Art of Operative Techniques

Transcatheter aortic valve replacement explant various techniques

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Surgical aortic valve replacement (SAVR) has long been the gold standard for treating significant aortic valve dysfunction. Since the introduction of transcatheter aortic valve replacement (TAVR) in 2011, the number of TAVRs has grown rapidly, surpassing SAVR volumes by 2018 and now accounting for approximately 80% of all aortic valve replacements (AVRs) performed in the United States. In conjunction with the rapid expansion of TAVR, the number of TAVR valves requiring surgical explantation (TAVR-explant) has also increased due to procedure-related failure, endocarditis, structural valve degeneration with unfavorable anatomy for redo-TAVR, paravalvular leak, delayed migration, or prosthesis-patient mismatch. Often involving concomitant cardiac surgery, TAVR-explant has been associated with higher operative mortality than redo-SAVR. TAVR-explant is currently the fastest-growing cardiac procedure in the United States and is expected to continue growing, especially as TAVR is increasingly used for lower surgical risk and younger patients. Accordingly, describing and disseminating a standardized set of technical principles for performing TAVR-explant is essential for preparing all cardiac surgeons to appropriately treat these patients. TAVR-explant requires a comprehensive preoperative clinical and cross-sectional imaging assessment to plan an effective operation, including cannulation, aortotomy, explantation, and implantation strategies. Particular considerations for self-expanding and balloon-expandable TAVR valves are important for guiding the operation and optimizing outcomes. Special considerations, such as the need for concomitant aortic, coronary, or mitral valve surgery and the presence of snorkel coronary artery stents adjacent to the TAVR valve, must be considered and addressed at the time of TAVR-explant surgery. Currently, TAVR-explant confers a high operative mortality and is performed at very low volumes per surgeon. As this operation becomes increasingly common, it will become essential for all cardiac surgeons to understand and implement the operation's various techniques to optimize patient outcomes.

Keywords: Transcatheter aortic valve replacement (TAVR); surgical aortic valve replacement (SAVR); aortic stenosis; endocarditis

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Introduction

The number of transcatheter aortic valve replacement (TAVR) procedures surpassed the number of surgical aortic valve replacements (SAVR) in 2018 and now accounts for more than 80% of all aortic valve replacement (AVR) procedures performed in the United States (1,2). Consequently, the surgical explantation of transcatheter heart valves (THVs) (TAVR-explant) has emerged as the fastest-growing cardiac surgical procedure in the United States (3). Early TAVR-explant data from institutional, statewide, national, and international registries exhibit high operative mortality ranging from 11.6% to 20% (4-15), with approximately half of TAVR-explant patients undergoing concomitant cardiac procedures (4,5,11,14). The most common indications for TAVR-explant include procedure-related failure, endocarditis, structural valve degeneration in patients with unfavorable anatomy for redo-TAVR, paravalvular leak, delayed migration, and prosthesis-patient mismatch (4-10,13,14). As the number of low-risk

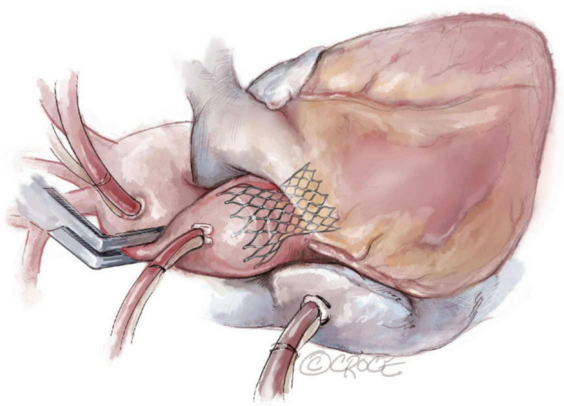

Figure 1 Cannulation set up for SEVs. The presence of a tall SEV necessitates cannulation typically in the proximal aortic arch to allow room for cross-clamping of the distal ascending aorta without impinging upon the SEV. SEV, self-expanding valve.

patients undergoing TAVR increases, the number of TAVR-explant procedures is expected to rise exponentially, driven by an increasing incidence of valve failure for indications including prosthesis-patient mismatch and structural valve degeneration.

The high operative mortality associated with TAVR-explant may be due to both patient risk profiles at the time of surgery, including the need to address concomitant cardiac pathology, as well as the technical challenges of performing an effective TAVR-explant procedure (5,7,8). With the increasing incidence of TAVR-explant, various techniques have been developed and described (16-18). As TAVR becomes more common in low-risk and younger patients, the frequency of TAVR-explant procedures will continue to rise (2,19). This will likely result in a higher proportion of late (>1 year) TAVR-explant procedures, which may introduce additional operative complexity. Developing the skillset to treat these patients is essential for contemporary cardiac surgeons. Establishing a clear set of operative principles for TAVR-explant may help standardize the operative approach and improve outcomes for this high-risk procedure. In this report, we describe and depict the key steps involved in performing a TAVR-explant.

Operative techniques

Preparation

Standard laboratory tests, a transthoracic echocardiogram, and a computed tomography (CT) scan of the chest, abdomen, and pelvis (with contrast if possible) should be obtained for every patient undergoing TAVR-explant. A transesophageal echocardiogram should be performed in patients with a high suspicion of infective endocarditis to better characterize aortic root involvement. Lastly, the coronary arteries should be evaluated either by coronary CT angiography (CTA) or left heart catheterization. Coronary CTA may be preferred in patients with active prosthetic endocarditis, an aortic root abscess, and/or in those who are young with minimal risk factors for coronary disease. For patients with known prosthetic valve endocarditis, with or without an aortic root abscess, cross-sectional imaging of the brain, either by CT or magnetic resonance imaging (MRI), may be obtained for perioperative risk stratification or to determine the presence of mycotic aneurysms that may require pretreatment.

Exposition

Invasive monitoring, including an arterial line, central venous access, and intraoperative transesophageal echocardiography, is recommended in all patients. The use of pulmonary artery catheters and femoral venous and/or arterial access should be determined on an individualized basis. A primary or redo median sternotomy or a minimal access approach should be performed in all patients according to patient anatomy and surgeon preference.

Importantly, aortic cannulation should be tailored to the specific valve type being explanted, as evaluated on preoperative CT and intraoperatively. Self-expanding valves (SEVs) extend further into the ascending aorta and often necessitate proximal aortic arch or even peripheral cannulation (*Figure 1*), whereas balloon-expandable valves (BEVs) usually allow for distal ascending aortic cannulation (*Figure 2*).

The cardioplegia type and strategy of administration should also be tailored to the individual patient and THV anatomy. Retrograde cardioplegia is often required for two reasons: first, in cases of significant aortic regurgitation, and second, when the coronary ostia are difficult to access. This applies to both BEVs and SEVs, and the threshold for utilizing retrograde should be low in TAVR-explant procedures. After explantation of the THV, the coronary ostia can be accessed for the ostial administration of additional antegrade cardioplegia if necessary. If antegrade cardioplegia is pursued through the closed aorta, as may be the case in patients with stenotic valve degeneration, the cannulation site must be high enough to ensure clearance

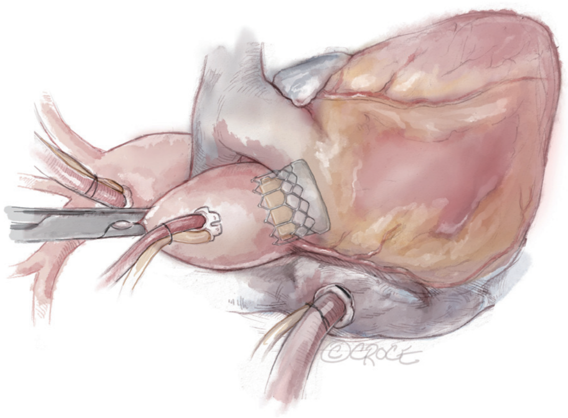

Figure 2 Cannulation setup for BEVs. BEVs are seated significantly lower in the aorta, within the aortic root, allowing for standard aortic cannulation in the distal ascending aorta. This position ensures sufficient space for a proximal cross-clamp and, in some instances, a root vent. BEV, balloon-expandable valve.

of the THV frame or administered through a needle. Left ventricular venting through the right superior pulmonary vein may be performed to facilitate decompression in the setting of significant aortic regurgitation and is recommended to improve visualization of the aortic root.

Operation

Aortotomy

Preoperative planning using CT imaging is imperative and should include determining the length of the ascending aorta, the relative length of the stent frame, the locations of cannulation and clamp sites, and even the root vent site. As with determining the aortic cannulation site, the stent frame can often be palpated through the aorta. If palpation is not feasible, epiaortic ultrasound may be utilized to locate the borders of the frame. For BEVs, the aortotomy may be performed at a standard location 1–2 cm above the sinotubular junction through a transverse or oblique incision. For SEVs, the aortotomy may be performed at the top of the valve frame or within it (*Figure 3*).

Explantation

Various techniques may be utilized for explantation of the valve. The double Kocher technique may be used to deform the stent frame of the valve inwardly to facilitate removal for both BEVs and SEVs (8). The initial step of this technique involves separating the stent frame from the aortic wall with either endarterectomy spatulas or, in the setting of significant adhesions, a No. 15 scalpel should be used carefully along the stent frame. Once dissection progresses to approximately halfway down the stent frame, two long Kocher clamps can be applied perpendicularly to mobilize the sharp edges of the valve and serve as a handle for removal of the stent (*Figure 4*). As more of the frame is separated from the aorta, the clamps may be repositioned deeper toward the base of the valve. Key considerations include entering the plane between the native valve leaflets and the TAVR cuff and, in the setting of deep TAVR implantation, avoidance of the mitral valve, left

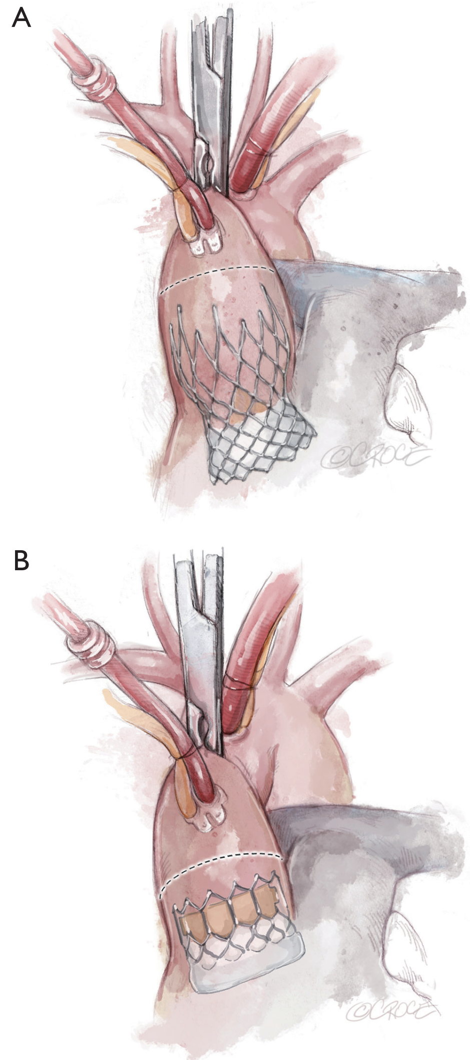

Figure 3 Aortotomy locations for SEVs (A) and BEVs (B). BEV, balloon-expandable valve; SEV, self-expanding valve.

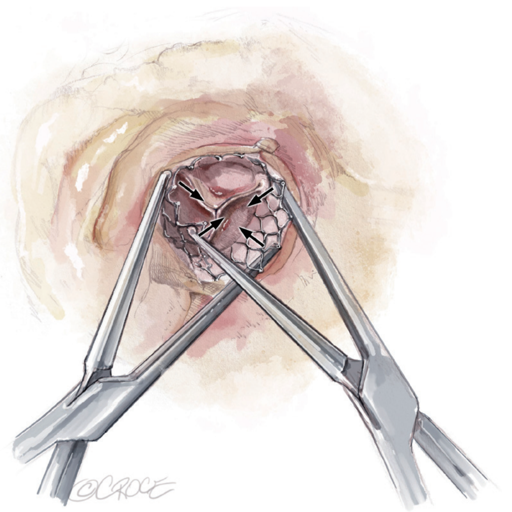

Figure 4 Double Kocher technique for BEVs and SEVs. After the stent frame is separated from the aortic wall at least halfway down the height of the stent frame, the stent may be grasped perpendicularly with two long Kocher clamps to mobilize the sharp edges of the valve and serve as a handle for removal while closing the instrument to deform the transcatheter heart valve (black arrows). Surgeons should focus on entering the plane between the native valve leaflets and the transcatheter heart valve cuff. BEV, balloon-expandable valve; SEV, self-expanding valve.

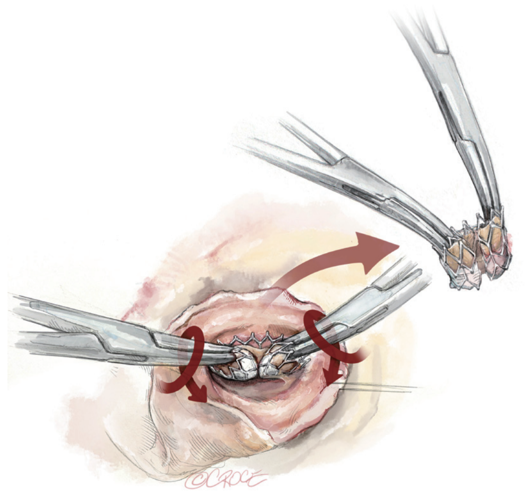

Figure 5 Roll technique for BEVs. The valve should be grasped at the top of the commissures with a Tonsil or long clamp, after which a Freer elevator is used to bluntly dissect down to the cuff. Two clamps are placed 180 degrees apart, with one jaw inside the BEV to the bottom of the cuff and the other between the native valve and BEV. Both clamps are rolled inwardly and turned 360 degrees (red arrows), collapsing the valve to its smallest diameter to facilitate easy removal. BEV, balloon-expandable valve.

ventricular outflow tract, and conduction system below the membranous septum.

For BEVs, the roll technique is another option. The valve should first be grasped at the top of the commissures using a Tonsil or long clamp, after which a Freer elevator is used to bluntly dissect the plane between the native valve and the TAVR frame until the cuff is reached. Two clamps are then placed 180 degrees apart, with one jaw inside the BEV at the bottom of the cuff and the other positioned in the plane between the native valve and BEV. Both clamps are rolled inward simultaneously, each completing a full 360-degree turn (*Figure 5*). The valve will then collapse to the smallest diameter, allowing for easier removal. By rolling the valve radially, less force is used than when trying to fold it along its diameter, which results in a smaller overall profile and reduces the risk of injury from the exposed stent frame, therefore making the technique less prone to damaging the ascending aorta or root.

In contrast, most SEVs are composed of nitinol and extend higher into the ascending aorta with an hourglass supraannular shape, making dissection around the frame more difficult. The tourniquet technique utilizes a Freer elevator to carefully lift the neointima and frame from the aortic wall. Silk ties are then passed through the top cells of the frame at opposite ends and snared through a 3/8-inch pump tubing piece (*Figure 6*). The tubing is advanced toward the valve to create a tourniquet effect and effectively recapture the valve, significantly reducing its profile and allowing for easier removal.

An alternative technique for SEV explantation is the mustache handlebar technique, which focuses on radial infolding. The valve is first divided in half transversely to remove the crown and then cut longitudinally. While cutting the valve longitudinally, two clamps are used to grasp, stabilize, and infold the valve while the cutting is performed with scissors and/or a wire cutter (*Figure 7*). One potential downside of this technique is that cutting the valve frame creates numerous sharp edges.

Implantation and other cardiac surgery

After explantation, the ascending aorta and aortic root should be thoroughly examined for any damage, and aortic repair should be performed if necessary. Standard SAVR

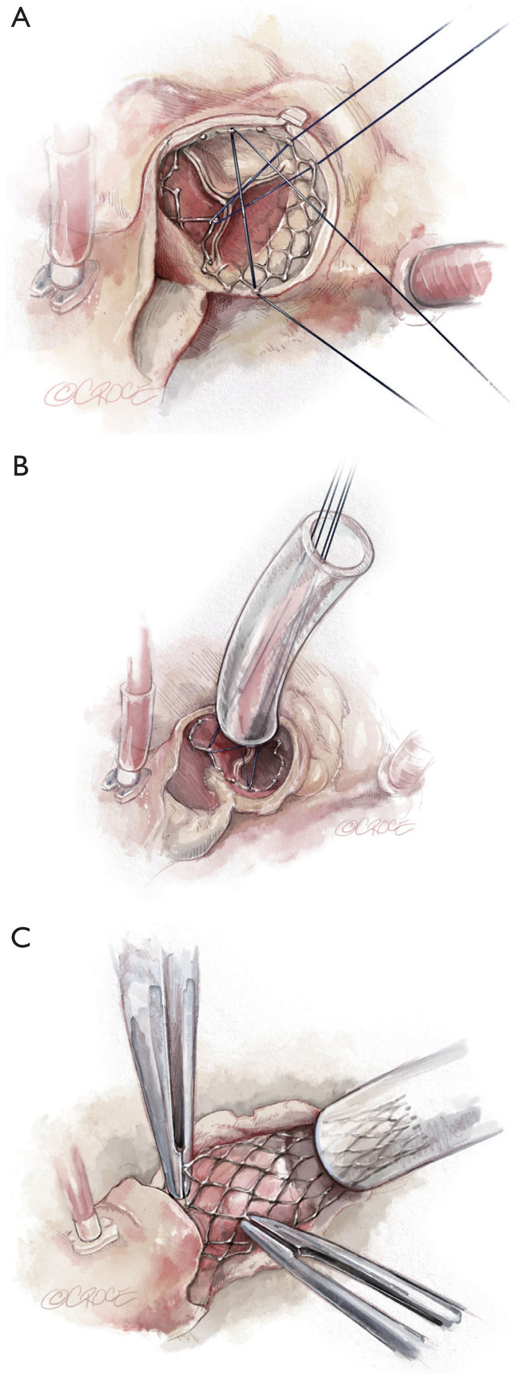

Figure 6 Tourniquet technique for SEVs. The tourniquet technique utilizes a Freer elevator to carefully lift the neointima and frame from the aortic wall. Silk ties are then passed through the top cells of the frame at opposite ends (A) and snared through a 3/8-inch pump tubing piece (B). This tubing is advanced toward the valve to create a tourniquet, effectively recapturing the valve (C), creating a smaller profile and allowing for easier removal. SEV, self-expanding valve.

Figure 7 The handlebar and mustache technique for SEVs focuses on radial infolding. The valve is first divided in half transversely to remove the crown, then cut longitudinally. While cutting the valve longitudinally, two clamps are used to grasp, stabilize, and infold the valve while performing the cuts with scissors or a wire cutter. SEV, self-expanding valve.

can then be performed, with aortic annular enlargement considered if needed due to prosthesis-patient mismatch or to optimize future transcatheter intervention. Infrequently, aortic root replacement may be required, particularly in the setting of coronary compromise or aortic root abscess and destruction. If there is significant intimal disruption of the ascending aorta, a patch can be utilized to reduce tension on the closure.

Concomitant mitral valve surgery has been required in more than 20% of TAVR-explant operations in large series (4,5). If possible, mitral surgery should be performed as usual. In some instances, a deeply implanted TAVR may interfere with the anterior leaflet of the mitral valve, and dissection must be performed carefully to avoid damaging the aortomitral curtain. In the setting of endocarditis, particularly when associated with an abscess, destruction of the aortomitral curtain may necessitate a Commando procedure to reconstruct aortomitral continuity.

Special circumstances

The Surgical Resection of Prosthetic Valve Leaflets Under Direct Vision (SURPLUS) technique is a hybrid approach that combines surgical resection of THV leaflets with direct implantation of a BEV under both direct vision and fluoroscopic guidance (20). After initiating cardiopulmonary bypass and cross-clamping, the TAVR leaflets are

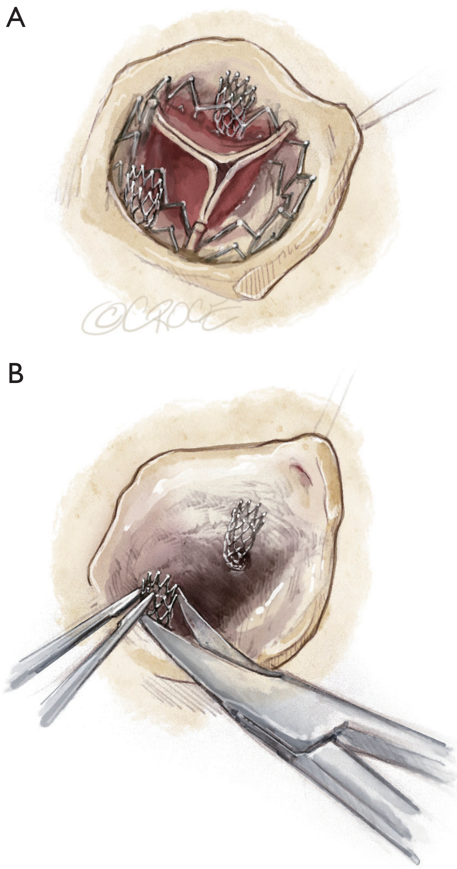

Figure 8 Navigating TAVR-explant in the setting of coronary snorkel stents. When snorkel coronary stents are present prior to TAVR-explant procedure, they will almost assuredly be damaged by fracturing or crushing during extraction of the THV (A). After extraction of the THV, these stents should be cut flush with the plane of the coronary ostium using heavy scissors and should never be pulled or removed, due to the risk of coronary intima injury, which may result in catastrophic thrombosis (B). TAVR, transcatheter aortic valve replacement; THV, transcatheter heart valve.

resected. A BEV is then placed over a guidewire under direct vision, positioned, and ultimately deployed under fluoroscopic guidance. The advantage of this technique is that it avoids tissue dissection, making it potentially beneficial for failed SEVs in which redo-TAVR is not feasible due to coronary obstruction and when transcatheter leaflet laceration is unreliable. However, this technique should not be utilized in the setting of endocarditis or prosthesis-patient mismatch.

Some TAVR-explant procedures may take place in the setting of snorkel coronary stents, which are placed adjacent to the TVH stent frames either as a mechanism to protect the coronary ostia during primary TAVR placement or to treat coronary disease (*Figure 8*). During TAVR-explant, these coronary stents will almost assuredly be damaged, either by fracturing or crushing during extraction of the THV. Importantly, any coronary stents should be cut flush with the plane of the coronary ostium using heavy Mayo (not Metzenbaum) scissors. A mosquito or other small spreading instrument may be used to test stent patency, which can also be confirmed by delivering retrograde cardioplegia. These stents should never be forcibly removed or pulled, as disruption of the coronary intima may result in catastrophic thrombosis.

Comments

Clinical results

Initial reports from national and international registries have demonstrated an operative mortality of approximately 13–20% for TAVR-explant procedures (4-6,10). These data include many patients who underwent primary TAVR at prohibitive or high surgical risk and were subsequently at an even greater risk by the time of TAVR-explant. In addition, a portion of these patients' elevated risk derives from concomitant pathology, which has resulted in approximately half of all patients undergoing additional concomitant cardiac surgery. The additional pathology treated may have gone unaddressed at the time of the index TAVR or may have progressed by the time of TAVR-explant. In the Society of Thoracic Surgeons Adult Cardiac Surgery Database (STS ACSD), patients undergoing concomitant surgery had higher rates of readmission, prolonged ventilation, postoperative sepsis, and blood transfusion requirements (5). A large international registry further demonstrated 1-year mortality and stroke rates of 28.5% and 18.7%, respectively, illustrating the significant morbidity and mortality associated with this operation (4).

Two analyses from the STS ACSD have assessed differences in outcomes between BEVs and SEVs (5,11). More than twice as many BEVs have been performed compared with SEVs, yet overall 30-day mortality and other major complications did not differ between groups. However, patients undergoing TAVR-explant of SEVs more frequently required ascending aorta replacement (22% *vs.* 9%, P<0.001), whereas aortic root replacement and other concomitant procedures did not differ in frequency (11). We believe that explantation of any THV type is reasonable, and appropriate preparation with regard to cannulation, aortotomy, and explantation technique—based on the individual valve type and its location within the aortic root and ascending aorta—is essential for successful removal.

Advantages

The primary advantage of TAVR-explant over redo-TAVR is the ability to fully address all pathology in a single operation, whether limited to the aortic valve or requiring additional concomitant cardiac surgery. Multiple analyses have demonstrated that a substantial proportion of primary TAVRs result in anatomical changes that make redo-TAVR infeasible, including sinus sequestration, unfavorable coronary anatomy, paravalvular leak, prosthesis-patient mismatch, and concomitant cardiac pathology (4,13). This creates a major group of patients who will require TAVR-explant if they outlive the lifespan of their index TAVR.

In the setting of THV endocarditis, with or without a root abscess, TAVR-explant is the only method capable of achieving source control; any other intervention would be palliative in nature. Lastly, even if redo-TAVR is feasible, TAVR-explant allows for an aortic annular or root enlargement to be performed if necessary, which is particularly advantageous for patients with early THV failure in a small aortic annulus with small TAVR prosthesis.

The goals of TAVR-explant should include using a Freer or similar instrument to safely enter the plane between the TAVR stent frame and native tissue without disrupting the aortic intima. At the valve level, the burden of bulky calcium or the presence of an abscess will dictate the ease of valve removal. In some instances, the pathology may dictate which technique is best. We believe surgeons should familiarize themselves with all options while developing comfort with at least one technique for each BEV and SEV TAVR-explant.

Caveats

The TAVR-explant operation may confer a high operative mortality due to patient risk factors and the frequent need for additional concomitant procedures. Early studies of this procedure have demonstrated a consistently high observed-to-expected mortality ratio, potentially due to the perioperative risks of TAVR-explant not being adequately captured (5,6). To improve risk assessment for TAVR-explant, a separate risk calculator has been made available by the STS to better estimate perioperative risk and integrate these data into discussions among providers and patients (21).

In addition, the STS ACSD showed that the median number of TAVR-explants performed per cardiac surgeon was one, across 483 individual surgeons (5). Given the high operative mortality of this procedure, future discussions may revolve around whether regionalization and referrals to centers specializing in TAVR-explant would be beneficial. Alternatively, as the number of low-risk patients requiring TAVR-explant increases, ensuring adequate access to care may necessitate reinforcing the concept that every cardiac surgeon should be familiar with these core principles for performing TAVR-explant in their practice.

Conclusions

TAVR-explant is the fastest-growing cardiac surgical procedure in the United States. Early experience with TAVR-explant has been associated with a high operative mortality, largely due to the presence of extremely high-risk patients with multiple comorbidities and unaddressed concomitant cardiac pathology. Cardiac surgeons, especially those performing TAVR, must be familiar with the general concepts and strategies for the technical aspects of TAVR-explant to ensure appropriate treatment and optimize patient outcomes.

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Footnote

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