Surgical explantation of failed transcatheter heart valves: indications and results

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Original Article

Abstract

Given the recent surge in transcatheter heart valve replacement (THVR), cardiac surgeons will surely face the challenge of eventual explantation. The aim of this study was to determine indications for reoperation, while exploring pertinent technical aspects and survival after THV explantation in a cohort originally deemed high risk or even inoperable. Between February 2008 and March 2019, 31 patients with failed transcatheter aortic valve replacement (TAVR) underwent surgical explantations at our facility. Data were prospectively collected for retrospective analysis of procedural indications, technical issues, and postoperative survival. The major reason for TAVR removal was bioprosthetic valve failure (BVF) due to infective endocarditis (IE: 16/31 [51.6%]), non-structural (NSVD: 14/31 [45.2%]) and structural (SVD: 1/31 [3.2%]) valve deterioration accounting for the rest. Mean age at THV explantation was 76.3 ± 8.3 years, and median time from TAVR to explantation was 153 days (0 days–56.6 months). Median ICU and hospital stay were 6 days (1–44 days) and 23 days (8–62 days), respectively. Thirty-day and 1-year survival rates were 74.2% and 67.2%, respectively. Mean cardiopulmonary bypass time was 124.6 ± 46.8 min, and mean aortic cross-clamp time was 84.3 ± 32.9 min. There was no need for unplanned aortic root repair owing to tissue damage during dissection of the TAVR from surrounding tissue. The most common reason for THV explantation was (a) BVF for IE and (b) BVF secondary to NSVD. Although 30-day and 1-year mortality rates in this multimorbid cohort were predictably high, no procedural mortalities occurred.

Keywords Transcatheter aortic valve implantation · TAVR · THV · Surgical explantation

Introduction

Transcatheter aortic valve replacement (TAVR) is now a well-established procedure, no longer reserved for high-risk candidates only. In patients of intermediate risk, it is considered equivalent or superior to surgical aortic valve replacement (SAVR) [1, 2]. Therefore, increasing utilization of TAVR in intermediate and even low-risk patients can be expected. This may also present cardiothoracic surgeons with growing numbers of ensuing surgical explantations. Although data on feasibility, safety, and clinical outcomes of TAVR are rapidly accruing, less is known about outcomes of surgical THV explantation and subsequent SAVR.

Our intent was to determine indications for THV explantation, looking also at technical aspects of such procedures and survival rates in a cohort otherwise considered high risk or even inoperable.

Patients and methods

Study design and patient population

All patients undergoing surgical explantation of a THV at our center were identified via an institutional database. The intent was to gather information on THV explantation as a stand-alone procedure. All instances of emergency
intraoperative conversion from TAVR to SAVR were summarily excluded. Data were collected prospectively and analyzed in retrospect, reporting mortality according to Valve Academic Research Consortium (VARC)-2 criteria [3]. Indications for THV removal were categorized using standard definitions of structural deterioration and valve failure in assessing long-term durability of transcatheter and surgical aortic bioprosthetic valves [4].

Study endpoints

The primary study endpoint was to identify chief indications for THV removal. Secondary study endpoints were early and mid-term survival and analysis of specific surgical considerations for THV explantation.

Surgical technique

TAVR explantation procedures were performed through median or partial upper sternotomy and under routine cardiopulmonary bypass (CPB) support. Exposure of the THV was achieved through standard aortotomy.

Statistical analysis

Categorical variables were expressed as percentages, reporting continuous variables as mean (± SD) or median (range) values. Thirty-day and 1-year survival rates were plotted by Kaplan–Meier method. All analytics were driven by customary software (SPSS v25/IBM Corp/Armonk/NY/USA).

Results

Baseline patient characteristics

Between February 2008 and March 2019, a total of 31 patients submitted to surgical explantation of failing THV. During the same time period, 2568 TAVR procedures were performed in our centre. There were 23 men (74.2%), and the mean age was 76.3 ± 8.3 years. Median time between TAVR and valve explantation was 153 days (0 days–56.6 months). Initial TAVR in 16 patients (51.6%) were performed at our institution. Prior to TAVR, the mean Society of Thoracic Surgeons (STS) score was 3.0 ± 1.2%, and the mean logistic European System for Cardiac Operative Risk Evaluation (EuroSCORE) ranking was 12.6 ± 9.3%. Before TAVR explants, the corresponding values were 5.9 ± 5.0% and 25.1 ± 16.8%. Five patients (16.1%) had histories of prior conventional cardiac surgery, including aortic valve surgery. Baseline procedural patient characteristics are shown in Table 1, with more detailed profiling of patients in Table 2. Explantation of a CoreValve prosthesis (Medtronic/Dublin/Ireland) in a patient with IE (Infective Endocarditis) is depicted in Fig. 1.

Indications for transcatheter heart valve explantation

The most common indication for explantation was bioprosthetic valve failure (BVF) secondary to IE (16/17) or severe hemodynamic structural valve deterioration (SVD) (1/17), all explants undertaken after a 408-day

| Table 1 Baseline procedural patient characteristics |
|---------------------------------------------|
| Sex, n (%) |
| Male | 23 (74.2%) |
| Female | 8 (26.8%) |
| Age, years (mean ± SD) | 76.3 ± 8.3 |
| Previous cardiac surgery, n (%) | 5 (16.1%) |
| Risk prior to TAVR, % (mean + SD) |
| STS score | 3.0 ± 1.2 |
| Logistic EuroSCORE | 12.6 ± 9.3 |
| Risk at TAVR explantation, % (mean ± SD) |
| STS score | 5.9 ± 5.0 |
| Logistic EuroSCORE | 25.1 ± 16.8 |
| Indication for explantation, n (%) |
| IE | 16 (51.6%) |
| NSVD | 14 (32.3%) |
| Severe hemodynamic SVD | 1 (3.9%) |
| Time from TVR to explantation, median (range) | 153 days (0 days–56.6 months) |
| Follow-up after AVR, median (range) | 364 days (3 days–80 months) |

SD standard deviation, TAVR transcatheter aortic valve replacement, IE infective endocarditis, NSVD non-structural valve deterioration, SVD structural valve deterioration, AVR aortic valve replacement
### Table 2: Comprehensive patient profiles

| Patient | Age at time of TAVR explanation (years) | Sex | TAVR device | logEuroSCORE at time of TAVR procedure | STS score at time of AVR procedure | Previous cardiac surgery (yes/no, CABG/valve) | LVEF (%) | Indication for explantation | Time between TAVR and AVR procedure (days) | CPB time (min) | Cross-clamp time (min) | Concomitant procedure | Hospital stay (days) | ICU stay (days) | Follow-up after AVR (days) | Status |
|----------|----------------------------------------|-----|-------------|----------------------------------------|------------------------------------|--------------------------------------------|---------|----------------------------|---------------------------------------------|-----------------|-------------------------|---------------------|-------------------|-----------------|------------------------|---------|
| 1        | 83                                     | Male| SEV         | 10,32                                  | 7,4                                | No                                         | 50      | NSVD                       | 11                           | 96              | 56                     | None               | 21                | 5              | 2060                  | Alive  |
| 2        | 80                                     | Male| SEV         | 6                                       | 2,5                                | No                                         | 55      | NSVD                       | 7                            | 108             | 84                     | None               | 25                | 4              | 472                   | Dead    |
| 3        | 75                                     | Female| SEV       | 9                                       | 21                                 | No                                         | 60      | NSVD                       | 1                            | 89              | 60                     | None               | 8                 | 3              | 2                     | Dead    |
| 4        | 82                                     | Male| SEV         | 26,7                                    | 4,6                                | No                                         | 33      | NSVD                       | 8                            | 100             | 70                     | MVR                | 44                | 44             | 25                    | Dead    |
| 5        | 71                                     | Female| BEV       | 25,54                                   | 4,25                               | Yes/valve (AVR homograft)                  | 50      | IE                         | 186                          | 106             | 78                     | None               | 14                | 9              | 2433                  | Alive   |
| 6        | 80                                     | Female| SEV       | 20,5                                    | 3,5                                | No                                         | 30      | NSVD                       | 8                            | 73              | 50                     | None               | 23                | 12             | 2204                  | Alive   |
| 7        | 65                                     | Male| BEV         | 29,23                                   | 4,5                                | No                                         | 34      | IE                         | 462                          | 153             | 71                     | CEA                 | 16                | 12             | 255                   | Alive   |
| 8        | 72                                     | Male| BEV         | 6,55                                    | 1,8                                | No                                         | 55      | NSVD                       | 27                           | 224             | 94                     | CABG               | 21                | 2              | 2212                  | Alive   |
| 9        | 70                                     | Male| BEV         | 10,2                                    | 1,6                                | No                                         | 45      | NSVD                       | 3                            | 201             | 103                    | None               | 14                | 5              | 1152                  | Alive   |
| 10       | 76                                     | Female| BEV       | 18,49                                   | 4,7                                | No                                         | 60      | IE                         | 147                          | 174             | 143                    | MVR + CABG         | 16                | 1              | 1417                  | Alive   |
| 11       | 78                                     | Female| BEV       | 28,38                                   | 7,68                               | No                                         | 60      | NSVD                       | 8                            | 64              | 43                     | None               | 32                | 1              | 478                   | Alive   |
| 12       | 80                                     | Male| SEV / BEV  | 44,66                                   | 3,42                               | Yes/valve (AVR, HAART-ring)                | 50      | NSVD                       | 61                           | 107             | 65                     | None               | 10                | 2              | 502                   | Alive   |
| 13       | 79                                     | Male| SEV         | 45,4                                    | 13,8                               | Yes/valve (AVR, CABG)                      | 60      | IE                         | 579                          | 138             | 100                    | None               | 62                | 43             | 1207                  | Alive   |
| 14       | 49                                     | Female| SEV       | 3,13                                    | 0,9                                | No                                         | 40      | severe hemodynamic SVD     | 1596                         | 100             | 81                     | None               | 14                | 3              | 567                   | Alive   |
| 15       | 77                                     | Male| SEV         | 17,47                                   | 3,88                               | Yes/valve (AVR, CABG)                      | 55      | NSVD                       | 566                          | 132             | 87                     | None               | 18                | 1              | 364                   | Alive   |
| 16       | 84                                     | Male| SEV 2x      | 17,51                                   | 2,37                               | No                                         | 46      | NSVD                       | 1                            | 76              | 49                     | None               | 42                | 35             | 43                    | Dead    |
| 17       | 75                                     | Male| BEV 2x      | 26,7                                    | 3,2                                | Yes/valve (AVR Toronto Root)               | 61      | IE                         | 1722                         | 178             | 130                    | CABG               | 25                | 5              | 667                   | Alive   |
| 18       | 75                                     | Male| BEV         | 16,88                                   | 2,53                               | No                                         | 45      | IE                         | 83                           | 87              | 63                     | None               | 35                | 5              | 897                   | Alive   |
Table 2 (continued)

| Patient number | Age at time of TAVR explantation (years) | Sex | TAVR device | logEuroSCORE at time of AVR procedure | STS score at time of AVR procedure | Previous cardiac surgery (yes/no, CABG/valve) | LVEF (%) | Indication for explantation | Time between TAVR and AVR procedure (days) | CPB time (min) | Cross-clamp time (min) | Concomitant procedure | Hospital stay (days) | ICU stay (days) | Follow-up after AVR (days) | Status |
|----------------|-----------------------------------------|-----|--------------|--------------------------------------|-----------------------------------|---------------------------------------------|---------|---------------------------|---------------------------------------------|----------------|-------------------------|----------------------|----------------------|----------------|--------------------------|--------|
| 19             | 77                                      | Male | SEV          | 28.75                                | 3.59                              | No                                          | 45      | NSVD                      | 449                         | 228            | 154                     | MVR + TVR + replacement ascending aorta | 23       | 14                      | 14                     | Dead                 |
| 20             | 78                                      | Male | BEV          | 64.53                                | 2.78                              | No                                          | 35      | IE                        | 233                         | 125            | 95                      | None                | 20       | 6                       | 662                    | Alive                |
| 21             | 86                                      | Male | BEV          | 29.71                                | 4.49                              | No                                          | 43      | IE                        | 876                         | 107            | 81                      | CABG                | 31       | 31                      | 30                     | Dead                 |
| 22             | 75                                      | Male | BEV          | 39.60                                | 8.56                              | No                                          | 41      | IE                        | 153                         | 152            | 109                     | MVR + TVR           | 21       | 7                       | 245                    | Alive                |
| 23             | 81                                      | Male | SEV          | 7.3                                  | 2.1                               | No                                          | 56      | NSVD                      | 0                           | 158            | 86                      | None                | 11       | 5                       | 395                    | Alive                |
| 24             | 82                                      | Female | SEV         | 53.6                                 | 16.6                             | No                                          | 45      | IE                        | 169                         | 67             | 44                      | None                | 23       | 23                      | 19                     | Dead                 |
| 25             | 83                                      | Male | BEV          | 37.13                                | 14.4                             | No                                          | 50      | IE                        | 757                         | 54             | 36                      | None                | 29       | 22                      | 22                     | Dead                 |
| 26             | 79                                      | Male | BEV          | 16.34                                | 2.84                             | No                                          | 57      | IE                        | 1594                        | 114            | 97                      | None                | 12       | 2                       | 143                    | Alive                |
| 27             | 53                                      | Male | SEV          | 26.8                                 | 14.4                             | No                                          | 45      | IE                        | 490                         | 117            | 89                      | MVR                 | 11       | 11                      | 11                     | Dead                 |
| 28             | 71                                      | Male | BEV          | 4.92                                 | 1.566                            | No                                          | 45      | NSVD                      | 76                          | 99             | 63                      | VSD-closure        | 62       | 7                       | 161                    | Dead                 |
| 29             | 82                                      | Male | SEV          | 20.16                                | 7.696                            | No                                          | 65      | IE                        | 328                         | 110            | 66                      | None                | 50       | 29                      | 49                     | Alive                |
| 30             | 84                                      | Male | BEV          | 19.56                                | 3.753                            | No                                          | 55      | IE                        | 408                         | 209            | 179                     | MVR                 | 25       | 4                       | 75                     | Alive                |
| 31             | 83                                      | Male | BEV          | 68.79                                | 6.404                            | No                                          | 50      | IE                        | 45                          | 116            | 88                      | None                | 26       | 25                      | 25                     | Dead                 |

TAVR transcatheter aortic valve replacement, STS score Society of Thoracic Surgeon score, CABG coronary artery bypass graft, LVEF left ventricular ejection fraction, AVR aortic valve replacement, CPB cardiopulmonary bypass, ICU Intensive Care Unit, NSVD non-structural valve deterioration, SVD structural valve deterioration, IE infective endocarditis, MVR mitral valve replacement, CEA carotid endarterectomy, TVR tricuspid valve repair, LVOT left ventricular outflow tract, PPM prosthesis-patient-mismatch, BEV balloon-expandable valve, SEV self-expandable valve
median (45–1722 days). Second in frequency was BVF secondary to non-structural valve deterioration (NSVD: 14/31 [45.2%]), including paravalvular leakage (PVL, 10/14), THV dislocation (2/14), prosthesis-patient mismatch (PPM, 1/14), and failed aortic reconstruction (1/14). In patients presenting this way, THV explantation was performed after a median of 8 days (0–566 days). PCR test results were available in 10 patients (negative 7/10, positive 3/10) with IE. There was a variety of causative organisms in patients with IE. Information was available in 15/16 cases. *Staphylococcus aureus* (3/15), *Staphylococcus epidermidis* (3/15), *Staphylococcus aureus* (2/15), *Staphylococcus capitis*/Abiotrophia defectiva/Staphylococcus haemolyticus/Lactococcus garciiae/Cardiobacter hominis/Streptococcus agalactiae/Streptococcus mitis* (1/15).

Explanted prostheses

There were two patients with existing THV implants during THVR procedures. Consequently, 33 prostheses were explanted from 31 patients, including 18 self-expandable valves (SEVs: Medtronic CoreValve, 12; Medtronic Evolut R, 2; Medtronic Engager, 1; Edwards Centera, 1; Symetis [Boston Scientific/Marlborough/MA/USA], 2) and 15 balloon-expandable valves (BEVs: Edwards SAPIEN XT, 9; Edwards SAPIEN 3, 6).

SEVs were explanted for BVF secondary to NSVD (n = 11), IE (n = 6), or SVD (n = 1). BEVs were explanted for BVF secondary to IE (n = 10) or NSVD (n = 5). One patient with both SEV and BEV implants was discounted when calculating respective operative times.

### Technical aspects of transcatheter heart valve explantation

In 24 of 31 patients, there were no substantial adhesions to hamper THV removal from native aortic annulus. For the remainder of patients (SEV, 1; BEV, 6), explantation was described as arduous, requiring dissection of dense adhesions to prevent collateral tissue damage. BVF was attributable to IE (n = 6) or NSVD (n = 1).

### Operative results and clinical outcomes

At explantation, patients underwent median re-sternotomy or partial sternotomy and AVR using either a bioprosthesis (n = 30) or a mechanical prosthesis (n = 1). Peri- and intraoperative data are summarized in Tables 3 and 4.

A total of 20 patients (NSVD, 10; IE, 9; SVD, 1) underwent THV explantation (SEV, 13; BEV, 8) and subsequent SAVR as isolated cardiac procedures. In eleven patients (35.5%), concomitant procedures were performed as follows: coronary artery bypass graft (CABG), 3; carotid endarterectomy (CEA), 1; mitral valve replacement (MVR), 3; MVR + CABG, 1; MVR + tricuspid valve repair (TVR), 1; MVR + TVR and replacement of ascending aorta, 1; and closure of ventricular septal defect (VSD), 1.

MVR was necessary due to mitral valve IE, 3 and concomitant mitral valve insufficiency, 3.

Median ICU stay was 5 days (1–44 days) in patients with NSVD and 10 days (1–43 days) in patients with IE.

### Table 3 Ancillary peri- and intraoperative data

| Concomitant procedures | n (%)  |
|------------------------|--------|
| CABG                   | 3      |
| MVR                    | 1      |
| MVR + CABG             | 1      |
| MVR + TVR + ascending aorta replacement | 1 |
| MVR + TVR              | 1      |
| CEA                    | 1      |
| CPB time, mean ± SD, min | 124.6 ± 46.8 |
| Aortic cross-clamp time, mean ± SD, min | 84.3 ± 32.9 |
| Total operative time (mean ± SD), min | 268.2 ± 89.3 |
| ICU stay, mean (range) | 6 (1–44) |
| Hospital stay, mean (range), days | 23 (8–62) |

*CABG* coronary artery bypass graft, *CPB* cardiopulmonary bypass, *ICU* Intensive Care Unit, *MVR*: mitral valve replacement, *CEA* carotid endarterectomy, *TVR* tricuspid valve repair.
Median hospital stay was 10 days (8–62 days) for NSVD and 24 days (11–62 days) for BVF ($p=0.662$).

Eleven patients died during follow-up (IE, 6; NSVD, 5). Median follow-up time after THV explantation was 364 days (2–2433 days). Median follow-up time after THV explantation was 433 days (2–2212 days) for NSVD-related BVF and 194 days (11–2433 days) for IE-related BVF. Estimated 30-day and 1-year survival rates were 74.2% and 67.2%, respectively. As defined by VARC-2 criteria, all deaths were cardiovascular in nature. Figure 2 is a Kaplan–Meier plot of overall patient survival. The 30-day and 1-year survival estimates were the same (68%) in patients with IE, differing distinctly (80% and 66.7%, respectively) in those with other reasons for THV explantation.

### Table 4 Intraoperative THV explantation data

| BVF secondary to: | CPB time (mean ± D) | Aortic cross-clamp time (mean ± SD) | Total operative time (mean ± SD) |
|------------------|---------------------|-------------------------------------|----------------------------------|
| NSVD             | 125.4 ± 55.6 min    | 76 ± 29 min                         | 276.4 ± 109.3 min               |
| IE               | 125.4 ± 40.8 min    | 91.8 ± 36.3 min                     | 263 ± 73.9 min                  |

| Isolated SAVR: BVF secondary to: | CPB time (mean ± D) | Aortic cross-clamp time (mean ± SD) | Total operative time (mean ± SD) |
|---------------------------------|---------------------|-------------------------------------|----------------------------------|
| NSVD                            | 110.4 ± 42.6 min    | 68.3 ± 20.3 min                     | 259.6 ± 73.8 min                 |
| IE                              | 97.7 ± 23.8 min     | 72.8 ± 21.6 min                     | 224.3 ± 56.7 min                 |

| Isolated SAVR                   | CPB time (mean ± D) | Aortic cross-clamp time (mean ± SD) | Total operative time (mean ± SD) |
|---------------------------------|---------------------|-------------------------------------|----------------------------------|
| BEV                             | 115 ± 39.7 min      | 99.4 ± 32.5 min                     | 261.9 ± 50.3 min                 |
| SEV                             | 81.4 ± 19.9 min     | 65.0 ± 20.7 min                     | 239.2 ± 85.2 min                 |

**Discussion**

In the present study, we examined early and mid-term outcomes of 31 patients undergoing surgical explantation of failed TAVR prostheses. Given the popularity of TAVR procedures, THV failure and the need for surgical explantation...
may soon become a pressing issue [5]. However, little is known regarding modes of THV failure, treatment entailed, and outcomes in instances where surgical explantation is required.

Mylotte et al. [6] have cited endocarditis of prosthetic valves, SVF, and valvular thrombosis as modes of failure tantamount to surgical bioprosthetic failure. Indeed, late THV embolization and chest compressions that damage THV implants during cardiopulmonary reanimation seem unique to THV as modes of failure, as do PVL and stent fractures. Still, only case reports of THV explantation for BVF or NSVD are chiefly available at present [7, 8]. Fukuhara et al. [9] studied 17 patients undergoing TAVR explantation on the basis of PVL (7/17), SVD (4/17), TAVR procedural complications (4/17), and IE (1/17) or as a bridge to definitive open surgery (1/17). They ultimately determined that risk scores (STS-Score) at time of TAVR procedures and those at times of explantations differed significantly (9.9% vs 3.5%; p < 0.001). Neoendothelization of THV implants prompted aortic root repairs in two cases.

**Infected endocarditis (IE)**

The 5-year incidence of IE after TAVR is at 5% [10] and was the most common indication for THV explantation in our cohort. Other studies have indicated no difference between SAVR and TAVR in terms of IE risk [11, 12]. However, it is feasible that differing implantation techniques used for BEVs and SEV cause disparities in IE. Thus far, the limited data on this subject has produced conflicting results. Reguiero et al. were focused on post-TAVR IE in their analysis of 245 patients, finding no difference in early or late mortality or reoperation rate by prosthesis type (BEV vs SEV) [13].

On the other hand, Mylotte et al. [6] and Amat-Santos et al. have separately recorded higher rates of post-TAVR IE for BEV (vs SEV) implants (59% vs 41%, and 64% vs 36%, respectively), with the reverse being documented by Brouwer et al. (SEV, 56%; BEV, 44%) [14].

There are three studies reporting onset of IE at 6 months after TAVR [13–15], whereas Butt et al. seem to refute this, citing a median of 12 months for rehospitalization due to IE [10]. In our study, IE-related prosthetic failures were explanted 368 days after prior TAVR. This discrepancy between onset of IE and final surgical treatment suggests that patients admitted with post-TAVR IE are treated conservatively for prolonged periods [14, 15] before considering open explantation and referred late for surgical intervention. There are lacking data on ratio and outcome between surgical and medical management for THV endocarditis. Future studies or register analysis are needed to evaluate this matter.

**Paravalvar leakage (PVL)**

Moderate or severe PVL after TAVR may significantly influence long-term outcomes [16, 17]. In a systematic review, the pooled estimate for overall incidence of moderate or severe PVL was 11.7% for first-generation THV devices [18]. During the PARTNER IB trial, moderate to severe PVL was associated with an increased 5-year mortality risk in the TAVR group [19]. Although PVL is potentially treatable through interventional therapies [20], PVL emerged in our series as the second most common indication for surgical THV explantation, with more SEV devices explanted due to PVL (SEV,8; BEV,2). This outcome is aligned with data published elsewhere showing a higher rate of PVL in first-generation SEVs [21]. PVL rates in new third-generation SEVs and BEVs do not show such differences [22].

Although post-TAVR PVL is still a concern, the risk may be lowered by accurate annular measurement, adequate valve sizing, and precise positioning of the valve. Second- and third-generation THV prostheses allow repositioning during implantation and are equipped with an external sealing skirt to reduce the incidence of PVL. There were 8/10 THV explantations due to PVL in the first 16 of our patients, and all involved first-generation devices. In the 15 patients that followed, only 2/10 required explantations were linked to PVL. This issue may then be dramatically lessened by current and upcoming device generations [17, 23].

**Hemodynamic structural valve deterioration (SVD)**

Recent studies have validated the good long-term functional results of TAVR devices [24] in ~7 years of accrued durability data [25]. However, as TAVR procedures trend higher in younger patients, prosthetic degeneration may become problematic. Two case reports of TAVR in patients < 60 years old have implicated early bioprosthetic valve failure [8, 26], the first case being a 53-year-old man with severe hemodynamic SVD 3 years after TAVR.

The second report describes a 48-year-old woman initially slated for AVR. TAVR was performed as a rescue therapy for acute heart failure requiring CPR. This patient presented 4.4 years later with bioprosthetic valve failure due to severe hemodynamic SVD. Her left ventricular function had significantly improved after TAVR, allowing uneventful explantation and SAVR using a mechanical prosthesis. Van Steenenberge et al. insist that TAVR is contraindicated in operable patients [26], but we consider it a viable option in select cases, serving as a bridge to surgery for unstable or critically ill patients.

**Dislocation**

After an initial learning curve, a dislocated or malpositioned THV device is very rare nowadays, owing to delivery...
catheters with repositioning features [33]. Dislocation may occur retrograde into the left ventricle or antegrade into the aorta. If such complications arise, conversion to conventional AVR is one possibility [27, 28], or the displaced prosthesis may be anchored in the ascending or descending aorta. During the present study, two patients required THV explantations due to left ventricular prosthetic valvular dislocations (0–3 days after TAVR). In the first patient, proper positioning of a BEV was initially achieved. Two days later, signs of acute heart failure had developed, the dislocated prosthetic valve identified in left ventricular outflow tract (LVOT) by echocardiography. Surgery showed, it was set transversely, causing near-complete LVOT obstruction. In the second patient, a BEV dislocated during implantation, becoming lodged in the mitral valve chords and stuck in the LVOT.

Survival

In the present study, the mean STS score upon device explantation was 5.9%, and the mean logistic EuroScore was 25.1%, both quite consistent with a high-risk cohort. The 30-day and 1-year survival rates were 74.2% and 67.2%, respectively (Fig. 2). IE is a serious medical condition, with a mortality rate of ~ 30% [15, 29], and was the chief indication for THV explantation in our cohort; so a high mortality rate was not unexpected.

All deaths were categorized as cardiovascular in nature. Interestingly, survival after THV explantation, whether due to IE or other causes, did not differ significantly. Patients with IE showed a complex clinical picture of sepsis leading to multiorgan failure, neurologic impairments, and eventual death. Additional studies are needed to further assess these findings.

Technical aspects

There is only limited information on technical aspects of THV explantation, stemming from a case series where Fukuhara et al. examined TAVR explants of 17 patients. SAVR was performed 12 months after TAVR in five of these subjects, each displaying degrees of device neoendothelialization that required “intense aortic endarterectomy”. Unplanned aortic root repairs were needed in two patients as well. As stated by Fukuhara et al., the importance of proper patient selection was duly underscored, noting the clear potential for aortic repair during TAVR explants [9].

THV explantations may also necessitate aortotomy modifications. Standard aortotomy is feasible for low-frame TAVR devices, such as the Edwards SAPIEN, whereas the higher stent frame of a Medtronic CoreValve device demands a slightly higher aortotomy. In this setting, suitable aortic access may be determined by palpating upper portions of the THV frames.

To achieve prosthetic removal, we largely resorted to blunt dissection. However, the ingrowth and solid adhesions of BEVs render explantation more difficult, compared with surgical bioprostheses. In the beginning, we used ice-cold saline to support mobilization of the nitinol frames. This proved unhelpful and was soon abandoned. Use of wire cutters to snip stent frames was beneficial for dislocated THVs caught up in left ventricle and mitral valve.

It is possible that BEVs may be more daunting than SEVs during explantations, given the high radial forces applied to such prosthetic valves and native tissues during implantations. The time intervals between TAVR and SAVR may also influence degree of neoendothelialization, further challenging THV dissections.

We did not incur any aortic wall or aortic root injury during operations, even if severe periprosthetic adhesions called for time-consuming dissection. In one case, however, patch reconstruction of the aortic annulus was necessary to rectify annular abscess formation in a patient with severe IE.

Limitations

This study was confined to our single-center experience, hampered by a small sample size and a retrospective study design. None of the data generated has been reviewed by an independent adjudication committee.

Conclusion

We found that the most common indication for THV explantation was IE. One-year survival in this high-risk patient population (considered ineligible for conventional surgery) was nearly 70%. There were more annular adhesions in conjunction with BEV (vs SEV) implantation, but no substantial damage to native aortic annulus or aortic root resulted from THVR.

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Declarations

Conflict of interest Prof. Lange received consulting fees/royalties from Medtronic and is stockholder. Dr. Ruge received consulting fees from Medtronic. The remaining authors have no disclosures to report.

Ethical approval The study was approved by the local ethics committee (755/20 S-SR) and has been performed in accordance with the ethical
standards laid down in the 1964 Declaration of Helsinki and its later amendments.

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References

1. Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP 3rd, Fleisher LA, Jneid H, Mack MJ, McLeod CJ, O’Gara PT, Rigolin VH, Sundt TM 3rd, Thompson A (2017) 2017 AHA/ACC focused update of the 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American college of cardiology/American heart association task force on clinical practice guidelines. Circulation 135(25):e1159–e1195

2. Leon MB, Smith CR, Mack MJ, Makkar RR, Svensson LG, Kodali SK, Thourani VH, Tuzcu EM, Miller DC, Herrmann HC, Doshi D, Cohen DJ, Pichard AD, Kapadia S, Dewey T, Babaliaros V, Szeto WY, Williams MR, Kereiakes D, Zajarias A, Greason KL, Whisenant BK, Hodson RW, Moses JW, Trento A, Brown DL, Fearon WF, Pibarot P, Hahn RT, Jaber WA, Anderson WN, Alu MC, Webb JG, Investigators (2016) Transcatheter or surgical aortic valve replacement in intermediate-risk patients. N Engl J Med 374(17):1609–1620

3. Kappetein AP, Head SJ, Genereux P, Piazza N, van Mieghem NM, Blackstone EH, Brott TG, Cohen DJ, Cutlip DE, van Es GA, Hahn RT, Kirtane AJ, Krucoff MW, Kodali S, Mack MJ, Mehran R, Rodes-Cabau J, Vranckx P, Webb JG, Windecker S, Serruys PW, Leon MB (2012) Updated standardized endpoint definitions for transcatheter aortic valve implantation: the valve academic research consortium-2 consensus document. J Am Coll Cardiol 60(15):1438–1454

4. Capodanno D, Petronio AS, Prendergast B, Eltchaninoff H, Vahanian A, Modine T, Lancellotti P, Sondergaard L, Ludman PF, Tamburino C, Piazza N, Hancock J, Mehilli J, Byrne RA, Baumbach A, Kappetein AP, Windecker S, Bax J, Haude M (2017) Standardized definitions of structural deterioration and failure in assessing long-term durability of transcatheter and surgical aortic bioprosthesis valves: a consensus statement from the European association for percutaneous cardiovascular interventions (EAPCI) endorsed by the European society of cardiology (ESC) and the European association for cardiac-thoracic surgery (EACTS). Eur J Cardiothorac Surg 52(3):408–417

5. Erlebach M, Wotke M, Deutsch MA, Krane M, Piazza N, Lange R, Bleiziffer S (2015) Redo aortic valve surgery versus transcatheter valve-in-valve procedure: a meta-analysis of patient-based studies. J Thorac Dis 7(9):1494–1500

6. Mylotte D, Andalib A, Theriault-Lauzier P, Dorfmeister M, Girgis M, Alharbi W, Chretin M, Galatas C, Mamane S, Sebag I, Buithieu J, Bilodeau L, de Varennes B, Lachapelle K, Lange R, Martucci G, Virmani R, Piazza N (2015) Transcatheter heart valve failure: a systematic review. Eur Heart J 36(21):1306–1327

7. Wang LW, Granger EK, McCourt JA, Pye R, Kaplan JM, Muller DW (2015) Late surgical explantation and aortic valve replacement after transcatheter aortic valve implantation. Ann Thorac Surg 99(4):1434–1436

8. Deutsch MA, Mayr NP, Assmann G, Will A, Krane M, Piazza N, Bleiziffer S, Lange R (2015) Structural valve deterioration 4 years after transcatheter aortic valve replacement: imaging and pathohistological findings. Circulation 131(7):682–685

9. Fukuhara S, Brescia AA, Shiomi S, Rosati CM, Yang B, Kim KM, Deeb GM (2021) Surgical explantation of transcatheter aortic bioprostheses: results and clinical implications. J Thorac Cardiovasc Surg 162(2):539–547.e1

10. Butt JH, Ilethemann N, De Backer O, Sonderraad G, Havers-Bergersen E, Gislason GH, Torpen-Pedersen C, Kober L, Fosbol EL (2019) Long-term risk of infective endocarditis after transcatheter aortic valve replacement. J Am Coll Cardiol 73(13):1646–1655

11. Summers MR, Leon MB, Smith CR, Kodali SK, Thourani VH, Herrmann HC, Makkar RR, Pibarot P, Webb JG, Leipsic J, Alu MC, Crowley A, Hahn RT, Kapadia SR, Tuzcu EM, Svensson L, Cremer PC, Jaber WA (2019) Prosthetic valve endocarditis after TAVR and SAVR: insights from the PARTNER trials. Circulation 140(24):1984–1994

12. Moriyama N, Laakso T, Biancari F, Raivio P, Jalava JA, Jaakkola J, Dahlbacka S, Kinnunen EM, Juvelen J, Hruso A, Nie-mela M, Ahvenraa T, Tauringe T, Virtanen M, Maaranen P, Eskola M, Rosato S, Makikallio T, Savontaus M, Valtola A, Anttila V, Airaksinen J, Laine M (2019) Prosthetic valve endocarditis after transcatheter or surgical aortic valve replacement with a bioprosthesis: results from the finnvillage registry. EuroIntervention 15(6):e500–e507

13. Regueiro A, Linke A, Latib A, Ilethmann N, Urena M, Walther T, Husser O, Herrmann C,ombela-Francol, Cheema A, Le Breton H, Stortecyck S, Kapadia S, Bartorelli L, Sinning J, Amat-Santos I, Munoz-Garcia J, Leraisik S, Gutierrez-Ibanes E, Abdel-Wahab M, Tchetchte D, Testa L, Eltchaninoff H, Livi U, Castillo JL, Jilaihawi H, Web G, Barbanti M, Kodali S, de Brito JS, Ribeiro B, Miceli A, Fiorina C, Actis Dato GM, Rosato F, Serra V, Masson JB, Wijesundersa C, Mangione A, Ferreira MC, Lima C, Carvalho A, Abizaid A, Marino A,Esteves V, Andrea CM, Messika-Zeitoun D, Hirmont D, Kim WK, Pellegrini C, Auffret V, Nitielsphar F, Filip Trum D, Endur E, Lisko J, Makkar R, Lemos P, Leon B, Puri R, San Roman A, Vahanian A, Sondergard L, Mangner N, Rodes-Cabau J (2019) Infective endocarditis following transcatheter aortic valve replacement: comparison of balloon- versus self-expandable valves. Circ Cardiovasc Interv 12(11):e007938

14. Brouwer J, van den Brink FS, Nijenhuis VJ, Vossenbon TN, Delewi R, van Mourik RS, den Heijer P, Kievit PC, Fontvoet W, Hermanides RS, Ten Berg JM (2020) Incidence and outcome of prosthetic valve endocarditis after transcatheter aortic valve replacement in the Netherlands. Neth Heart J 28(10):520–525

15. Amat-Santos JI, Messika-Zeitoun D, Eltchaninoff H, Kakahian S, Larakis S, Cheema AN, Gutierrez-Ibanes E, Munoz-Garcia AJ, Pan M, Webb JG, Herrmann HC, Kodali S, Ombela-Francol L, Tamburino C, Jilaihawi H, Masson JB, de Brito JS Jr, Ferreira MC, Lima VC, Mangione JA, jung B, Vahanian A, Durand E, Tuzcu EM, Hayek SS, Angulo-Llanos N, Gomez-Dolias JJ, Castillo JC, Dvir D, Leon MB, Garcia E, Cobilli J, Vilacosta I, Barbanti M, R RM, Ribeiro HB, Urena M, Dumeont E, Pibarot P, Lopez J, San Roman A, Rodes-Cabau J (2015) Infective endocarditis after transcatheter aortic valve implantation: results from a large multicenter registry. Circulation 131(18):1566–1574

16. Kampakis SN, Ullal AV, Minutello RM, Feldman DN, Swamianathan RV, Voudris K, Badushwilly A, Pastella K, Pawar S, Kaple
RK, Vavuranakis M, Bergman GS, Skubas NJ, Lin F, Salemi A, Devereux RB, Chiu Wong S (2016) Impact of paravalvular aortic insufficiency on left ventricular remodeling and mortality after transcatheter aortic valve replacement. J Heart Valve Dis 25(3):301–308

17. Grover FL, Vemulapalli S, Carroll JD, Edwards FH, Mack MJ, Thourani VH, Brindis RG, Shahian DM, Ruiz CE, Jacobs JP, Hanzel G, Bavaria JE, Tuzcu EM, Peterson ED, Fitzgerald S, Kourits M, Michaels J, Christensen B, Seward WF, Hewitt K, Holmes DR Jr, Registry SAT (2017) 2016 annual report of the society of thoracic surgeons/american college of cardiology transcatheter valve therapy registry. Ann Thorac Surg 103(3):1021–1035

18. Athappan G, Patwardhan E, Tuzcu EM, Svensson LG, Lemos PA, Fraccaro C, Tarantini G, Sinning JM, Nickenig G, Capodanno D, Tamburino C, Latib A, Colombo A, Kapadia SR (2013) Incidence, predictors, and outcomes of aortic regurgitation after transcatheter aortic valve replacement: meta-analysis and systematic review of literature. J Am Coll Cardiol 61(15):1585–1595

19. Mack MJ, Leon MB, Smith CR, Miller DC, Moses JW, Tuzcu EM, Webb JG, Douglas PS, Anderson WN, Blackstone EH, Kodali SK, Makkar RR, Fontana GP, Kapadia S, Bavaria J, Hahn RT, Thourani VH, Babaliaros V, Pichard A, Herrmann HC, Brown DL, Williams M, Akin J, Davidson MJ, Svensson LG, PARTNER 1 trial investigators (2015) 5-year outcomes of transcatheter aortic valve replacement or surgical aortic valve replacement for high surgical risk patients with aortic stenosis (PARTNER 1): a randomised controlled trial. Lancet 385(9986):2477–2484

20. Kumar A, Block PC (2018) Paravalvular leak after transcatheter aortic valve replacement: avoid it or treat it if you can! Catheter Cardiovasc Interv 92(5):981–982

21. Abdel-Wahab M, Mehilli J, Frerker C, Neumann FJ, Kurz T, Tolg R, Zachow D, Guerra E, Massberg S, Schafer U, El-Mawardy M, Richardt G, investigators C (2014) Comparison of balloon-expandable vs self-expandable valves in patients undergoing transcatheter aortic valve replacement: the CHOICE randomized clinical trial. JAMA 311(15):1503–1514

22. Lanz J, Kim WK, Walther T, Burgdorf C, Mollmann H, Linke A, Redwood S, Thilo C, Hilker M, Joner M, Thiele H, Conzelmann L, Conradi L, Kerber S, Schymik G, Prendergast B, Husser O, Stortecky S, Heg D, Juni P, Windecker S, Pilgrim T, investigators SI (2019) Safety and efficacy of a self-expanding versus a balloon-expandable bioprosthesis for transcatheter aortic valve replacement in patients with symptomatic severe aortic stenosis: a randomised non-inferiority trial. Lancet 394(10209):1619–1628

23. Mas-Peiro S, Fichtlscherer S, Walther C, Vasa-Nicotera M (2020) Current issues in transcatheter aortic valve replacement. J Thorac Dis 12(4):1665–1680

24. Blackman DJ, Saraf S, MacCarthy PA, Myat A, Anderson SG, Malkin CJ, Cunningham MS, Somers K, Brennan P, Manoharan G, Parker J, Aldalati O, Brecker SJ, D Bowling C, Hoole SP, Dorman S, Mullen M, Kenna S, Jerrum R, Chandrula P, Roberts DH, Tay J, Doshi SN, Ludman PF, Fairbairn TA, Crowe J, Levy RD, Banning AP, Ruparel N, Spence MS, Hildick-Smith D (2019) Long-term durability of transcatheter aortic valve prostheses. J Am Coll Cardiol 73(5):537–545

25. Deutsch MA, Erlebach M, Burri M, Happelmeier A, Witt OG, Ziegelmueller JA, Wottke M, Ruge H, Krane M, Piazzza N, Bleiziffer S, Lange R (2018) Beyond the five-year horizon: long-term outcome of high-risk and inoperable patients undergoing TAVR with first-generation devices. EuroIntervention 14(1):41–49

26. van Steenberghhe M, de Vasconcelos CY, Delay D, Niclauss L, Kirsch M (2016) Early transcatheter aortic valve degeneration in the young. Int J Cardiol 222:786–787

27. Eggebrecht H, Schmermund A, Kahlert P, Erbel R, Voigtlander T, Mehta RH (2013) Emergent cardiac surgery during transcatheter aortic valve implantation (TAVI): a weighted meta-analysis of 9,251 patients from 46 studies. EuroIntervention 8(9):1072–1080

28. Pineda AM, Harrison JK, Kleiman NS, Rihal CS, Kodali SK, Kirtane AJ, Leon MB, Sherwood MW, Manandhar P, Vemulapalli S, Beohar N (2019) Incidence and outcomes of surgical bailout during TAVR: insights from the STS/ACC TVT registry. JACC Cardiovasc Interv 12(18):1751–1764

29. Cahill TJ, Prendergast BD (2016) Infective endocarditis. Lancet 387(10021):882–893

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