Transcatheter Valve-in-Valve Implantation for Failed Surgical Bioprosthetic Valves

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When bioprosthetic cardiac valves fail, reoperative valve replacement carries a higher risk of morbidity and mortality compared with initial valve replacement. Transcatheter heart valve implantation may be a viable alternative to surgical aortic valve replacement for high-risk patients with native aortic stenosis, and valve-in-valve (V-in-V) implantation has been successfully performed for failed surgical bioprostheses in the aortic, mitral, pulmonic, and tricuspid positions. Despite some core similarities to transcatheter therapy of native valve disease, V-in-V therapy poses unique clinical and anatomic challenges. In this paper, we review the challenges, selection criteria, techniques, and outcomes of V-in-V implantation. (J Am Coll Cardiol 2011;58:2196–209) © 2011 by the American College of Cardiology Foundation

Despite the shorter durability of bioprosthetic cardiac valves compared with mechanical prostheses, the former are often used to reduce thromboembolic risk and to avoid anticoagulation and the associated increased risk of bleeding (1,2). When bioprosthetic valves degenerate, reoperative valve replacement is the current standard of care (3–5). However, patients requiring redo valvular surgery are generally at an increased risk of adverse perioperative events. Factors that have been shown to portend a higher reoperative risk include advanced age, renal failure, pulmonary disease, cognitive impairment, reduced ejection fraction, increased ejection fraction, higher New York Heart Association functional class, need for concomitant bypass surgery, need for more than 1 reoperation, and reoperation for failed mitral valves (higher risk than aortic) (3,5–12). Operative mortality for redo valve surgery may be higher than 20% in such high-risk patients, whereas in low-risk patients, it may be <4% (8,12).

Transcatheter aortic valve replacement for native aortic stenosis has evolved as a viable alternative to open heart surgery in patients with high or prohibitive surgical risk (13–20). As transcatheter aortic valve replacement evolved and clinical outcomes improved, transcatheter treatment of degenerated bioprosthetic valves became possible using valve-in-valve (V-in-V) implantation, in which the new transcatheter valve is inserted inside the degenerated bioprosthesis. V-in-V implantation has been successfully performed in degenerated aortic, mitral, pulmonic, and tricuspid bioprostheses as well as in pulmonary conduits. A variety of percutaneous and minimally invasive surgical techniques have been used. This article reviews the challenges, selection criteria, techniques, and what is known of the outcomes of this evolving therapy.

Structural elements of bioprosthetic valves. Contemporary surgical bioprostheses generally incorporate leaflets derived from porcine valve leaflets or bovine pericardium (heterograft/xenograft). These are generally preserved in glutaraldehyde to attenuate calcific degeneration by cross-linking collagen fibers, reducing antigenicity, and preventing remodeling of extracellular matrix (21,22). Human tissue (homograft) is less commonly used. For the less common pulmonic position, valve conduits of various types are often used.

Bioprosthetic valves may be stented or stentless. Stented valves are usually constructed of whole porcine aortic valves or bovine pericardium, suspended from a support structure such as a stent or frame (Fig. 1). The support structures of current valves are composed of various alloys or plastics, designed to absorb forces on the leaflets during valve function and maintain structural integrity. The support structure is attached to a basal ring, which is covered by a fabric sewing cuff. The basal ring may be circular or scallop shaped. Newer valve designs often incorporate low-profile
or supra-aortic design features intended to optimize hemodynamic functioning (e.g., Mitroflow or Soprano valve, Sorin, Canada).

Stentless valves are sutured to the root in the position of a native valve and eliminate the support stent/frame to improve hemodynamic performance and durability (23,24). These may be of autograft, heterograft, or homograft origin. Although stentless valves tend to have better laminar flow and lower post-operative gradients, clinical outcomes have not been superior to stented valves (25,26). Some stentless valves have been associated with exuberant calcification of the aortic root, posing a particular challenge for reoperation. Stentless valves pose unique challenges for V-in-V therapy given the lack of a frame to anchor the new transcatheter heart valve (THV), and the absence of radiopaque markers to aid with positioning.

**Causes of bioprosthetic valve failure.** Failure of bioprosthetic valves may occur due leaflet failure or nonleaflet failure or both. Leaflet failures are the result of leaflet degeneration (wear and tear or calcification) or leaflet destruction (due to endocarditis). Nonleaflet failures are typically the result of pannus, thrombus, or paravalvular leaks. The outcomes of these failures may be stenosis, regurgitation, or a combination of both. In general, failure due to calcification, pannus formation, or thrombus results in valvular stenosis, and failure due to leaflet destruction (endocarditis) or paravalvular leak results in regurgitation. In failure due to wear and tear, which is frequently associated with calcification and abnormal leaflet coaptation, mixed stenosis/regurgitation is common. With current bioprosthetic valves, freedom from failure at 10 years is between 70% and 90% and at 15 years between 40% and 70% (22,27–31). Common risk factors for bioprosthetic failure include mitral valve position, younger age at implantation, renal failure, and hyperparathyroidism (22,29–31). Bioprosthetic valve calcification is markedly accelerated in younger patients, with failure rates as high as 40% at 4 years in patients younger than 30 years old (29). Not surprisingly, the lifetime risk of needing reoperation decreases with the increasing age of the patient (29,32).

When bioprosthetic valves degenerate, calcific deposits are often located within the leaflet tissue, with particular predisposition to areas of high leaflet stress (e.g., commissural and attachment points). Glutaraldehyde fixation treatments creating stable crosslinks between collagen aim to render the valve material inert, although residual glutaraldehyde may also serve as calcium binding sites (22). Various anticalcification treatments aim to reduce residual glutaraldehyde or phospholipids (e.g., Medtronic AOS [Medtronic Inc., Minneapolis, Minnesota] or Edwards ThermaFix [Edwards Lifesciences, Irvine, California]). Frequently, leaflet calcification and subsequent tears also result in some degree of valvular regurgitation. Although calcification is responsible for the majority of bioprosthetic valve failures, progressive collagen damage related to a number of immune and atherosclerotic processes may also be contributory (33–35). Pannus formation results from growth of host...
tissue and is to some extent part of the normal healing reaction to prosthesis implantation. More than 60% of explanted valves show evidence of mild pannus at the tissue-valve interface. In those with severe pannus formation, leaflet dysfunction can occur largely due to leaflet stiffness and restricted mobility. An important distinction must be made between pannus and thrombus, with qualitative and quantitative ultrasound intensity on transesophageal echocardiography helping differentiate them (36).

In patients with bioprosthetic valve regurgitation, clinicians must clarify whether it is transvalvular or paravalvular regurgitation. Although the former may be successfully treated using V-in-V therapy, the latter is not suitable for such techniques. Patients with bioprosthetic paravalvular regurgitation who are deemed unsuitable for reoperation may, however, benefit from other percutaneous techniques to occlude the paravalvular leak (37).

Technical Considerations

Transcatheter systems for V-in-V implantation. To date, 3 devices have been described in the setting V-in-V implantation. 1) The Edwards SAPIEN valve (Edwards Lifesciences) is balloon expandable, composed of a metal stent frame with bovine pericardial leaflets crimped onto a balloon catheter (15,16) (Fig. 2). Initial models used stainless steel frames, whereas recent versions use a lower profile cobalt chromium frame (38). The current SAPIEN XT...
valve is manufactured with expanded external diameters of 20, 23, 26, and 29 mm, allowing treatment of failed bioprostheses in all positions. 2) The CoreValve system (Medtronic Inc.) is composed of a self-expandable nitinol multilevel frame with porcine pericardial leaflets (Fig. 2). This valve is available in external diameters of 26 and 29 mm, with additional sizes anticipated. The device is deployed by retraction of a sheath. The valve can only be mounted in 1 direction within the restraining sheath; hence, the current device can only be delivered in a retrograde orientation via a transfemoral or subclavian/axillary/transaortic approach. The long frame limits its utility for V-in-V implantation for failed aortic bioprostheses. 3) The Melody transcatheter valve (Medtronic Inc.) is composed of a bovine jugular venous valve attached to a platinum iridium stent scaffold delivered using a balloon-in-balloon system to facilitate positioning during expansion (Fig. 2). The valve is designed for use in the pulmonary circulation, mostly to treat dysfunctional right ventricular outflow tract conduits or other pulmonary bioprostheses in patients with congenital heart disease.

**Manufacturer sizing and labeling of surgical bioprosthetic heart valves.** The methodologies for labeling valve sizes are not standardized and vary by the different manufacturers. Internal diameters vary markedly for a given labeled size (39,40). The labeling of valve sizes may refer to internal or outer diameters of the valve (in the case of stented valves, Fig. 1) or the external diameter for most stentless valves. In most cases, the labeled size of a stented valve refers to the stent outer diameter (apart from the Soprano valve in which the label reflects the internal diameter). Different bioprostheses with the same label size frequently have different internal diameters and external sewing ring diameters. The external sewing ring diameter generally reflects the original native annulus diameter as measured by the surgeon at the time of the original valve implantation.

The exact *internal* dimensions of a surgical bioprosthesis are those that are most relevant for V-in-V therapy, and in the case of most stented valves, these diameters are significantly smaller than the labeled valve size. Most stented bioprostheses with labeled diameters of 19 to 21 mm may have internal diameters that are too small to achieve acceptable hemodynamics with V-in-V therapy. Given the heterogeneity of valve types and sizing nomenclature, operators contemplating V-in-V therapy must familiarize themselves with the structural elements and dimensions of the specific bioprosthesis that they are treating. Obtaining a detailed operative report is critical.

### Table 1

**Valve Dimensions for Selected 18- to 23-mm Stented Surgical Bioprostheses, per Manufacturer Product Information**

<table>
<thead>
<tr>
<th>Valve Type/Model (Manufacturer)</th>
<th>Sewing Ring External Diameter, mm</th>
<th>Stent Outer Diameter, mm</th>
<th>Stent Internal Diameter, mm</th>
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<tr>
<td><strong>18 Soprano (Sorin Biomedica)</strong></td>
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<td>Magna (Edwards Lifesciences)</td>
<td>24</td>
<td>19</td>
<td>18</td>
</tr>
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<td>Perimount (Edwards Lifesciences)</td>
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<td>N/A</td>
<td>N/A</td>
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<td>15.4</td>
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<tr>
<td><strong>22 Soprano (Sorin Biomedica)</strong></td>
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<td>Epic Supra/Biocor Supra (St. Jude Medical)</td>
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N/A = not available.
provide the relevant dimensions for a range of commonly implanted surgical bioprostheses.

In general, a V-in-V implant is chosen with a nominal external diameter matching or exceeding the reported internal diameter of the failed surgical valve to allow for secure fixation and sealing. It is important to consider that excess V-in-V oversizing may be associated with significant underexpansion the newly implanted valve, resulting in compromised hemodynamics and durability. The acceptable boundaries of underexpansion remain undefined in this context, although clinical experience suggests that a range of 10% to 15% may be acceptable.

The mechanism of failure of the initial valve deserves consideration. Regurgitant valves with torn leaflets may have relatively larger internal diameters, whereas valves with prominent pannus or calcification may have reduced internal dimensions. Sizing consideration needs to take into account the reported internal diameter, bulkiness of the degenerated valve, nature of the valve failure, and location of calcification or pannus. Pre-procedural screening with both computed tomography and transesophageal echocardiography may help quantify discrepancies between in vitro and in vivo bioprosthetic internal diameters; provide information regarding valve bulkiness, calcification, and pannus; and define the internal diameters when the specific valve model or size is unknown.

**Access route.** Depending on the valve location and the delivery system, a number of approaches may be considered. Aortic V-in-V implantation may be performed using transapical access, which may facilitate crossing a stenotic valve and coaxial positioning, or various transarterial approaches that may avoid the need for a thoracotomy and a general anesthetic. Mitral V-in-V implantation appears ideally suited, at least anatomically, for the transapical approach, although the more circuitous transvenous-transseptal approach has been successfully used and avoids the need for a thoracotomy and possibly the need for general anesthesia (41–46). Pulmonary conduits are ideally suited for percutaneous femoral, subclavian, or internal jugular venous access depending on the characteristics of the particular delivery system (47–49). Tricuspid V-in-V implantation has been achieved using percutaneous transvenous access from the superior vena cava and the femoral vein, as well as using an open transatrial approach with direct right atrial puncture (44,48,50,51).

**The role of pre-dilation.** Balloon pre-dilation may be performed to facilitate crossing or positioning during THV implantation. However, degenerated bioprostheses are often

### Table 2 Valve Dimensions for Selected 24- to 29-mm Stented Surgical Bioprostheses, per Manufacturer Product Information

<table>
<thead>
<tr>
<th>Valve Label Size</th>
<th>Valve Type/Model (Manufacturer)</th>
<th>Sewing Ring External Diameter, mm</th>
<th>Stent Outer Diameter, mm</th>
<th>Stent Internal Diameter, mm</th>
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<tbody>
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<td>24</td>
<td>Soprano (Sorin Biomedica)</td>
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<td>27</td>
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<tr>
<td>25</td>
<td>Magna (Edwards Lifesciences)</td>
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<tr>
<td>Perimount (Edwards Lifesciences)</td>
<td>Mosaic/Hancock II (Medtronic)</td>
<td>Mosaic Ultra/Hancock I Ultra (Medtronic)</td>
<td>Mitroflow (Sorin Biomedica)</td>
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<tr>
<td>26</td>
<td>Soprano (Sorin Biomedica)</td>
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<td>29</td>
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<td>Soprano (Sorin Biomedica)</td>
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| N/A = not available.
bulky and friable. Debris embolization is of particular concern for left-sided bioprostheses, and leaflet tears may result in acute severe regurgitation, which may be problematic if there is any delay in implanting the THV. Predilation may be necessary when a retrograde technique is used for a severely stenosed and calcified valve (e.g., transarterial crossing of an aortic bioprosthesis). Predilation is generally not necessary with antegrade crossing of a stenotic bioprosthesis as the funneled inflow and leaflets facilitate THV crossing. Similarly, predilation is not generally necessary with severely regurgitant bioprostheses, regardless of the access mode or the type of THV chosen.

Device selection for V-in-V implantation. No doubt many of the valves currently undergoing evaluation or under development will be used for future V-in-V implantations. To date only 3 types of THVs have been used in this setting.

AORTIC. The Edwards SAPIEN/XT and the Medtronic CoreValve devices have been widely used in the aortic position. The Medtronic Melody valve has also been used, but the durability of this venous valve in the systemic circulation is doubtful.

MITRAL. Only the SAPIEN/XT valves have been used in the mitral position to our knowledge (Fig. 3). The design of the current CoreValve system is not suited to mitral implantation and the Melody device would not be anticipated to be sufficiently durable in the systemic circulation.

PULMONARY. The Melody and SAPIEN/XT (Fig. 4) valves have been used in this position. Pulmonary valve disease is mostly part of more complex congenital structural disease, with pulmonary conduits of relatively low pressure and mostly tubular, often in patients who have undergone multiple previous procedures and hence ideally suited to V-in-V therapy.

TRICUSPID. The Edwards SAPIEN/XT (Fig. 5) and Melody valves have been used in this position.

Positioning principles and deployment. For secure deployment without embolization, the THV is ideally positioned to overlap the surgical valve annular sewing ring (Fig. 6). To achieve this, the exact type of bioprosthesis and its characteristics must be known, including whether it is stented or stentless, dimensions, and radiologic appearance (Fig. 7). Some valves may have radiopaque markers or rings at the basal portion close to the anatomic sewing ring (Fig. 8), whereas in others, the markers may be close to the tip of the stent posts or there may be no radiopaque markers at all.

Accurate placement requires coaxial positioning within the valve, which in turn requires determining the appropriate C-arm angulation representing perpendicularity to the valve plane (52). Fluoroscopically visible components of surgical valves can be used effectively to achieve perpendicularity. If the radiographic marker is a basal ring, rotating the C arm until the ring is side on (appearing as a straight “line”) suggests perpendicularity to the valve plane and an appropriate implant view (Fig. 9). The typical aortic valve is directed slightly to the right and posterior, such that left anterior oblique–cranial views are often helpful. The typical mitral valve is directed to the left and anterior, such that right anterior oblique views are often helpful. Further
manipulation of the delivery system or guidewire may then be required to achieve coaxial alignment. For radiolucent valves (e.g., stentless) angiography with a pigtail catheter in one of the valve cusps and transesophageal echocardiographic guidance may be helpful.

When treating failed pulmonic homografts/conduits, pre-stenting with a bare metal stent may provide additional radial strength and reduce the risk of stent fracture with the Melody valve. Similarly, pre-stenting may provide a longer “landing zone” with a greater margin of safety during positioning with the relatively short Edwards SAPIEN/XT valve (less necessary when treating failed stented bioprostheses that may provide an adequate support structure). Pre-stenting with a covered stent may also reduce the risk associated with conduit rupture when this is a concern.

Pacing. The Edwards valves have generally been deployed with rapid ventricular pacing to aid accurate positioning of the relatively short valve. This may not be required in the lower pressure venous system; although, if cardiac motion is problematic, we have used either rapid pacing or induced ventricular fibrillation. The Medtronic Melody valve is generally deployed without rapid pacing in the more commonly treated pulmonary and tricuspid positions (50), but with pacing in the aortic position. Rapid pacing is generally not used when using the CoreValve device, although this may be of value during difficult deployment, particularly when treating a severely regurgitant bioprosthesis.

Results

Early pre-clinical studies. Boudjemline et al. (53) evaluated the concept of mitral V-in-V therapy in a sheep model. A bovine jugular valve was mounted onto a stent and implanted off-pump using a transcatheter approach. Walther et al. (54) evaluated the use of a more contemporary transcatheter system in both the aortic and mitral positions in pigs. Edwards THVs were implanted into Carpentier Edwards xenografts transapically in the beating heart model. Azadani et al. (55) evaluated the hemodynamic performance of 23-mm THVs within degenerated surgical bioprostheses. They demonstrated in an in vitro model that incomplete stent expansion resulted in leaflet distortion and central regurgitation when implanted in 19- and 21-mm bioprostheses. In a subsequent report, the same group used a
custom-designed supravalvular THV (56), achieving more favorable hemodynamics.

**Valve hemodynamics post–V-in-V.** THV expansion during V-in-V therapy is constrained by the internal dimensions of the bioprosthetic valve, especially by the relatively undilatable sewing ring (Fig. 8F). Although this may reduce the chance of annular rupture, heart block, and coronary occlusion compared with therapy with native aortic valve
stenosis, valve underexpansion may contribute to hemodynamically significant residual gradients after V-in-V implantation. Table 4 provides a summary of the hemodynamic outcomes associated with V-in-V implantation (57–66).

Valve underexpansion may be expected to affect transvalvular gradients, effective orifice areas, and leaflet and stent durability. Post-procedural transaortic mean gradients are in the range of 10 to 22 mm Hg in most series (range: 4 to 30 mm Hg). In comparison, mean gradients after transcatheter therapy for native aortic stenosis are generally around 10 mm Hg (67,68). Although elevated gradients may be acceptable in some patients who cannot undergo open-heart surgery, they may be inadequate in others with longer expected survival.

There are currently insufficient long-term outcome data to understand the clinical sequelae of such residual gradients. From our own experience, we have yet to see patients fail to improve or return for further intervention because of elevated gradients. For example, 2 patients from our cohort had transaortic gradients of 24 and 27 mm Hg, and at a follow-up of 610 and 540 days, respectively; both remain improved and relatively asymptomatic. However, it is likely that some patients may fail to obtain adequate symptomatic improvement if sufficiently low transvalvular gradients are not obtained. V-in-V designs that minimize residual gradients will become increasingly important as younger and lower risk patients are treated in the future.
Regurgitation post-V-in-V. Although paravalvular leaks are common after transcatheter aortic valve replacement for native aortic stenosis, regurgitation appears to be absent or mild in most published V-in-V reports thus far. The circular sewing ring of surgical bioprostheses appears to facilitate intervalvular sealing. We suggest reporting 3 sources of regurgitation in the context of V-in-V therapy (Fig. 10):

![Fluoroscopic Positioning for V-in-V Implantation for Bioprosthetic Aortic Valve Failure](image)

**Figure 8** Fluoroscopic Positioning for V-in-V Implantation for Bioprosthetic Aortic Valve Failure

Importance of knowing the radiological appearance of the surgical valve treated. (A) Carpentier Edwards pericardial valve (the wire frame within the valve posts is visible, although the rigid sewing ring below this required for V-in-V fixation is radiolucent in this model). (B) Positioning of the Edwards SAPIEN just below the lowest radiopaque portion (arrow indicates lowest portion of the SAPIEN valve). (C) Sorin Mitroflow valve. (D) Positioning the Edwards SAPIEN just below the lowest radiopaque portion. (E) Medtronic Mosaic valve: the radiopaque markers are near the top of the surgical stent posts (black arrows), hence the valve is positioned completely below these markers (white arrows). (F) Deployed Edwards SAPIEN valve. The “waist” at the lower part of the implanted valve demonstrates the narrowest location of the surgical valve (white arrow). The SAPIEN valve remained slightly underexpanded, and the residual mean gradient was 30 mm Hg.

![Perpendicular Alignment for Implantation](image)

**Figure 9** Perpendicular Alignment for Implantation

Fluoroscopic images of a Carpentier Edwards pericardial valve in the mitral position. (A) In the posterior-anterior projection, the valve is not perpendicular to the image intensifier, leading to foreshortening. (B) In the 25° right anterior oblique projection, the valve is now perpendicular/orthogonal to the image intensifier, allowing more accurate positioning of a transcatheter valve.
1. Paravalvular: arising between the native valve and the original failed bioprosthetic valve. THV implantation is unlikely to ameliorate this, and paravalvular leak closure with an occlusive plug may be an option.

2. Intervalvular: arising from the area between the old “outer” bioprosthetic valve and the new “inner” transcatheter valve. This may occur from incomplete THV expansion (undersizing, severe calcification of bioprosthetic valve leaflets). This has not been a major issue in published series thus far.

3. Transvalvular: arising through the newly implanted THV. This may occur from incomplete leaflet coaptation due to an oversized and deformed THV or a THV leaflet “stuck” in an open position. This has not been a major issue in published series thus far.

Coronary concerns. Most stented surgical bioprostheses have leaflet tissue mounted internal to the stent frame (Fig. 11). To some extent, this ensures that degenerated bioprosthetic tissue will not be displaced external to the valve posts. When bioprosthetic tissue is mounted external to the valve frame or there is no stent frame, there is no such assurance. For example, acute coronary ostial occlusion by displaced externally mounted pericardial tissue has been reported after V-in-V implantation within the Mitroflow valve (Sorin Group, Burnaby, British Columbia, Canada) (69), although many successful and uncomplicated such implantations have also been performed. Coronary obstruction has similarly been observed with stentless prostheses. It is reasonable to think that post–V-in-V implantation coronary compromise might also occur with other failed bioprostheses that have externally mounted leaflets, are nonstented, implanted in a supra-annular position, or have unusually bulky diseased leaflets, particularly in patients with low-lying coronary ostia and shallow sinuses. When considering aortic V-in-V im-

![Figure 10 Possible Sources of Regurgitation After V-in-V Implantation](image-url)

“Down the barrel/end on” image of an Edwards SAPIEN valve (white arrow) implanted within a Medtronic Mosaic valve (black arrows indicate the radiopaque markers). The large surrounding circle (black arrows) indicates the large surrounding circle representing surrounding native tissue. Regurgitation may arise from 3 areas depicted schematically by the 3 black circles: 1, paravalvular, arising between the native tissue and the original failed bioprosthetic valve; 2, intervalvular, arising from the area between the old “outer” surgical valve and the new “inner” transcatheter valve; and 3, transvalvular, arising from within the transcatheter valve.
plants, the relationship of the failed valve to the coronary ostia must be carefully evaluated.

Conclusions

Initial results with V-in-V therapy are very encouraging. However, in the absence of rigorous evaluation and long-term follow-up, V-in-V therapy is probably best considered only for patients who present with a prohibitive reoperative risk. Therapy of small (e.g., ≤21-mm aortic valves) should be approached with caution as significant residual gradients may remain with currently available valves. Operators should be encouraged to share their experience, whether favorable or unfavorable. Future technologic advances may continue to improve both hemodynamic and clinical outcomes.

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