± 8.7) (Table 1A). 23 patients with bicuspid valves, 14 with pure aortic regurgitation and 85 patients undergoing TAVR due to surgical bioprosthesis failure were included in this analysis. 53.5% of patients underwent pre-procedural CT scan to evaluate vascular access sites, aortic annulus dimensions, calcification extension and aortic angulation.

The most frequent access route used for TAVR was transfemoral (1183, 87.8%), followed by transapical (90, 6.7%), transaxillary (58, 4.3%) and transaortic (17, 1.3%).

**Table 2**
univariate and multivariate regression model for clinical, echocardiographic and procedural parameters; COPD: chronic obstructive pulmonary disease; BMI: body mass index; GFR: glomerular filtration rate; CKD: chronic kidney disease, GFR ≪ 60 ml/min/1.73 $m^2$; severe CKD: GFR ≤ 30 ml/min/1.73 $m^2$; AF: atrial fibrillation; CAD: coronary artery disease; CS: cardiac surgery; BAV: balloon aortic valvuloplasty; ViV: valve-in-valve; LVEF: left ventricular ejection fraction; low EF: ≤30%; G: gradient; AVA: aortic valve area; CT: computed tomography; high STS: ≥8%; low STS: ≪8%; high LogES: ≥20%; old generation includes: Edwards Sapien, Sapien XT, CoreValve; new generation includes: Sapien 3, Evolut R, Evolut Pro, Direct Flow, Lotus, Acurate Neo, Portico, Centera, Jena, Engager; SE: self-expanding, including Evolut R, Evolut Pro, Acurate Neo, Portico, Centera, Jena, Engager; BE: balloon expandable, including Edwards Sapien, Sapien XT, Sapien 3; Other deployment: neither SE nor BE, includes Direct Flow and Lotus devices.

| Predictors of primary outcome | | | | |
|---|---|---|---|---|
| | Univariate analysis | | Multivariate analysis | |
| Variable | OR (95% CI) | p-Value | OR (95% CI) | p-Value |
| Male | 1.13 (0.66–1.93) | 0.663 | | |
| Female | 0.89 (0.52–1.52) | 0.663 | | |
| Age | 0.98 (0.95–1.01) | 0.209 | | |
| Age ≫ 80 yo | 0.81 (0.47–1.40) | 0.459 | | |
| Hypertension | 0.48 (0.27–0.85) | **0.012** | | |
| Diabetes | 1.14 (0.77–1.70) | 0.505 | | |
| Dyslipidemia | 0.59 (0.33–1.03) | **0.062** | | |
| Smoke | 0.95 (0.70–1.30) | 0.730 | | |
| COPD | 0.64 (0.31–1.31) | 0.223 | | |
| BMI | 0.95 (0.89–1.02) | 0.122 | | |
| Creatinine | 1.08 (0.95–1.23) | 0.246 | | |
| Mean eGFR | 0.98 (0.97–0.99) | **0.019** | | |
| CKD | 1.70 (0.82–3.54) | 0.154 | | |
| Severe CKD | 1.94 (1.06–3.54) | **0.030** | | |
| AF | 1.18 (0.64–2.16) | 0.595 | | |
| Previous CAD | 0.91 (0.52–1.58) | 0.729 | | |
| Previous CS | 1.10 (0.59–2.03) | 0.781 | | |
| Previous TAVR | 4.60 (1.3–16.30) | **0.018** | | |
| Previous BAV | 0.90 (0.12–6.77) | 0.920 | | |
| ViV | 1.18 (0.78–4.53) | 0.158 | | |
| LVEF | 0.98 (0.96–1) | **0.039** | | |
| Low EF | 1.36 (0.65–2.82) | 0.415 | | |
| Mean G | 0.97 (0.96–1) | 0.188 | | |
| Mean AVA | 1.02 (0.24–4.31) | 0.973 | | |
| CT scan | 1.10 (0.64–1.90) | 0.729 | | |
| Mean STS | 1.03 (1.01–1-05) | **0.002** | | |
| High STS | 1.78 (1.00–3.16) | **0.047** | 1.82 (0.99–3.37) | 0.055 |
| Low STS | 0.45 (0.26–0.77) | **0.004** | | |
| STS MM | 1.02 (1.00–1.04) | **0.007** | | |
| Log ES | 1.03 (1.02–1.04) | **0.000** | | |
| High Log ES | 1.81 (1–3.28) | **0.049** | | |
| 3rd-4th Quartile | 0.56 (0.32–0.98) | **0.041** | 0.5 (0.26–0.94) | **0.031** |
| Emergency | 37.2 (6.1–27.7) | **0.000** | | |
| Old Generation | 1.60 (0.92–2.73) | **0.100** | | |
| New Generation | 0.63 (0.37–1.1) | **0.100** | | |
| Prosthesis Generation | 0.45 (0.3–0.83) | **0.010** | | |
| SE | 1.12 (0.65–1.92) | 0.691 | | |
| BE | 0.77 (0.44–1.37) | 0.382 | | |
| Other Deploy | 0.98 (0.47–2.02) | 0.947 | | |

Bold numbers correspond to those statistically significant

We implanted 13 different valve types including balloon-expandable ($n$ = 517), self-expanding ($n$ = 602) and other deployment-modality valves ($n$ = 225). Four patients (0.003%) undergoing TAVR procedure did not receive any valve due to major procedural complications occurring before valve deployment.

In the analysis by procedure date quartiles, we observed significant temporal trends of increasing mean age at procedure and decreasing surgical risk. The use of pre-procedural CT scan increased over time and the type of device progressively shifted from balloon-expandable to self-expanding prostheses (Table 1A).

According to VARC-2 criteria, procedural success was reached in 1259 (93.4%) patients (Table 1B). The incidence of stroke, new pacemaker implantation, acute kidney injury and moderate to severe paravalvular leak were 1.9%, 15.9%, 8.4% and 13.7%, respectively.

Overall, the primary endpoint occurred in 56 (4.1%) patients; 47 patients (3.5%) experienced procedural mortality, of which 19 patients (1.4%) died within 72 h of the procedure. Seventeen patients (1.2%) needed an emergent conversion to open surgery and among them 7 (41.2%) did not survive [4 died during or soon after emergency surgery, 3 died later for subsequent complications].

The occurrence of the primary and secondary endpoints did not have any significant variation among procedural date quartiles. Of note, analyzing patients dichotomized at the median procedural date (2014), we observed a significant reduction in the occurrence of the primary endpoint in more recent years (3.0% vs 5.2%, $p$ = 0.041).

Mechanical complications were the most frequent causes of immediate adverse events, while heart failure and intensive care complications were more frequently related to delayed in-hospital adverse events (Supplementary Table 1). The incidence of mechanical complications and heart failure-related adverse events remained steady over time, while a significant decrease in intensive care-related events was observed (Table 1C, Supplementary Fig. 1B).

At univariate analysis, significant predictors of the primary outcome were a higher surgical risk (by both STS and logistic EuroScore scores), old generation devices, poor kidney function, TAVR in TAVR procedures and TAVR performed emergently. Hypertension, dyslipidemia and a more recent procedural date (third and fourth vs. first and second quartiles) were protective features. No interactions of older age and lower EF with outcomes were observed.

At multivariate analysis, a more recent procedural date was the single feature independently associated with the outcome (HR 0.5, 95% confidence interval 0.26–0.94, $p$ = 0.031) (Table 2).

## 4. Discussion

From initial experiences to more recent studies, the overall 30-day mortality rate of TAVR has decreased from ≫9% to ≪4% [2,3,16,17], with a need for conversion to emergency surgery as low as 1% [13]. In line with these observations, we found an overall procedural mortality rate of 3.5% and a need for conversion to surgery rate of 1.2% [17–19]. Consistently with previous literature, we also observed that the risk profile of patients undergoing TAVR improved over time, reflecting the expansion of TAVR indications to lower risk patients. Additionally, during the study period first generation devices were “replaced” by newer ones, with the advantage of enhanced technologies in prosthesis performance and smaller delivery systems; pre-procedural planning benefited from a progressively wider use of CT scan too.

While we could not detect significant temporal trends in outcomes improvements in the by-procedure date quartiles analysis, we found a significant improvement in the primary endpoint when the same analysis was carried in patients dichotomized at the median value corresponding to the year 2014.

Importantly, this finding was independent of the STS and EuroScore at multivariate analysis, as well as we could not find any significant association between pre-procedural CT scan employment or device generation and the primary outcome (possibly because of covariation

with more recent procedural data); we speculate that a combination of the above factors, including pre-procedural assessment, device evolution, operator experience and post-procedural management, can contribute to improved outcomes in more recent times. Improvement in post-TAVR patient management is further suggested by the reduction observed in intensive care-related adverse events. These hypotheses are further supported by existing literature demonstrating the association of the above factors with improved outcomes [19].

The main limitation of this study is the small proportion of events that limits the identification of differences and predictors with a good statistical power. This is however due to the single-center nature of this study, which in turns allow for an unbiased assessment of the evolution of TAVR procedure in a high-volume real-world setting, with a long-standing experience.

In conclusion, the high-volume 10-year experience in TAVR procedures at our center shows that, despite an encouraging temporal trend toward adverse events reduction, a not negligible risk of procedural mortality or need for conversion to emergency surgery still persists: further research is needed to detect the determinants of early procedural adverse outcomes and find the optimal means to effectively reduce them in clinical practice, especially in the low risk patients era [5].

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijcard.2019.06.060.

## Disclosures

Nothing to disclose.

## References


[1] Cribier A, Eltchaninoff H, Bash A, et al. Percutaneous transcatheter implantation of an aortic valve prosthesis for calcific aortic stenosis: first human case description. Circulation 2002;106:3006–8.

[2] M.B. Leon, C.R. Smith, M.J. Mack, et al., Transcatheter or surgical aortic-valve replacement in intermediate-risk patients, N. Engl. J. Med. 374 (2016) 1609–1620.

[3] Leon MB, Smith CR, Mack M, et al. PARTNER trial investigators. Transcatheter aortic-valve implantation for aortic stenosis in patients who cannot undergo surgery. N. Engl. J. Med. 2010 Oct 21;363(17):1597–607.

[4] Reardon MJ, Van Mieghem NM, Popma JJ, et al. SURTAVI Investigators. Surgical or transcatheter aortic-valve replacement in intermediate-risk patients. N. Engl. J. Med. 2017 Apr 6;376(14):1321–1331.

[5] Mack MJ, Leon MB, Thourani VH, et al; PARTNER 3 Investigators. Transcatheter Aortic-Valve Replacement with a Balloon-Expandable Valve in Low-Risk Patients. N Engl J Med. 2019 Mar 17. doi:https://doi.org/10.1056/NEJMoa1814052. [Epub ahead of print] PubMed PMID: 30883058.

[6] H. Baumgartner, V. Falk, J.J. Bax, M. De Bonis, et al., ESC Scientific Document Group. 2017 ESC/EACTS guidelines for the management of valvular heart disease, Eur. Heart J. 38 (36) (2017 Sep 21) 2739–2791.

[7] Thielmann M, Tsagakis K, El Gabry M, Jakob H, Wendt D. Transcatheter aortic valve implantation (TAVI) in patients with aortic regurgitation. Ann Cardiothorac Surg. 2017 Sep;6(5):558–560.

[8] Perlman GY, Blanke P, Webb JG. Transcatheter aortic valve implantation in bicuspid aortic valve stenosis. EuroIntervention. 2016 Sep 18;12(Y):Y42–5.

[9] Rosato S, Santini F, Barbanti M, et al. OBSERVANT Research Group. Transcatheter aortic valve implantation compared with surgical aortic valve replacement in low-risk patients. Circ Cardiovasc Interv. 2016 May; 9(5):e003326.

[10] Eggebrecht H, Schmermund A, Kahlert P, Erbel R, Voigtländer T, Mehta RH. Emergent cardiac surgery during transcatheter aortic valve implantation (TAVI): a weighted meta-analysis of 9,251 patients from 46 studies. EuroIntervention. 2013 Jan 22;8(9):1072–80.

[11] H. Eggebrecht, R.H. Mehta, P. Kahlert, et al., Emergent cardiac surgery during transcatheter aortic valve implantation (TAVI): insights from the Edwards SAPIEN Aortic Bioprosthesis European Outcome (SOURCE) registry, EuroIntervention 10 (2014) 975–981.

[12] G. Schymik, M. Heimeshoff, P. Bramlage, et al., Ruptures of the device landing zone in patients undergoing transcatheter aortic valve implantation: an analysis of TAVI Karlsruhe (TAVIK) patients, Clin. Res. Cardiol. 103 (2014) 912–920.

[13] Eggebrecht H, Vaquerizo B, Moris C, et al. European Registry on Emergent Cardiac Surgery during TAVI (EuRECS-TAVI). Incidence and outcomes of emergent cardiac surgery during transfemoral transcatheter aortic valve implantation (TAVI): insights from the European Registry on Emergent Cardiac Surgery during TAVI (EuRECS-TAVI). Eur. Heart J. 2018 Feb 21;39(8):676–684.

[14] Kappetein AP, Head SJ, Généreux P, et al. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document. J. Am. Coll. Cardiol. 2012 Oct 9;60(15):1438–54.

[15] Rhodes A, Evans LE, Alhazzani W, et al. Surviving Sepsis Campaign: International Guidelines for Management of Sepsis and Septic Shock: 2016. Intensive Care Med. 2017 Mar;43(3):304–377.

[16] Ludman PF, Moat N, de Belder MA, et al. UK TAVI Steering Committee and the National Institute for Cardiovascular Outcomes Research. Transcatheter aortic valve implantation in the United Kingdom: temporal trends, predictors of outcome, and 6-year follow-up: a report from the UK Transcatheter Aortic Valve Implantation (TAVI) Registry, 2007 to 2012. Circulation. 2015 Mar 31;131(13):1181–90.

[17] Auffret V, Lefevre T, Van Belle E, et al. FRANCE TAVI Investigators. Temporal trends in transcatheter aortic valve replacement in France: FRANCE 2 to FRANCE TAVI. J. Am. Coll. Cardiol. 2017 Jul 4;70(1):42–55.

[18] Moreno R, Calvo L, Salinas P, et al. Causes of peri-operative mortality after transcatheter aortic valve implantation: a pooled analysis of 12 studies and 1223 patients. J Invasive Cardiol. 2011 May;23(5):180-4.

[19] Terzian Z, Urena M, Himbert D, et al. Causes and temporal trends in procedural deaths after transcatheter aortic valve implantation. Arch Cardiovasc Dis. 2017 Nov;110(11):607–615.