Percutaneous Valve in Valve Implantation for Dysfunctional Bioprosthetic Valves

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Percutaneous valve-in-valve (ViV) therapy is an option for patients with prohibitive risk of reoperation and a prior history of dysfunctional bioprosthetic valves. While initially reported for valves in the aortic position, ViV therapy is now being extended to tricuspid and mitral valves (native and dysfunctional bioprostheses). The ViV procedure requires a combination of fluoroscopic and 3-dimensional transesophageal echocardiography (3D TEE) guidance. In addition, 3D TEE can also precisely diagnose specific procedure-related complications, eg, perivalvular regurgitation, device malfunction, and misplacement.

While currently an esoteric therapeutic option, with its minimally invasive nature, the ViV procedure is likely to become an attractive option for high-risk cases. Perioperative 3D TEE imaging is a key element to assess suitability, for procedural guidance, to establish success, and to exclude complications. Knowledge of key steps and procedure-specific imaging requirements has clinical value for perioperative echocardiographers. Because of the challenging nature, clinicians can often encounter clinical scenarios with limited evidence in the literature to support decision making. Despite being a minimally invasive option, the ViV procedure can have serious immediate and long-term anatomical and physiological consequences. These may include but are not limited to structural disruptions, obstructions, and regurgitations. It is important for anesthesiologists to be cognizant of these perioperative complications as they can have location-specific hemodynamic consequences.

Drawing on our institutional experience, we present the management of an aortic, mitral, and tricuspid ViV procedure and a brief literature review.

Written consents have been obtained from all the patients for the publication of the case report.

MITRAL VALVE ViV PROCEDURE

A 66-year-old woman was admitted with a history of progressive shortness of breath due to severe mitral stenosis (MS) with annular calcification. She had a history of bioprosthetic aortic valve replacement and a balloon mitral valvuloplasty 2 years before current admission. The bioprosthesis in the aortic position was functioning normally without any evidence of stenosis or regurgitation. Considering her high operative risk, she was offered and consented to undergo a percutaneous ViV procedure for MS.

After an uneventful induction of general anesthesia, the intraoperative TEE examination was initiated with an X7-2t probe and an EPIQ ultrasound system (Philips Medical Systems, Andover, MA). Severe mitral annular calcification and moderately thickened mitral valve leaflets with severe MS (valve area = 0.69 cm²) were revealed (Figure 1A). Mild symmetric left ventricular (LV) hypertrophy with a 1.37-cm thick LV wall was also noted (Figure 1B). During the percutaneous intervention, Edwards Commander Delivery System (Edwards Lifesciences, Irvine, CA) catheters were echocardiographically guided across the interatrial septum (IAS) (Supplemental Digital Content 1, Video 1, http://links.lww.com/AACR/A112). Subsequently, the IAS was dilated with a 12-mm balloon before introduction of the valve sheath assembly. A 23-mm Sapien 3 prosthetic valve (Edwards Lifesciences Corporation) was deployed under TEE and fluoroscopic monitoring (Supplemental Digital Content 1, Video 1, http://links.lww.com/AACR/A112).

Immediately after the deployment, a well-seated trileaflet prosthetic valve was visualized in the mitral position with trace perivalvular regurgitation (Figure 2A). The peak pressure gradient across the mitral valve was 7 mm Hg with continuous wave Doppler (Figure 2B). Interrogation of the LV outflow tract demonstrated turbulence on color flow Doppler in the mid-esophageal long-axis view, which was a new finding (Figure 2C). By using continuous wave Doppler, the peak and mean gradients across the LV outflow tract were measured as 57 and 31 mm Hg, respectively (Figure 2D). Further interrogation with real-time 3D
imaging demonstrated a fixed partial mechanical obstruction of the LV outflow tract with the lower edge of the prosthetic valve in mitral position (Figure 3). The findings were discussed with the primary cardiology team. It was decided to follow-up the patient and consider alcohol septal ablation if needed. The intraoperative and immediate postoperative courses were uneventful. The patient was extubated 24 hours postoperatively and discharged home on the sixth postoperative day.

**AORTIC VALVE VI V PROCEDURE**

An 82-year-old man was admitted with complaints of progressive shortness of breath. He had undergone a bioprosthetic aortic valve replacement 16 years before this admission for aortic stenosis (AS). Preoperative workup demonstrated severe AS in the prosthetic valve. Considering his high surgical risk, he was scheduled for a transcatheter aortic valve replacement. Intraoperative TEE with an X7-2t probe and a Philips iE-33 ultrasound system (Philips Medical Systems) demonstrated severely thickened leaflets of the prosthetic valve in aortic position with a flail leaflet (Figure 4A and B), severe aortic insufficiency, and moderate AS (Figure 4C and D).

A 26-mm Evolut R valve (Medtronic, Minneapolis, MN) was advanced through the femoral artery and positioned across the prosthetic valve in aortic position. It was successfully deployed in an appropriate position with rapid ventricular pacing. Immediate postdeployment TEE assessment
demonstrated minimal transvalvular gradient and traced perivalvular leaks (Figure 5A and B). The patient was extubated after 24 hours and discharged on postoperative day 3.

TRICUSPID VALVE ViV PROCEDURE
A 58-year-old woman was admitted with progressive shortness of breath and lower extremity edema (Supplemental Digital Content 2, Video 2, http://links.lww.com/AACR/A113). She had undergone bioprosthetic tricuspid valve replacement for infective endocarditis 11 years before the current admission. A preoperative transthoracic echocardiography demonstrated severe prosthetic valve stenosis (increased gradient, reduced area, and depressed right ventricular function). Because of her high risk, she was offered and consented to undergo a transcatheter ViV in the tricuspid position with a Sapien 3 valve (29 mm). After induction of anesthesia and endotracheal intubation, the TEE examination was performed with the Z6Ms True Volume TEE Transducer using a Siemens ACUSON SC2000 ultrasound system (Siemens Medical Solutions USA, Inc, Malvern, PA), and preoperative findings were confirmed (Supplemental Digital Content 3, Video 3, http://links.lww.com/AACR/A114). Vascular access was obtained through

Figure 3. R wave gated 3-dimensional echocardiography imaging, en face view of aortic valve, stent pointed out by red arrow obstructed left ventricular outflow tract.

Figure 4. Pressure gradient (PG) and velocity time integral (VTI). A, Midesophageal aortic valve short axis view demonstrated thickened aortic valve leaflets. B, Midesophageal long axis view; flail aortic valve leaflet was pointed out by red arrow. C, Deep transgastric long axis view; color flow Doppler demonstrated severe aortic regurgitation. D, Deep transgastric long axis view; transvalvular mean PG measured with continuous wave Doppler showed moderate aortic valve stenosis.
the left femoral artery, and a pacemaker wire was placed in the left ventricle for emergency pacing. The right femoral vein was cannulated for the insertion of the valve delivery system. The prosthetic valve in the tricuspid position was subsequently balloon dilated during rapid ventricular pacing (Supplemental Digital Content 4, Video 4, http://links.lww.com/AACR/A115). A Sapien 3 valve was then advanced and positioned across the prosthetic valve in the tricuspid position. Immediate postprocedure TEE examination confirmed a well-positioned prosthetic ViV with trace tricuspid regurgitation and minimal transvalvular gradient (Figure 6). The patient was extubated after 24 hours, and the patient was discharged on postoperative day 5.

DISCUSSION

With advances in imaging and instrumentation, percutaneous and minimally invasive interventions are becoming popular options for structural heart disease. The first ViV was performed in 2007 when Wenaweser et al. reported a transcatheter valve (Medtronic CoreValve system, Medtronic CV Luxembourg S.a.r.l., Luxembourg, Germany) implanted into a degenerated surgical aortic bioprosthesis. As a result, interventions are being offered to patients who were otherwise unsuitable for open surgical procedures because of prohibitive risk profile. Although this procedure avoids a redo sternotomy and extensive dissection, it can have physiological and anatomical consequences. Common complications include but are not limited to anatomical disruptions, residual intracardiac shunts, outflow tract obstructions, and conduction abnormalities.

Initial attempts for ViV were limited to the aortic valve, but with improved imaging and instrumentation, percutaneous interventions are being extended to other cardiac valves. The availability of low-profile percutaneous aortic valves (Sapien) with a minimal physical and anatomical footprint has enabled the clinicians to deploy them in other valvular positions because of prohibitive risk profile. Although this procedure avoids a redo sternotomy and extensive dissection, it can have physiological and anatomical consequences. Common complications include but are not limited to anatomical disruptions, residual intracardiac shunts, outflow tract obstructions, and conduction abnormalities.

The role of intraoperative imaging includes confirmation of preoperative diagnoses, assessment of suitability for interventions, real-time procedural guidance, establishment of success/failure of the procedure, and exclusion of complications. There are no commercially available location-specific ViV prostheses. Based on its low-profile and less-prominent margins, the Sapien 3 valve used for transcatheter aortic valve replacement is commonly used for all ViV procedures. The size of the implant is limited to the inner diameter of the existing prosthesis. The presence of significant calcification and pannus formation can further limit the size of the ViV prosthesis. Deployment of the selected ViV prosthesis is often preceded by balloon valvuloplasty to dilate the leaflets and create deployment space.

For the ViV in the mitral position, the TEE and 3D TEE provide excellent guidance throughout the procedure. The interatrial septal puncture is the first challenging step during the procedure. The needle needs to be directed toward the superior and the anterior aspect of the IAS. Fluoroscopy provides no clear orientation in the appropriate positioning, but 2-dimensional or 3D TEE live views are clearly more accurate in guiding the puncture. In the mitral position, perivalvular regurgitation is commonly observed after ViV implantation and may require balloon reexpansion after deployment to improve the valve seating. Shape incompatibilities between the
preexisting prosthesis and the ViV prosthesis may not be addressed by balloon inflation. In patients with narrow LV outflow tract and acute aortomitral angle, fixed LV outflow tract obstruction can occur in 4% to 5% cases.\textsuperscript{13} The mechanism can be device protrusion, flaring in the LV, unfavorable aortomitral angle, and septal bulge (asymmetrical). Preoperative 3D reconstruction software can be used to predict the likelihood of LV outflow tract obstruction. Linear measurements of the leaflet lengths, position of the coaptation point, aortomitral angle, and leaflet lengths can assist in predicting risk of LV outflow tract obstruction.
In aortic valve position besides mechanical stability and perivalvular regurgitation, it is important to exclude coronary artery ostial occlusion with the deployed prosthesis. It generally presents as immediate hemodynamic instability requiring inotropic support and as wall motion abnormalities on the immediate postdeployment TEE examination. Currently, computed tomography is the gold standard for localizing and measuring the height of coronary ostium. TEE imaging becomes unreliable especially in the presence of calcification and artifacts. Perivalvular regurgitation after a ViV procedure in the aortic position occurs frequently. Management depends on the severity assessed by the immediate postdeployment TEE examination or contrast fluoroscopy. It is most commonly managed by balloon dilation within the ViV. There is limited experience of the ViV procedure in tricuspid position. Most reported cases consist of a ViV procedure for a stenotic prosthetic valve.

Lack of depth perception precludes fluoroscopic imaging as the primary imaging modality during ViV procedures. Echocardiographic imaging is an integral component of this procedure. While it is not the standard of care, enhanced spatial orientation and depth perception achieved with real-time 3D imaging are invaluable procedural adjuncts. Technology is now available to blend the fluoroscopic and 3D echocardiographic imaging on 1 screen. The procedure mandates close communication across specialty lines. Real-time guidance requires the use of universal terminology, anatomical orientation, and understanding the strengths and limitations of various imaging modalities. Real-time intraoperative 3D TEE is essential for success of the ViV procedure. Although data on immediate complications are accumulating and long-term outcomes are unclear, currently, the ViV procedure is the best technique for those with high surgical risk.

**REFERENCES**