Taylor & Francis
Taylor & Francis Group

Structural Heart
The Journal of the Heart Team

ISSN: 2474-8706 (Print) 2474-8714 (Online) Journal homepage: https://www.tandfonline.com/loi/ushj20

Transcatheter Valve Implantation in Degenerated Bioprosthetic Surgical Valves (ViV) in Aortic, Mitral, and Tricuspid Positions: A Review

Uri Landes & Ran Kornowski

To cite this article: Uri Landes & Ran Kornowski (2017) Transcatheter Valve Implantation in Degenerated Bioprosthetic Surgical Valves (ViV) in Aortic, Mitral, and Tricuspid Positions: A Review, Structural Heart, 1:5-6, 225-235, DOI: 10.1080/24748706.2017.1372649

To link to this article: https://doi.org/10.1080/24748706.2017.1372649

Accepted author version posted online: 28 Aug 2017.
Published online: 11 Sep 2017.

Submit your article to this journal

Article views: 80

View Crossmark data

Full Terms & Conditions of access and use can be found at
https://www.tandfonline.com/action/journalInformation?journalCode=ushj20

STRUCTURAL HEART
2017, VOL. 1, NOS. 5–6, 225–235
https://doi.org/10.1080/24748706.2017.1372649

REVIEW ARTICLE

Transcatheter Valve Implantation in Degenerated Bioprosthetic Surgical Valves (ViV) in Aortic, Mitral, and Tricuspid Positions: A Review

Uri Landes, MD [a,b] and Ran Kornowski, MD[a,b]

[a]Department of Cardiology, Rabin Medical Center, Petach Tikva, Israel; [b]Sackler Faculty of Medicine, Tel Aviv University, Ramat Aviv, Israel

ABSTRACT

Bioprosthetic surgical heart valves (SHVs) tend to degenerate with time, and valve re-operation carries substantial risks. Transcatheter heart valve (THV) implantation into a degenerative biological bioprosthesis (valve-in-valve [ViV] procedure) has evolved as a viable strategy in suitable cases of SHV degeneration, and nearly all heart valves have already been treated using the ViV technique. The creation of an optimal effective orifice area and a sufficient, yet atraumatic, expansion and sealing of the neo-valve (in-valve) apparatus is key for optimal ViV implantation. Several aspects are necessary to achieve this, including a detailed appreciation of the SHV and THV, pre-procedural learning of the anatomy, optimal access selection, and avoidance of any interference with the perivalvular structures. This review based on the authors' personal experience and an updated review of the literature is aimed at covering contemporary accumulated knowledge of ViV therapeutics in the aortic, mitral, and tricuspid positions, focusing on practical issues and challenges for optimal patient outcomes.

ARTICLE HISTORY Received 22 May 2017; Revised 17 July 2017; Accepted 23 August 2017

KEYWORDS Aortic; bioprosthetic surgical heart valve; degeneration; mitral; transcatheter heart valve; tricuspid; valve-in-valve

Introduction

The standard of care for patients with significant valvular heart disease is open-heart surgery to correct or replace the damaged valve. Bioprosthetic surgical heart valves (SHVs) are less thrombogenic than mechanical valves and do not require lifelong anticoagulation therapy. These advantages, together with the aging of the population, has shifted the balance between mechanical and bioprosthetic SHV utilization towards the latter.[1] Nevertheless, bioprostheses eventually tend to degenerate. The frequency of bioprosthetic SHV degeneration is age dependent. In the aortic position, it has been reported to be 60–70% at 20 years in patients <65 years old, whereas in patients aged ≥65 years it is approximately half as high. Similarly, the frequency of mitral bioprosthetic SHV deterioration at 20 years has been reported to be 73% in patients <65 years old and 41% in patients ≥65 years old.[2,3] Reported re-operation rates following modern device implantation are approximately 5% at 5 years, 10% at 10 years, and 30% at 15 years.[4–7] However, re-operation is a limited surrogate for valve degeneration, as it does not encompass the full spectrum of this clinical syndrome, and certainly not the full scope of hazards associated with such a deleterious scenario. Although still the benchmark, valve re-operation carries substantial morbidity and mortality risks.[8–13] Therefore, less-invasive, catheter-based approaches are slowly but surely gaining domination over the traditional therapeutic armamentarium. Transcatheter heart valve (THV) implantation into a degenerative biological bioprosthesis (valve-in-valve [ViV] procedure) has evolved as a viable strategy in suitable cases of SHV degeneration. Most current experience is in the aortic ViV position (A-ViV). Nonetheless, nearly all heart valves have already been treated using the ViV technique. This review based on the authors' personal experience and on an updated review of the literature is aimed at covering contemporary accumulated knowledge on ViV therapeutics in the A-ViV, mitral (M-ViV), and tricuspid (T-ViV) positions, focusing on practical issues and challenges for optimal ViV patient outcomes.

Discussion

Current evidence

Existing clinical evidence is based on a few medium-sized registries, case series, and case reports. Table 1 summarizes the characteristics of the main clinical ViV publications[14–31] excluding <10 cases/reports and those focused on children/congenital heart disease.

Clinical presentation and patient selection

Current ViV candidates are patients with significant bioprosthetic SHV dysfunction who are at high surgical risk. Though the peak incidence is 7–15 years after the index surgery, patients may present any time after SHV implantation.[24,28,29] Candidate patients for M-ViV therapy are usually younger than A-ViV candidates and older than T-ViV candidates. Females comprise approximately half of all A-ViV patients, M-ViV patients are predominantly females, and the proportion of females is even higher among T-ViV patients.[24,28,29] Clinical manifestation varies from an incidental finding (i.e. a change in heart sounds on

CONTACT Ran Kornowski ran.kornowski@gmail.com Chairman, Department of Cardiology, Rabin Medical Center, Petach Tikva 49100, Israel.
© 2017 Cardiovascular Research Foundation

Table 1. Characteristics of studies of transcatheter heart valve (THV) implantation into a degenerative biological bioprosthesis (ViV) in adults.

									Outcome		
Reference	Study year	No. of cases	ViV type	Age (years)	Baseline NYHA III–IV	STS	Log. Euroscore	THV type	Valve-Success[e]	Survival[f]	NYHA I–II
Webb et al.[14]	2010	24	A/M/T	68 ± 16	88%	12.4 ± 8.8	30.9 ± 16.4	BE	96%	96%	88%
Pasic et al.[15]	2011	14	A	73 ± 13	100%	21.9 ± 10.9	45.3 ± 22.2	BE	100%	100%	100%
Piazza et al.[16]	2011	20	A	75 ± 13	NA	7 ± 4	27 ± 13	BE/SE	90%	85%	NA
Cheung et al.[17]	2011	11	M	81 ± 6	96%	12.1 ± 6.8	NA	BE	100%	100%	96%
Eggebrecht et al.[18]	2011	47	A	80 ± 7	96%	11.6 ± 8.5	35.0 ± 18.5	BE/SE	94%	83%	98%
Roberts et al.[19]	2011	15	T	32 (8–64)	73%	NA	NA	BE	93%	93%	87%
Bapat at al.[20]	2012	23	A	77 ± 14	100%	7.6 ± 5.4	31.8 ± 20.3	BE	96%	100%	100%
Linke et al.[21]	2012	27	A	74 ± 8	78%	NA	31 ± 17	SE	100%	93%	92%
Ihlberg et al.[22]	2013	45	A	80 ± 6	100%	15.0 ± 10.8	35.4 ± 16.1	BE/SE	96%	96%	88%
Cullen et al.[23b]	2013	19	M/T	65 (10–88)	79%	13.3 ± 5.6	NA	BE	100%	100%	74%
Dvir et al./VIVID[24]	2014	459	A	78 ± 10	92%	10 (6.2–16.1)	29 (19–42)	BE/SE	86%	92%	93%
Godarta et al.[25]	2014	71	T	28 ± 17	82%	NA	NA	BE	97%	97%	NA
Conradi et al.[26c]	2015	73	A/M/T	74 ± 13	NA	8.8 ± 7.4	26.2 ± 17.8	BE/SE	97%	92%	NA
Codner et al.[27]	2015	33	A/M/T	81 ± 7	94%	9.1 ± 5.5	28.0 ± 13.5	BE/SE	100%	100%	100%
McElhinney et al.[28]	2016	156	T	40 (5–84)	72%	NA	NA	BE	99%	97%	77%
Landes et al.[29d]	2017	155	A/M/T	77 ± 13	88%	7.7 ± 5.2	24.7 ± 12.4	BE/SE	95%	92%	98%
Webb et al.[30]	2017	365	A	79 ± 10	90%	9.1 ± 4.7	12.3 ± 9.8	BE	97%	97%	89%
Kornowski et al./VIVA[31]	2017	202	A	80 ± 7	71%	6.6 ± 5.1	25.0 ± 14.3	SE	98%	98%	93%

Note. [a]A: 10 cases; M: 7 cases; T: 1 case. [b]M: 9 cases; T: 10 cases. [c]A: 54 cases; M: 17 cases; T: 2 cases. [d]A: 110 cases; M: 36 cases; T: 9 cases. [e]Correct positioning of functioning single prosthesis with no moderate regurgitation, death, or urgent surgery during the procedure. [f]In-hospital/30 day.

A, aortic; M, mitral; T, tricuspid; NYHA, New York Heart Association functional class; STS, Society of Thoracic Surgeons score; BE, balloon expandable; SE, self expandable; NA, not applicable.

auscultation or an asymptomatic increase in transvalvular gradient/regurgitation on echocardiography), worsening dyspnea and heart failure (right or left heart failure with respect to the degenerated SHV side), new onset atrial fibrillation, or more rarely as hemolytic anemia or an embolic cerebrovascular event (when left-sided SHV is involved). Currently, data from the largest global ViV registry (Valve-in-Valve International Data [VIVID] registry) may serve as a point of reference for expected outcomes of ViV.[24,28] Accordingly, the 30-day survival rate is 92.4% after A-ViV, 91.1% after M-ViV, and 96.8% after T-ViV, and 1-year survival rates are 83.2% and 90.4% for A-ViV and T-ViV, respectively (the 1-year data on M-ViV has not yet been published). In A-ViV patients, factors associated with all-cause mortality are small or stenotic SHV (vs. large and regurgitant SHVs, respectively). Age > 60 years, severe symptoms at rest (baseline NYHA functional class IV), and renal insufficiency predict mortality among T-ViV patients.

The patient's assessment is crucial and, as guidelines emphasize, should be carried out by a dedicated team of multidisciplinary professionals, including cardiologists with expertise in valvular heart disease, heart surgeons, imaging specialists, anesthesiologists, and nursing professionals (Heart Team), integrating the risk-benefit ratio of different treatment strategies with the patient's preferences and values. A shared decision-making approach must integrate multiple concerns, such as the estimated surgical risk (evaluated by the logistic EuroScore and Society of Thoracic Surgeons [STS] risk scores), the patient's frailty and functional status, life expectancy, kidney function, and other comorbidities, similar to risk assessments before native valve transcatheter aortic valve implantation (TAVI) procedures.[7,32]

Failure of the SHV may manifest as valve stenosis, insufficiency, or both (mixed). In the VIVID registry,[24,28] degeneration presented as stenosis (39.4% and 29%), regurgitation (30.3% and 24%), and mixed (30.3% and 47%) in the degenerated aortic and tricuspid SHVs, respectively. Also in our experience,[29] most patients with mitral or tricuspid SHV degeneration suffer from significant regurgitation, whereas pure stenosis in these valve positions is less common. In the aortic position, the three phenotypes (stenosis/regurgitation/mixed) generally occur equally and significantly influence outcome, which is inferior in patients with pure SHV stenosis.[21] Although the mode of pathogenesis is mostly calcification, wear and tear, and pannus formation, valve thrombosis and/or active endocarditis are also common and must be excluded, as they will disqualify patients from catheter-based intervention. In addition, in regurgitant SHV, the location of the leak must be determined intravalvular versus paravalvular, as the rigid band of the surgical device will not allow good paravalvular leak (PVL) sealing, making most PVLs more suitable for other therapeutic techniques.[16,33–35]

Procedural planning and execution

The creation of an optimal effective orifice area (EOA) and a sufficient, yet atraumatic, expansion and sealing of the neo-valve (in-valve) apparatus, is key for optimal ViV implantation. To achieve this goal, the operator and Heart Team must master two fundamental matters: sizing and positioning. Performing these tasks erroneously may lead to device embolization, increase the risk for coronary obstruction (in A-ViV) or left ventricular outflow tract (LVOT) obstruction (M-ViV), and/or leave valvular regurgitation; too low/oversized THV will reduce leaflet mobility and result in central regurgitation and/or excessive post-procedural pressure gradients, whereas too high/undersized THV will result in inadequate intervalvular sealing and PVL. Experience and technical skills are necessary for both sizing and positioning, but at the outset, a detailed appreciation of SHV and THV anatomy, fluoroscopic appearances, and interactions (with both each other and surrounding tissue structures) must be attained (see Figure 1).

The surgical bioprosthetic heart valve

SHVs are broadly classified based on the absence or presence of a rigid stent frame.

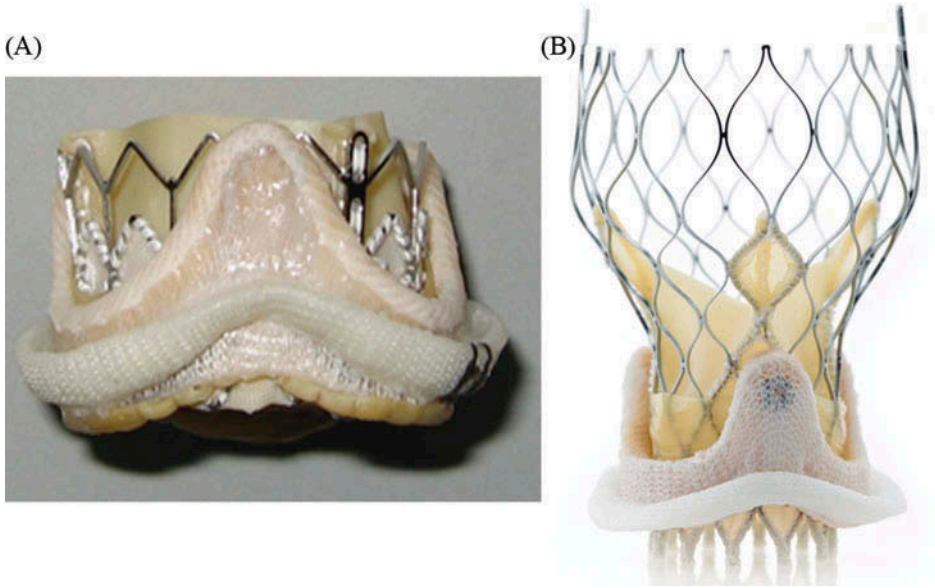

Figure 1. Photographs of two transcatheter heart valves (THVs) inside a Carpentier Edwards surgical bioprosthetic valve (Edwards Lifesciences, Irvine, CA, USA). (A) Sapien valve (Edwards Lifesciences, Irvine, CA, USA). (B) CoreValve (Medtronic, Inc., Minneapolis, MN, USA). THVs are broadly classified as balloon expandable (A) or self-expandable (B), each with advantages under certain circumstances in ViV procedures, mainly due to their different structures. Notice the low and symmetric frame shape of the Sapien and the high, supra-annular leaflet position of the CoreValve.

Stented valves

Stented valves are the most commonly used SHVs. They consist of a rigid frame with three posts, from which the leaflets are suspended, and a ring at the base, which is typically covered with a fabric sewing cuff that facilitates its suturing to the native valve annulus during surgery.[36] In the VIVID registry, stented SHVs constitute 76.7% of all SHVs; the most common types used were the Perimount Magna and porcine Edwards valves (Edwards Lifesciences, Irvine, CA, USA), Mitroflow (CarboMedics Inc., Sorin Group, Austin, TX, USA), Mosaic (Medtronic, Inc., Minneapolis, MN, USA), Biocor (St. Jude Medical Inc., St. Paul, MN, USA), and Hancock (Medtronic Inc., Minneapolis, MN, USA).[24] First, it is essential to assimilate that the manufacturers' label size corresponds to the external diameter of the ring with the aim to aid the surgeon during implantation. Therefore, it is larger than the internal diameter (ID) of the SHV, which itself may be larger than the "true ID" in the case where the leaflets are sutured from inside the SHV frame.[37] The differences between ID and "true ID" measurements will further increase if the intra-annular leaflets are relatively thick (i.e. porcine leaflets as opposed to bovine pericardial leaflets). As the "true ID" is the most relevant, though not the only, element in ViV sizing, stented valves should always be further classified relative to their leaflets' position with respect to the stent frame (i.e. intra or external leaflets, and intra or supra annular), as these features will greatly influence the choice of THV, outcome, and potential complications (as discussed below). Second, it is essential to remember that not all stented valves are visible during fluoroscopy (i.e. have a radio-opaque ring and/or stent frame), and that visible SHVs differ in their fluoroscopic appearance. As the SHV ring is the part that should be used as a reference plane during implantation, understanding its relationship with the fluoroscopy visible parts of the device is a key element in THV positioning. Figure 2 demonstrates some differences between stented SHV structures and their implications for ViV sizing and positioning. Essential and comprehensive information on the fluoroscopic and anatomical features of SHVs is accessible and free on the A-ViV and M-ViV web apps and may aid in mastering most diversities.[38,39]

Stentless valves

Stentless valves are usually made from porcine or human aortic root tissue and do not have a rigid stent frame. They are surgically implanted to the aortic root via full root replacement or subcoronary sutures. Stentless valves implanted by subcoronary sutures may potentially impose a higher risk during A-ViV, as the suture line and leaflets are placed close to the native coronary ostia, potentially capable of being pushed outwards by the THV and closing the ostia during implantation, further stressing the importance of obtaining a detailed surgical history.[40,41] In stentless SHVs, manufacturer sizes are not standardized, making them even less reliable as a sizing index than in stented SHVs. Importantly, these valves do not have any radiopaque landmarks, making ViV positioning much more challenging than in most stented SHVs. In the VIVID registry and our experience, stentless SHVs constitute 12–25% of ViV cases. The five most common types used are homografts, CryoValve (CryoLife, Inc., Kennesaw, GA, USA), Freestyle (Medtronic, Inc., Minneapolis, MN, USA), Freedom (Sorin Group, Austin, TX, USA), and Toronto SPV (St. Jude Medical Inc., St. Paul, MN, USA).[24,28,29]

Rapid deployment surgical valves

This relatively new subcategory of bioprosthetic SHVs in the aortic position can be considered "sutureless" SHVs (Perceval, Sorin Biomedica, Sallugia, Italy; Intuity, Edwards Lifesciences, Irvine, CA, USA; and Enable, Medtronic Inc., Minneapolis, MN, USA), and are

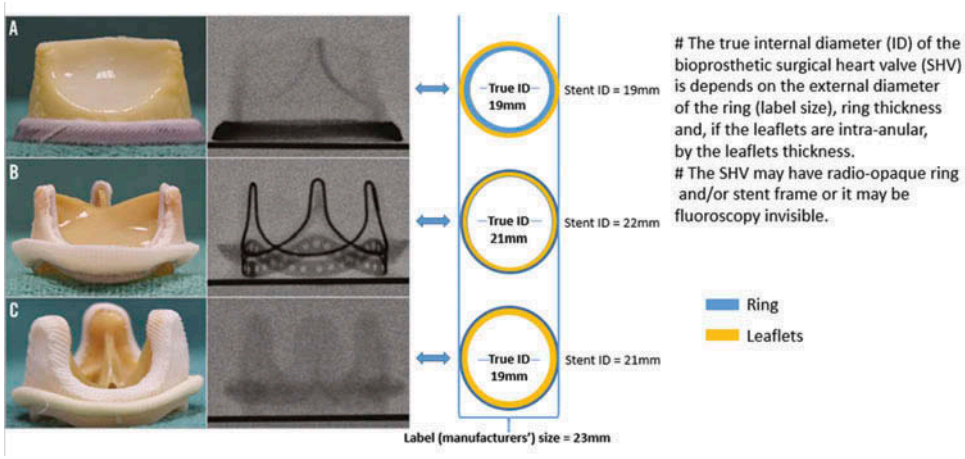

Figure 2. Three examples that demonstrate some differences in stented SHV structures and their implications on ViV sizing/positioning. (A) Mitroflow™ (CarboMedics Inc., Sorin Group, Austin, TX, USA): extra-annular pericardial leaflets and fluoroscopy visible sewing ring. (B) Perimount™ (Edwards Lifesciences, Irvine, CA, USA): intra-annular pericardial leaflets, invisible sewing ring but visible stent frame under fluoroscopy. (C) The Aspire™ (Vascutek, Leeds, UK): intra-annular porcine leaflets and completely invisible under fluoroscopy.

increasingly being used for a shorter cross-clamp time and to reduce the risk of surgical complications. These valves have no suturing ring, a very elastic stent body, and a unique bulky structure. Sutureless valves require several sutures to secure their position within the aortic annulus; thus, the proper term is "rapid deployment surgical valves with minimal sutures." Currently, all available sutureless SHVs are stented and visible on fluoroscopy. Experience with ViV sutureless SHVs is minimal, though we recently demonstrated that it is technically and clinically effective and safe.[42]

The transcatheter heart valve

Based on their expandability modus operandi, THVs are broadly classified as balloon-expandable or self-expandable. Although no comparative trials have been published, advantages to using one device over the other may exist in certain circumstances discussed below. In ViV procedures, as in native TAVI procedures, the two most commonly used devices are the balloon-expandable CoreValve (Medtronic, Inc., Minneapolis, MN, USA), which is used only in A-ViV procedures, and the self-expandable Sapien (Edwards Lifesciences, Irvine, CA, USA), which is used in A-ViV, as well as mitral and tricuspid ViV interventions. In a recent matched comparison of THVs for A-ViV implantation, the use of Portico versus CoreValve demonstrated differences in post-procedural hemodynamics and 1-year clinical outcomes in favor of the CoreValve device.[43] The Melody (Medtronic Inc., MN, USA) THV is often used in T-ViV, as it is the routinely available device in many congenital heart disease specialty centers. Although many other different THVs have been used in some ViV procedures[26,44–46] (i.e., Lotus, Boston Scientific Inc., MN, USA; Melody, Medtronic Inc., MN, USA; Portico, St. Jude Medical Inc., MN, USA; JenaValve, JenaValve Inc., Munich, Germany; and Engager, Medtronic Inc., MN, USA), the experience with these devices is more limited and will not be detailed in the current review.

The balloon-expandable Sapien valve

The Sapien valve (Edwards Lifesciences, Irvine, CA, USA) has evolved through three generations: the Edwards Sapien, the Sapien XT, and the contemporary Sapien 3. The device, bovine pericardial leaflets affixed on a cobalt-chromium stent frame, is currently available in 20, 23, 26, and 29 mm. The contemporary Sapien 3 has an excellent sealing ability due to an additional outer polyethylene terephthalate sealing skirt on its inflow portion on top of the previous inner skirt, though sealing may be less critical in ViV procedures than TAVI, as paravalvular leak is less common and less significant in ViV. It is geared with a lower profile delivery system (14 F, 16 F for femoral, and 18 F for transapical access) that is more flexible and facilitates navigation through small and tortuous peripheral vasculature, with an additional fine alignment wheel that allows more accurate and reproducible positioning. Compared to the CoreValve family, its multiple access proficiency (i.e. transfemoral, transaxillary, transapical, transaortic, and transatrial), low-symmetric frame design, and bidirectional (anterograde, retrograde) catheter adeptness make the Sapien valve the current THV of choice for atrio-ventricular ViV implantation and some A-ViV procedures.

The self-expandable corevalve

ey features of the first generation CoreValve (Medtronic, Inc., Minneapolis, MN, USA) have been preserved in the second generation Evolut R, specifically the porcine pericardial leaflets, which are suspended in a supra-annular fashion on a self-expanding nitinol frame that is allocated to three operational levels (high radial force inflow portion for anchoring, a more constrained mid portion, and a high dilated outflow portion originally made to maintain coaxiality with the aortic root). In addition, the distal skirt of the Evolut R has been extended and now offers better sealing. The current device is fully repositionable and retrievable up until the final detachment of the hooks. Available sizes are 23, 26, 29, 31, and 34 mm. Delivery can be achieved through the transfemoral,

subclavian, transaxillary, and transaortic accesses, but the device has only unidirectional-retrograde fitting on the delivery system. The supra-annular leaflet position, in which the frame is less constrained by the SHV ring/frame, may enable a larger residual EOA and reduce the residual gradients after ViV implantation. This element frequently makes the CoreValve/Evolut R the THV of choice for A-ViV in small SHVs, in which high residual gradients are a major concern. The slimmer caliber (14 Fr equivalent) delivery system and fully re-capturable capacity may offer some additional advantages for delivery and positioning, especially in challenging cases. On the other hand, due to its asymmetrical frame shape and height, the CoreValve is not recommended for use in atrioventricular ViV implantation, as it may be unstable and/or interfere with the perivalvular milieu by bulging into the atrium or LVOT.

Individual patient anatomy

An updated pre-procedural imaging study is necessary before all ViV procedures to determine suitability and tailor each implantation. In some clinical cases, ruling out obscure endocarditis or thrombi may be challenging; in others it may be difficult to determine the leak location. Assessing high risk anatomies (e.g. low laying coronaries, narrow Valsalva sinuses, proximal mechanical valve) may exclude some patients from the procedure and help in planning a personalized approach in others. Though most baseline SHV features can be recognized in advance, as detailed above, some post-implantation processes, such as pannus development, calcification spread, and tears, may propagate and cause substantial SHV disfigurement and variation that can affect decision making considerably. For these considerations and assessment of the etiology and severity of SHV failure, a comprehensive imaging study is necessary prior to each procedure based on 2D and 3D echocardiography, multislice computed tomography (CT) scans, and angiograms, as required. During the procedure, THV implantation controlled by fluoroscopy is usually sufficient. Angiography and echocardiography are not routinely required for valve positioning but may assist during THV placement in challenging cases (i.e. radiolucent SHVs).

Access

A-ViV has been successfully delivered using the transfemoral (58%), transapical (37%), transaxillary (2.8%), and direct aortic (1%) routes.[24] M-ViV is most commonly carried out transapically, but also through the atria (directly with right mini-thoracotomy) and over the transfemoral vein via transatrial septal puncture,[47] which is performed under echocardiographic guidance and is recently gaining more acceptance. T-ViV is generally performed through the femoral (69%) or jugular (28%) veins.[28] There seems to be a profound temporal trend towards transfemoral approach (arterial in A-ViV, venous in M/T-ViV) adherence in all ViV interventions, as is the case in native valve TAVI, due to many reasons, including advances in technology and the smaller catheter platform available, as well as the operators' experience.[48] As in TAVI, the suitability of the transfemoral (arterial) approach is determined optimally with a CT scan evaluating the aorta and its great branches. There are no well-defined cutoffs/definitions for tortuosity, calcifications, or minimal luminal dimensions, but a minimal ilio-femoral diameter should probably be 5.5–6.5 mm for the currently available delivery catheters (14 F-20 F). The major vascular complication rate is approximately 10% in A-ViV,[24] yet vascular complications can also occur in transvenous procedures (M-ViV or T-ViV),[28,29] and surgical apical handling is related to access site complications.[49] In this regard, no recommendations are yet available regarding pre-assessment of transvenous THV interventions for the evaluation of vascular complication risk. As these are more frequently implemented, it is a valid issue for future study.

Sizing

Small SHVs and post-procedural gradients

As optimal THV function necessitates leaflet coaptation and full device expansion, much of the hemodynamic performance of the THV after ViV is determined by the ID of the non/semi-distensible SHV ring and frame. Thus, the chink in the A-ViV armor is the small (< 23 mm) SHV, which is present in almost one-third of all A-ViV patients.[22] As the IDs of mitral and tricuspid SHVs are generally much larger, high residual gradients are not usually an issue in M-VIV and T-ViV. Although patients with degenerated mitral SHV ≤ 27 mm tend to have higher post gradients, most residual gradients found after M-ViV and T-ViV have been reported to be < 10 mmHg and 5 mmHg, respectively, regardless of THV type.[14,23,28,29]

Patients with small aortic SHVs have a 40% risk of ending the procedure with a small EOA and high (mean >20 mmHg) residual gradient. In addition, these patients are twice as likely to die at 30 days compared to patients with larger SHVs.[24] In addition to the absolute size of the aortic SHV, patient-prosthesis mismatch (PPM) and "predicted PPM" after the surgical AVR and prior to the A-ViV procedure is an independent predictor of long-term mortality in A-ViV patients.[50] The risk for high residual gradients further increases in stenotic (vs. regurgitant) SHVs and is associated with low THV implantation and Sapien THV utilization compared to a CoreValve with a similar size.[24,29,51–54] The favorable hemodynamics of CoreValve is attributed to its supra-annular leaflet design, which makes the leaflets less constrained by the SHV ring. Correspondingly, high Sapien A-ViV implantation may also increase the EOA and reduce the residual gradients.[54] THV sizing is more intricate in small SHVs; the concern is that a larger THV would result in more under-expansion and poorer hemodynamics. Nevertheless, a larger device may spread out the SHV posts better and result in a greater EOA. Typically, choosing a THV that is 10–15% larger than the "true ID" of the SHV is thought to achieve optimal results. Yet, contrary to conventional recommendations that support using a 23-mm Evolut R in a 23-mm and 25-mm Hancock II,[36,38] superior hemodynamic performance (lower residual gradient, higher EOA, and improved leaflet coaptation) was found with the 26-mm Evolut R (in Hancock II at these sizes) during *ex vivo*

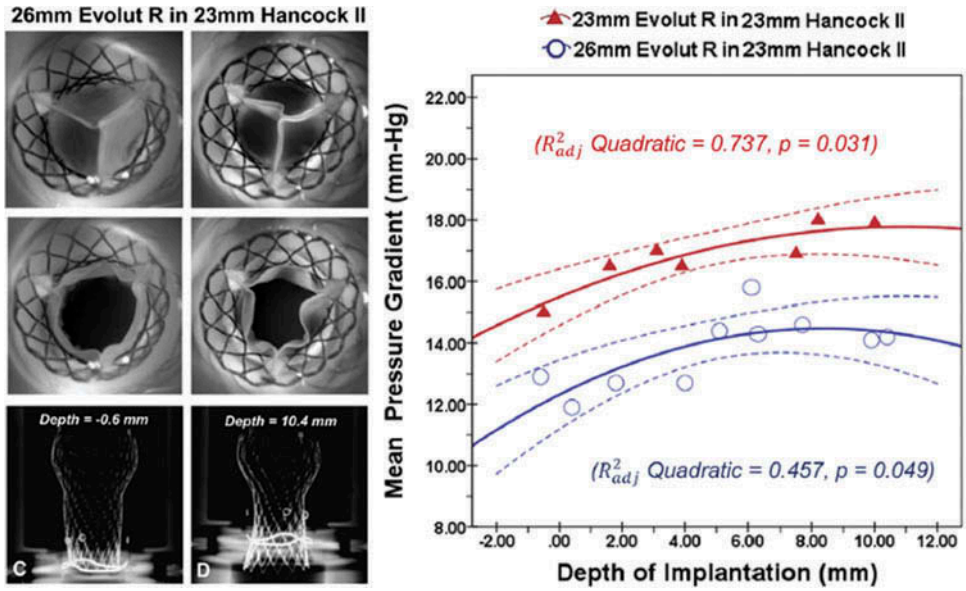

Figure 3. Hemodynamic outcomes and leaflet deformation of 23-mm and 26-mm CoreValve Evolut R devices within 23-mm Hancock II bioprostheses at different implantation depths. Dashed lines represent 95% confidence intervals. R2 adj, adjusted R Q10 squared. Reproduced from Ref. 55 with permission.

testing in a pulse duplicator system.[55] In other words, 40% oversizing was superior to 23.5% oversizing in the bench-testing study (see Figure 3). Although the residual gradients were lower, visual evaluation of the 26-mm THV revealed worse leaflet distortion compared to the 23-mm THV, raising concerns about premature THV degradation when using such extreme oversizing. Undoubtedly, additional testing and long-term follow-up data are essential to address these concerns and develop better ViV sizing guidelines. Recently, a high-pressure balloon 1 mm larger than the labeled aortic SHV was shown to be feasible for fracturing the frame of most of these devices to facilitate a larger effective orifice area (EOA) and more optimal post-procedural hemodynamics.[56] Naturally, the safety of this experimental approach requires further investigation before it can be recommended as favorable practice. However, we recommend using the ViV app sizing algorithms and provide a few basic rules below that should be adhered to during THV sizing. In the matter of small aortic SHVs, the benefit of reducing residual gradients by using larger THV devices should be weighed against the risk of leaflet distortion and potential THV degradation.

Large SHVs and grasping/sealing

As the size range for SHVs located in the mitral and tricuspid positions is usually 25–33 mm, the shortcoming of ViV in these sites may be the upper size limit, as the largest available THV may still be too small. Nevertheless, 33-mm and 31-mm SHVs have the same ID, and a 29-mm Sapien THV is usually sufficient for even the largest SHVs.[39,57] Reported cases of delayed atrial THV embolization have been described in M-ViV for both a relatively undersized device and a properly oversized, well-positioned THV.[58] Compared to THV embolization/malposition in the aortic and/or tricuspid sites due to under-sizing or placement errors, the THV in the mitral position faces considerably higher closing pressures (the left ventricular systolic pressure) than the pressures to which the THV is exposed in A-ViV or T-ViV. Therefore, it is advisable to not underestimate the true ID of the mitral SHV and to ensure proper oversizing. In addition, it is advisable to promote an inverted trunk pyramid shape or "flared" deployment, which will act as a wedge and prevent delayed migration.[57,58] Otherwise, the requirement for implantation within an excessively large orifice becomes an impediment whenever there is a need for "valve in ring" implantation (mostly in the atrioventricular positions). In this scenario, one can face a practice that is beyond the sizing limits of the currently available THVs.

Practically speaking, here are a few basic rules that may help in ViV sizing:

(1) Choose a THV that is at least 10–15% larger than the SHV "true ID."
(2) Compare the patient echocardiography and CT measures to each other and the references provided by the ViV apps to ensure consistency.
(3) Acknowledge size curbs, demarcate lower and upper size limits, and restrict the procedure to patients within this range.
(4) If re-do surgery is feasible, especially when the patient is relatively young (<70 years old) or at low risk, it should be reconsidered when the measured "true ID" is < 18 mm. Alternatively, apply high THV implantation and preferentially use the CoreValve device.

Positioning

As in TAVI, the first step is identifying the optimal "coplanar" or coaxial fluoroscopic view for device deployment. Although positioning of the c-arm view perpendicular to a stented SHV

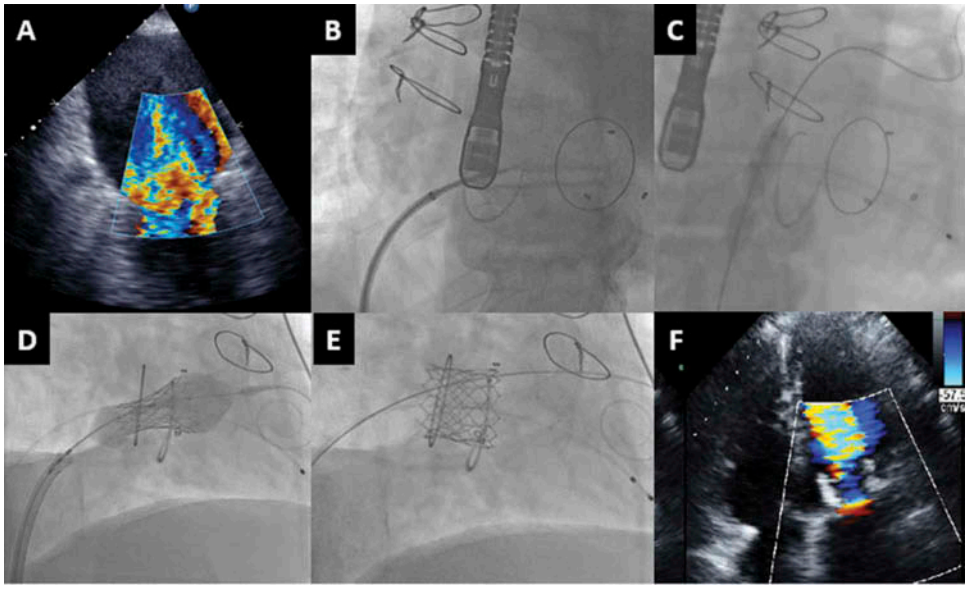

Figure 4. Transfemoral venous mitral valve-in-valve procedure (Sapien 3 29 mm in Hancock II 33 mm). (A) Severe regurgitation in the surgical bioprosthesis before implantation. (B) Trans (atrial) septal puncture and (C) dilatation. (D) The transcatheter valve is positioned and deployment starts. (E) Implantation is completed. Notice the mild "flaring" at the ventricular side of the Sapien and the lower margin of the device sitting 2–3 mm below the low margin of the Hancock ring. (F) After implantation there is no residual regurgitation.

is mostly straightforward, it can be more demanding when the SHV is radiolucent. Pre-procedural CT image reconstruction can forecast the optimal fluoroscopic delivery angle, potentially decreasing the number of angiograms required, shortening procedural time, decreasing contrast usage, and increasing the likelihood of coaxial implantation.

Currently, there are no guidelines regarding the need for bioprosthetic balloon valvuloplasty during ViV procedures.[57] The overall consensus is that such a maneuver should be avoided. In our practice, we use balloon valvuloplasty prior to implantation in less than 5% of A-ViV procedures, and very rarely in M-ViV and T-ViV procedures. In select cases, utilizing a small balloon pre-inflation may be a safe approach that supports a good high position of the THV in small stenotic SHVs during positioning. Post-implantation balloon inflation is sometimes required in A-ViV if a residual leak or high gradient persists. Again, this is very infrequent in M-ViV and T-ViV procedures.

In all ViV procedures (aortic, mitral, tricuspid), the level of the SHV ring, the so-called "neo-annulus," should be used as a reference plane for implantation.[40,59] Generally speaking, the lower margin of the THV should be kept 2–4 mm below the low margin of the ring. Therefore, it is critical to correctly identify the rings' plane, which again is simpler when the ring is radiopaque (e.g. Mitroflow, CarboMedics Inc., Sorin Group, Austin, TX, USA; Hancock, Medtronic Inc., Minneapolis, MN, USA) and more challenging when there is no such fluoroscopic demarcation. Then, other visible parts of the SHV may aid in positioning but a thorough understanding of their relation to the ring is required (e.g. Mosaic, Medtronic, Inc., Minneapolis, MN, USA). Positioning is most challenging when the SHV is completely radiolucent (e.g. stentless SHVs, Aspire [Vascutek, Inc., Koehler, Bellshill, Scotland] and Intact [Medtronic Inc., Minneapolis, MN, USA]). In such cases, repeated injections of contrast into the aortic root and intraprocedural echocardiography is obligatory, and moderate cardiac pacing to stabilize the heart during the THV settlement can assist in valve placement. There is a major difference in performing ViV using stented versus stentless rings. In the former, the procedure can be done under conscious sedation with minimal contrast, whereas procedures performed using stentless surgical valves in the aortic position could be considered for general anesthesia, guided by TEE to reduce the risk of device malposition. In all cases, the operator should be highly experienced and assure precision throughout the course of implantation.

Figure 4 illustrates the main stages during transvenous M-ViV implantation, though each ViV position and access will dictate different procedural planning/stages.

Interfering with the perivalvular structures

While crowding into its new nest, the superimposed THV creates a solid valve-stent cylinder with the SHV, which may inadvertently project and interact with surrounding structures, potentially causing dangerous complications. During A-ViV, the THV pushes the SHV leaflets outwards and may occlude the coronary artery ostium, particularly the left main coronary artery. During M-ViV, the device deflects the anterior mitral leaflet towards the intraventricular septum, potentially predisposing the patient to LVOT obstruction due to the proximity of the intraventricular septum.[60,61] In T-ViV, as the prevalence of permanent pacemakers is high (38%),[28] the THV may jail the right ventricular lead of the pacemaker, potentially causing lead fracture, insulation defect, or displacement.[62]

Coronary obstruction

The reported incidence of coronary artery obstruction is 2–3.5%,[24,52] though it is less common in our experience.[29]

Echocardiography, aortography, and CT are all extremely helpful in evaluating the risk and for preparation when necessary. Specific aortic root characteristics (e.g. short distance to coronary ostium, narrow sinotubular junction, and/or sinuses of Valsalva), SHV features (e.g. supra and extra annular leaflet configuration and stentless "less constrained" valves), and high THV implantation increase the risk.[24,63] Importantly, multi-slice CT is a reliable screening tool. In particular, the width and height of the aortic root sinuses and the virtual valve-to-coronary distance (VTCD) should be measured. To assure safety, the VTCD must be > 4 mm, ideally ≥ 6 mm.[64] In borderline cases, prewiring the culprit coronary ostia with a bailout angioplasty wire (± stent) is practical. Selecting a relatively small THV may also help decrease the risk.

LVOT obstruction

Although LVOT obstruction is well described after surgical mitral procedures, especially in patients with small ventricular cavities,[65,66] the incidence after M-ViV is likely low. Nevertheless, as LVOT obstruction is conceivable and dangerous, it should be acknowledged and considered before each case of M-ViV. The septal bulge in patients with septal hypertrophy, deep THV implantation, and a large THV may all increase the risk, though none have been clearly verified yet. A key measure to assess the risk may be the aorto-mitral-annular (AMA) angle, which is the angle between the aortic and mitral valves' annular planes. If the AMA angle is obtuse, then the mitral SHV struts will lie marginally to and outside the LVOT (i.e. AMA = 180^0 = no effect on the LVOT). If the AMA angle is more acute, then the SHV strut(s) will lie deeper in the LVOT and may violate the flow of blood. Therefore, a more acute AMA angle appears to be a good alerting signal during M-ViV planning.[61]

Pacemaker jailing

Pacemaker lead failure is feared as it may occur acutely during T-ViV deployment, which will force the right ventricular lead between the THV and SHV and possibly impair it. However, pacemaker interrogation results before and after T-ViV have shown that most parameters remain unaffected.[62] There was a very mild and transient decrease in ventricular sensing immediately after valve deployment, with no safety concerns observed. The risk of lead dislodgement during the passage of the delivery system is probably also low, particularly with active lead fixation and/or remote implantation. Nevertheless, a temporary pacemaker system should always be kept available as backup, especially in pacemaker-dependent patients.[62]

Final considerations

If, during patient evaluation, the Heart Team anticipates any of these technical hitches are likely to follow, reviewing alternative treatment strategies is advisable, as the optimal strategy is avoiding these complications. However, if there is no better alternative and the decision for ViV stands, it is prudent to implement some precautionary measures. Most importantly, the risk-benefit ratio should be re-evaluated, the patient and his/her family could take part in the decision making, and the surgeons should be notified and prepare standby circulatory bypass and/or surgical support.

Post-procedural patient follow-up

Generally speaking, the long-term management of patients after ViV is similar to that of patients after TAVI and should include cardiac rehabilitation, endocarditis prophylaxis, management of comorbid conditions, promotion of cardiac risk factor reduction, and a healthy lifestyle. A periodic, comprehensive, and detailed echocardiographic evaluation should be performed in a dedicated follow-up clinic in order to monitor valve functional integrity and overall cardiac function. Although subclinical leaflet thrombus formation detectable by imaging is more common than previously appreciated,[67–69] no specific data is available about the occurrence of this phenomenon among ViV-treated patients. In addition, there is no clear evidence concerning the optimal antithrombotic/anticoagulation therapy after ViV, and current recommendations are empirical and similar to after native TAVI (e.g. 75 mg clopidogrel orally daily for 3–6 months with 75–100 mg oral aspirin daily lifelong). Patients with atrial fibrillation or other indications for long-term anticoagulation should receive anticoagulants as per guidelines.[32]

Future perspectives

A potential limitation of A-ViV is the high residual gradients associated with small SHVs. Currently, small SHVs may argue against A-ViV implantation in some patients. Whether sex-related differences exist in ViV results in terms of residual gradients and/or PPM frequency remains to be explored. Whether SHV frame fracturing to augment residual EOA and hemodynamics is practical and effective requires further investigation, and the potential of dedicated surgical valves designed to aid ViV is also being examined. There are concerns regarding the long-term durability/longevity of THVs, and this topic is a key point for ongoing investigation in any valve location. To what extent the ViV option will impact surgical practice towards the utilization of more SHV bioprostheses versus mechanical valves, even among much younger surgical patients, remains to be seen. Surgeons would likely be mindful that their modus operandi is critical to allowing facilitated ViV implantation if and when SHV failure should occur. It is likely to be an ongoing learning experience, but the augmented risk associated with redo-surgery seems to warrant ViV becoming gradually more appealing to both patients and physicians.

Conclusions

ViV is a viable treatment strategy in a growing population of patients with bioprosthetic SHV degeneration. Though A-ViV is the most familiar procedure, expertise is already being gained in M-ViV and T-ViV, and ViV in any of these positions can benefit patients in need as an alternative to palliation or high risk re-do valve surgery. Current evidence confirms short- and mid-term safety and efficacy, but future studies must shed light on long-term durability, optimal anti-

thrombotic/coagulation therapies, and optimize the hemodynamics, especially after implantation in small SHVs. The Heart Team approach, careful patient assessment, meticulous valve sizing, and other technical considerations such as alignment and positioning, are all crucial to obtain optimal outcomes after ViV procedures.

Disclosure statements

Ran Kornowski, MD, instructs on ViV procedures for Medtronic and Edwards Lifesciences. Otherwise, he has no relevant affiliations or financial conflicts with the subject matter or materials discussed in this article. Dr Uri Landes has no relevant affiliations or financial conflicts with the subject matter or materials discussed in the manuscript.

ORCID

Uri Landes http://orcid.org/0000-0002-7271-2678

References

1. Brown JM, O'Brien SM, Wu C, Sikora JA, Griffith BP, Gammie JS. Isolated aortic valve replacement in North America comprising 108 687 patients in 10 years: changes in risks, valve types, and outcomes in the society of thoracic surgeons national database. *J Thorac Cardiovasc Surg*. 2009;137(1):82–90. doi:10.1016/j.jtcvs.2008.08.015.
2. Yun KL, Miller DC, Moore KA, et al. Durability of the Hancock MO bioprosthesis compared with standard aortic valve bioprostheses. *Ann Thorac Surg*. 1995;60:S221. doi:10.1016/0003-4975(95)00253-H.
3. Mykén PS, Bech-Hansen O. A 20-year experience of 1712 patients with the biocor porcine bioprosthesis. *J Thorac Cardiovasc Surg*. 2009;137:76–81. doi:10.1016/j.jtcvs.2008.05.068.
4. McClure RS, Narayanasamy N, Wiegerinck E, et al. Late outcomes for aortic valve replacement with the Carpentier-Edwards pericardial bioprosthesis: up to 17-year follow-up in 1,000 patients. *Ann Thorac Surg*. 2010;89:1410–1416. doi:10.1016/j.athoracsur.2010.01.046.
5. Hammermeister K, Sethi GK, Henderson WG, Grover FL, Oprian C, Rahimtoola SH. Outcomes 15 years after valve replacement with a mechanical versus a bioprosthetic valve: final report of the Veterans affairs randomized trial. *J Am Coll Cardiol*. 2000;36(4):1152. doi:10.1016/S0735-1097(00)00834-2.
6. Brennan JM, Edwards FH, Zhao Y, et al. Long-term safety and effectiveness of mechanical versus biologic aortic valve prostheses in older patients: results from the Society of Thoracic Surgeons Adult Cardiac Surgery National Database. *Circulation*. 2013;127(16)1647–1655. doi:10.1161/CIRCULATIONAHA.113.002003.
7. Vahanian A, Alfieri O, Andreotti F, et al. ESC Committee for Practice Guidelines (CPG); Joint task force on the management of valvular heart disease of the European Society of Cardiology (ESC); European Association for Cardio-Thoracic Surgery (EACTS). Guidelines on the management of valvular heart disease (version 2012): the joint task force on the management of valvular heart disease of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). *Eur J Cardiothorac Surg*. 2012;42:S1–S44.
8. Kaneko T, Vassileva CM, Englum B, et al. Contemporary outcomes of repeat aortic valve replacement: a benchmark for transcatheter valve-in-valve procedures. *Ann Thorac Surg*. 2015;100:1298–1304. doi:10.1016/j.athoracsur.2015.04.062.
9. Maganti M, Rao V, Armstrong S, Feindel CM, Scully HE, David TE. Redo valvular surgery in elderly patients. *Ann Thorac Surg*. 2009;87(2):521–525. doi:10.1016/j.athoracsur.2008.09.030.
10. Akay TH, Gultekin B, Ozkan S, et al. Mitral valve replacements in redo patients with previous mitral valve procedures: mid-term results and risk factors for survival. *J Card Surg*. 2008;23:415–421. doi:10.1111/j.1540-8191.2008.00630.x.
11. Filsoufi F, Anyanwu AC, Salzberg SP, Frankel T, Cohn LH, Adams DH. Long-term outcomes of tricuspid valve replacement in the current era. *Ann Thorac Surg*. 2005;80:845–850. doi:10.1016/j.athoracsur.2004.12.019.
12. Van Nooten GJ, Caes F, Taeymans Y, et al. Tricuspid valve replacement: postoperative and long-term results. *J Thorac Cardiovasc Surg*. 1995;110:672–679. doi:10.1016/S0022-5223(95)70098-6.
13. Vassileva CM, Shabosky J, Boley T, Markwell S, Hazelrigg S. Tricuspid valve surgery: the past 10 years from the Nationwide Inpatient Sample (NIS) database. *J Thorac Cardiovasc Surg*. 2012;143:1043–1049. doi:10.1016/j.jtcvs.2011.07.004.
14. Webb JG, Wood DA, Ye J, et al. Transcatheter valve-in-valve implantation for failed bioprosthetic heart valves. *Circulation*. 2010;121:1848–1857. doi:10.1161/CIRCULATIONAHA.109.924613.
15. Pasic M, Unbehaun A, Dreysse S, et al. Transapical aortic valve implantation after previous aortic valve replacement: clinical proof of the "valve in valve" concept. *J Thorac Cardiovasc Surg*. 2011;142:270–277. doi:10.1016/j.jtcvs.2010.09.049.
16. Piazza N, Bleiziffer S, Brockmann G, et al. Transcatheter aortic valve implantation for failing surgical aortic bioprosthetic valve: from concept to clinical application and evaluation (part2). *J Am Coll Cardiol Intv*. 2011;4:733–742. doi:10.1016/j.jcin.2011.05.007.
17. Cheung A, Webb JG, Barbanti M, et al. 5-year experience with transcatheter transapical mitral valve-in-valve implantation for bioprosthetic valve dysfunction. *J Am Coll Cardiol*. 2013;61:1759–1766. doi:10.1016/j.jacc.2013.01.058.
18. Eggebrecht H, Schäfer U, Treede H, et al. Valve-in-valve transcatheter aortic valve implantation for degenerated bioprosthetic heart valves. *J Am Coll Cardiol Intv*. 2011;4:1218–1227. doi:10.1016/j.jcin.2011.07.015.
19. Roberts PA, Boudjemline Y, Cheatham JP, et al. Percutaneous tricuspid valve replacement in congenital and acquired heart disease. *J Am Coll Cardiol*. 2011;58:117–122. doi:10.1016/j.jacc.2011.01.044.
20. Bapat V, Attia R, Redwood S, et al. Use of transcatheter heart valves for a valve-in-valve implantation in patients with degenerated aortic bioprosthesis: technical considerations and results. *J Thorac Cardiovasc Surg*. 2012;144:1372–1379. doi:10.1016/j.jtcvs.2012.07.104.
21. Linke A, Woitek F, Merx MW, et al. Valve-in-valve implantation of medtronic corevalve prosthesis in patients with failing bioprosthetic aortic valves. *Circ Cardiovasc Interv*. 2012;5:689–697. doi:10.1161/CIRCINTERVENTIONS.112.972331.
22. Ihlberg L, Nissen H, Nielsen NE, et al. Early clinical outcome of aortic transcatheter valve-in-valve implantation in the Nordic countries. *J Thorac Cardiovasc Surg*. 2013;146:1047–1054. doi:10.1016/j.jtcvs.2013.06.045.
23. Cullen MW, Cabalka A, Alli OO, et al. Transvenous, antegrade melody valve-in-valve implantation for bioprosthetic mitral and tricuspid valve dysfunction. *J Am Coll Cardiol Intv*. 2013;6:598–605. doi:10.1016/j.jcin.2013.02.010.
24. Dvir D, Webb JG, Bleiziffer S, et al. for the Valve-in-Valve International Data Registry Investigators. Transcatheter aortic valve implantation in failed bioprosthetic surgical valves. *JAMA*. 2014;312:162–170. doi:10.1001/jama.2014.7246.
25. Godarta F, Baruteaub AE, Petit J, et al. Transcatheter tricuspid valve implantation: a multicentre French study. *Arch Cardiovasc Dis*. 2014;107:583–591. doi:10.1016/j.acvd.2014.07.051.
26. Conradi L, Silaschi M, Seiffert M, et al. Transcatheter valve-in-valve therapy using 6 different devices in 4 anatomic positions: clinical outcomes and technical considerations. *J Thorac Cardiovasc Surg*. 2015;150:1557–1567. doi:10.1016/j.jtcvs.2015.08.065.

27. Codner P, Assali A, Vaknin-Assa H, et al. Treatment of aortic, mitral and tricuspid structural bioprosthetic valve deterioration using the valve-in-valve technique. *J Heart Valve Dis*. 2015;24:345–352.
28. McElhinney DB, Cabalka AK, Aboulhosn JA, et al. Transcatheter tricuspid valve-in-valve implantation for the treatment of dysfunctional surgical bioprosthetic valves. *Circulation*. 2016;133:1582–1593. doi:10.1161/CIRCULATIONAHA.115.019353.
29. Landes U, Segev A, Barbash I, et al. Transcatheter treatment of degenerated bioprosthetic valves: patients characteristics, procedural details and outcomes – A multicenter Israeli registry. Presented at: EuroPCR; May 17, 2017; Paris, France.
30. Webb JG, Mack MJ, White JM, et al. Transcatheter aortic valve implantation within degenerated aortic surgical bioprostheses. PARTNER 2 valve-in-valve registry. *J Am Coll Cardiol*. 2017;69:2253–2262. doi:10.1016/j.jacc.2017.02.057.
31. Kornowski R, Tchetche D, Verhoye JP, et al. VIVA. Presented at: EuroPCR; May 17,2017; Paris, France.
32. Otto CM, Kumbhani DJ, Alexander KP, et al. ACC expert consensus decision pathway for transcatheter aortic valve replacement in the management of adults with aortic stenosis. *J Am Coll Cardiol*. 2017;2017(69):1313–1346. doi:10.1016/j.jacc.2016.12.006.
33. Webb JG, Dvir D. Transcatheter aortic valve replacement for bioprosthetic aortic valve failure: the valve-in-valve procedure. *Circulation*. 2013;127:2542–2550. doi:10.1161/CIRCULATIONAHA.113.000631.
34. Alkhouli M, Sarraf M, Maor E, et al. Techniques and outcomes of percutaneous aortic paravalvular leak closure. *J Am Coll Cardiol Intv*. 2016;9:2416–2426. doi:10.1016/j.jcin.2016.08.038.
35. Reed GW, Tuzcu EM, Kapadia SR, Krishnaswamy A. Catheter-based closure of paravalvular leak. *Expert Rev Cardiovasc Ther*. 2014;12:681–692. doi:10.1586/14779072.2014.915193.
36. Bapat V, Mydin I, Chadalavada S, et al. A guide to fluoroscopic identification and design of bioprosthetic valves: a reference for valve-in-valve procedure. *Catheter Cardiovasc Interv*. 2013;81:853–861. doi:10.1002/ccd.24419.
37. Bapat VN, Attia R, Thomas M. Effect of valve design on the stent internal diameter of a bioprosthetic valve: a concept of true internal diameter and its implications for the valve-in-valve procedure. *JACC Cardiovasc Intv*. 2014;7:115–127. doi:10.1016/j.jcin.2013.10.012.
38. Bapat V. *Valve-in-Valve Aortic App*. https://www.pcronline.com/PCR-Publications/PCR…apps/Valve-in-Valve-Aortic-app
39. Bapat V. *Valve-in-Valve Mitral App*. https://www.pcronline.com/PCR-Publications/PCR. . .apps/Valve-in-Valve-Mitral-app
40. Noorani A, Radia R, Bapat V. Challenges in valve-in-valve therapy. *J Thorac Dis*. 2015;7:1501–1508.
41. Bapat V, Davies W, Attia R, et al. Use of balloon expandable transcatheter valves for valve-in-valve implantation in patients with degenerative stentless aortic bioprostheses: technical considerations and results. *J Thorac Cardiovasc Surg*. 2014;148:917–922. doi:10.1016/j.jtcvs.2014.05.029.
42. Landes U, Dvir D, Schoels W, et al. Valve-in-valve transcatheter aortic implantation in degenerative sutureless bioprostheses. Presented at: EuroPCR; May 17, 2017; Paris, France.
43. Alnasser S, Cheema AN, Simonato M, et al. Matched comparison of self-expanding transcatheter heart valves for the treatment of failed aortic surgical bioprosthesis. Insights from the Valve-in-Valve International Data Registry (VIVID). *Circ Cardiovasc Interv*. 2017;10:e004392. doi:10.1161/CIRCINTERVENTIONS.116.004392.
44. Castriota F, Nerla R, Micari A, et al. Transcatheter aortic valve-in-valve implantation using lotus valve for failed surgical bioprostheses. *Ann Thorac Surg*. 2017;104:638-644.
45. Latini RA, Testa L, Brambilla N, Tusa M, Bedogni F. Valve-in-valve with portico valve for a degenerative bioprosthetic surgical valve (Biocor). *G Ital Cardiol*. 2016;17:273–276.
46. Sponga S, Mazzaro E, Bagur R, Livi U. Transcatheter jenavalve implantation in a stentless prosthesis: a challenging case after 4 previous aortic procedures. *Can J Cardiol*. 2017;33:555.e17-555.e19. doi:10.1016/j.cjca.2016.10.031.
47. Ye J, Cheung A, Yamashita M, et al. Transcatheter aortic and mitral valve-in-valve implantation for failed surgical bioprosthetic valves. an 8-year single-center experience. *J Am Coll Cardiol Intv*. 2015;8:1735–1744. doi:10.1016/j.jcin.2015.08.012.
48. Landes U, Barsheshet A, Finkelstein A, et al. Temporal trends in transcatheter aortic valve implantation, 2008–2014: patient characteristics, procedural issues, and clinical outcome. *Clin Cardiol*. 2017;40:82–88. doi:10.1002/clc.22632.
49. Muraru D, Napodano M, Beltrame V, Badano LP. Left ventricular pseudoaneurysm after transapical aortic valve-in-valve implantation: use of transthoracic 3D echocardiography for guiding therapeutic approach. *Eur Heart J*. 2016;37:1255. doi:10.1093/eurheartj/ehv382.
50. Simonato M, Pibarot P, Dvir D. Severe predicted patient-prosthesis mismatch as a predictor of long term mortality after aortic valve-in-valve: insights from the valve-in-valve International Data Registry (VIVID). *J Am Coll Cardiol Intv*. 2017;10:S61–S62. doi:10.1016/j.jcin.2016.12.209.
51. Azadani AN, Jaussaud N, Matthews PB, Ge L, Chuter TA, Tseng EE. Transcatheter aortic valves inadequately relieve stenosis in small degenerated bioprostheses. *Interact Cardiovasc Thorac Surg*. 2010;11:70–77. doi:10.1510/icvts.2009.225144.
52. Dvir D, Webb J, Brecker S, et al. Transcatheter aortic valve replacement for degenerative bioprosthetic surgical valves: results from the global valve-in-valve registry. *Circulation*. 2012;126:2335–2344. doi:10.1161/CIRCULATIONAHA.112.104505.
53. Simonato M, Webb J, Kornowski R, et al. Transcatheter replacement of failed bioprosthetic valves: large multicenter assessment of the effect of implantation depth on hemodynamics after aortic valve-in-valve. *Circ Cardiovasc Interv*. 2016;9:e003651. doi:10.1161/CIRCINTERVENTIONS.115.003651.
54. Simonato M, Azadani AN, Webb J, et al. In vitro evaluation of implantation depth in valve-in-valve using different transcatheter heart valves. *EuroIntervention*. 2016;12:909–917. doi:10.4244/EIJV12I7A149.
55. Azadani AN, Reardon M, Simonato M, et al. Effect of transcatheter aortic valve size and position on valve-in-valve hemodynamics: an in vitro study. *J Thorac Cardiovasc Surg*. 2017;153:1303-1315.
56. Allen KB, Chhatriwalla AK, Cohen DJ, et al. Bioprosthetic valve fracture to facilitate transcatheter valve-in-valve implantation. *Ann Thorac Surg*. June 29, 2017. In press. doi:10.1016/j.athoracsur.2017.04.007.
57. Gallo M, Dvir D, Demertzis S, Pedrazzini G, Berdajs D, Ferrari E. Transcatheter valve-in-valve implantation for degenerated bioprosthetic aortic and mitral valves. *Expert Rev Med Devices*. 2016;13(8):749–758. doi:10.1080/17434440.2016.1207521.
58. Bapat V, Khaliel F, Ihleberg L. Delayed migration of Sapien valve following a transcatheter mitral valve-in-valve implantation. *Catheter Cardiovasc Interv*. 2014;83:E150–E154. doi:10.1002/ccd.25076.
59. Bapat V, Adams B, Attia R, et al. Neo-annulus: a reference plane in a surgical heart valve to facilitate a valve-in-valve procedure. *Catheter Cardiovasc Interv*. 2015;85:685–691. doi:10.1002/ccd.25586.
60. Bapat V, Pirone F, Kapetanakis S, Rajani R, Niederer S. Factors influencing left ventricular outflow tract obstruction following a mitral valve-in-valve or valve-in-ring procedure, part 1. *Catheter Cardiovasc Interv*. 2015;86:747–760. doi:10.1002/ccd.25928.
61. Blanke P, Naoum C, Dvir D, et al. Predicting LVOT obstruction in transcatheter mitral valve implantation: concept of the neo-LVOT. *J Am Coll Cardiol Img*. 2017;10:482–485. doi:10.1016/j.jcmg.2016.01.005.
62. Steinberg C, Dvir D, Krahn AD, Webb J. Feasibility of tricuspid valve-in-valve replacement in a patient with transvalvular pacemaker. *HeartRhythm Case Rep*. Accessed September 4, 2015. doi:10.1016/j.hrcr.2015.05.004.

63. Ribeiro HB, Webb JG, Makkar RR, et al. Predictive factors, management, and clinical outcomes of coronary obstruction following transcatheter aortic valve implantation: insights from a large multicenter registry. *J Am Coll Cardiol*. 2013;62:1552–1562. doi:10.1016/j.jacc.2013.07.040.
64. Dvir D, Leipsic J, Blanke P, et al. Coronary obstruction in transcatheter aortic valve-in-valve implantation: preprocedural evaluation, device selection, protection, and treatment. *Circ Cardiovasc Interv*. 2015;8:e002079. doi:10.1161/CIRCINTERVENTIONS.114.002079.
65. Rietman GW, van der Maaten J, Douglas YL, Boonstra PW. Echocardiographic diagnosis of left ventricular outflow tract obstruction after mitral valve replacement with subvalvular preservation. *Eur J Cardioth Surg*. 2002;22:825–827. doi:10.1016/S1010-7940(02)00465-7.
66. Wu Q, Zhang L, Zhu R. Obstruction of left ventricular outflow tract after mechanical mitral valve replacement. *Ann Thorac Surg*. 2008;85:1789–1791. doi:10.1016/j.athoracsur.2007.11.069.
67. Makkar RR, Fontana G, Jilaihawi H, et al. Possible subclinical leaflet thrombosis in bioprosthetic aortic valves. *N Engl J Med*. 2015;373:215–224. doi:10.1056/NEJMoa1509233.
68. Martí D, Rubio M, Escribano N, de Miguel R, Rada I, Morís C. Very late thrombosis of a transcatheter aortic valve-in-valve. *J Am Coll Cardiol Intv*. 2015;8:151–153. doi:10.1016/j.jcin.2015.04.017.
69. Whisenant B, Jones K, Miller D, Horton S, Miner E. Thrombosis following mitral and tricuspid valve-in-valve replacement. *J Thorac Cardiovasc Surg*. 2015;149:26–29. doi:10.1016/j.jtcvs.2014.10.075.