Transcatheter Paravalvular Leak Closure: Diagnosis, Devices, Techniques, and Outcomes

Where we've been, where we are now, and where we still need to go with transcatheter PVL closure.

BY JOHN T. SAXON, MD, AND ADNAN K. CHHATRIWALLA, MD

Paravalvular leak (PVL) is a common condition in which an unintended gap between a prosthetic heart valve and native annular tissue allows for regurgitation of blood from a downstream to an upstream chamber, similar to valvular regurgitation. The most common causes of PVL are native annular tissue friability, annular calcification, and endocarditis. PVL occurs in 5% to 17% of surgically implanted prosthetic valves, affecting both mechanical and biologic prostheses, and patients can present with multiple simultaneous PVL defects.[1-3] After valve surgery, PVL is more common in the mitral valve position than the aortic valve position[2]; however, PVL occurs more frequently after transcatheter aortic valve replacement (TAVR) than surgical aortic valve replacement (SAVR).[4,5] Although the incidence of PVL has been historically high following TAVR, rates of moderate or severe PVL have been substantially reduced with improved sizing techniques and newer iterations of transcatheter valves.[5-7]

Patients with symptomatic PVL can present with heart failure, hemolysis, or both. Heart failure is the most common presentation, but hemolysis due to PVL has been associated with a worse prognosis as compared with patients with heart failure alone.[8] The presence of moderate or severe PVL is associated with reduced survival after both TAVR[4,9] and SAVR.[10] Surgical repair of PVL has been the traditional approach and has demonstrated improved outcomes compared with conservative therapy.[11] However, morbidity and mortality rates following reoperation are high, and recurrence of PVL after surgical repair is common due to the inherent tissue friability and calcification in this subset of patients.[12]

Transcatheter repair of PVL was first described in 1992.[13] Since then, the technique has undergone considerable refinement, such that a transcatheter approach to PVL repair has gained favor as first-line approach in many centers. Procedural success with transcatheter repair of PVL is high[3,14] and is associated with similar survival compared with surgical repair.[15] Furthermore, an attempt at transcatheter PVL closure does not preclude later attempts at surgical repair of PVL, thus offering an attractive option because it is less invasive and less resource-intensive than repeat surgery. The American College of Cardiology/American Heart Association guidelines for valvular heart disease give percutaneous PVL closure a level IIa recommendation when performed in experienced centers.[16]

DIAGNOSIS AND IMAGING

The regurgitant jet of PVL can often be assessed on physical examination as a systolic or diastolic murmur, depending on the lesion location. However, the murmur is often attenuated by tissue and may be missed. Considering the high rate of PVL after SAVR, it

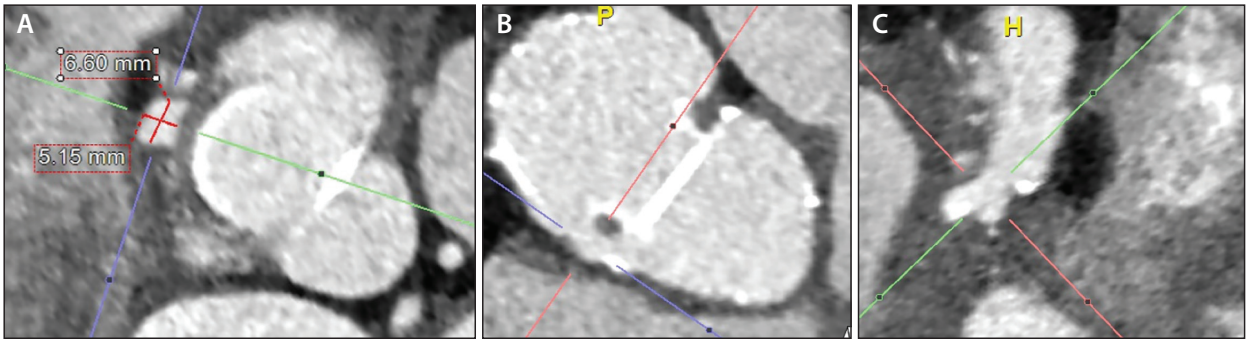

Figure 1. Multiplanar reconstruction and analysis of an aortic PVL. Cross-sectional image of the PVL tract, with measurements (6.6 X 5.15 mm) (A). Simultaneous view of mechanical prosthetic valve as well as the PVL tract (B). Establishing this imaging angle in the cath lab is ideal for PVL wiring technique. Longitudinal image of the PVL, demonstrating the variable course and diameter of some PVL tracts (C).

is important to have a high index of clinical suspicion. Multimodality imaging is a critical component of the modern diagnosis and care of PVL. Transthoracic echocardiography with color Doppler ultrasound interrogation is a common diagnostic tool; however, acoustic shadowing and anterior location of PVL—particularly in the case of aortic PVL—may render transthoracic imaging suboptimal.

The most important imaging modalities for diagnosis and to guide treatment are gated-heart CT and transesophageal echocardiography (TEE), particularly when paired with three-dimensional (3D) reconstruction (ie, 3D TEE). CT affords the advantage of determining the precise location of the PVL, as well as the advantages of image reconstruction and calculation of optimal imaging angles for the catheterization lab when transcatheter PVL closure is anticipated (Figure 1). CT also allows for understanding of the size and course of the PVL with a high degree of spatial resolution, as PVLs may be serpiginous and complex. TEE and 3D TEE are important in quantifying PVL severity and identifying the PVL location and are critical for in-lab procedural guidance—particularly for mitral PVL closure (Figure 2). Three-dimensional printing has been described to guide optimal device selection.[17] However, it is unknown whether 3D printing enhances the procedural efficiency and/or clinical outcomes of PVL closure, and the attendant overhead costs may be considerable.

REVIEW OF DEVICES

Transcatheter PVL closure consists of placing a space-occupying device within the gap between annular tissue and the prosthetic valve, thus preventing flow through that space. Several vascular closure devices have been used to perform transcatheter PVL closure; however, in the United States, there are currently no FDA-approved devices for this indication. The most commonly used devices to treat PVL in the United States are the Amplatzer vascular

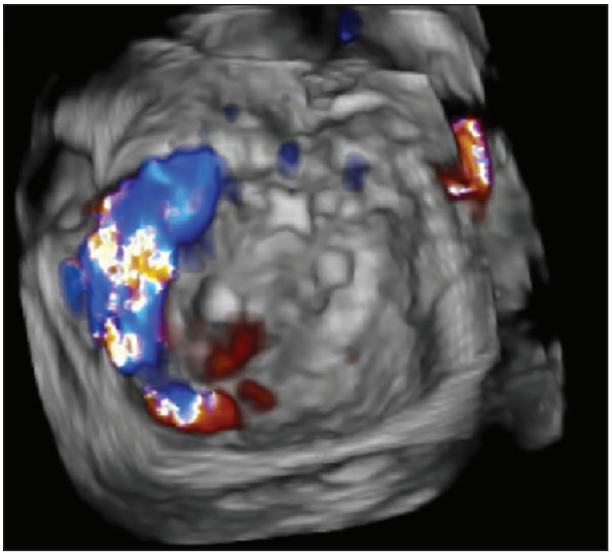

Figure 2. Three-dimensional TEE of mitral PVL from the "surgeon's view" with Doppler ultrasound demonstrating a single, severe mitral PVL at the 10 o'clock position along the mitral annulus.

plug (AVP) II (Abbott Vascular; Figure 3A) and AVP IV (Abbott Vascular; Figure 3B). The AVP devices consist of a self-expanding nitinol wire mesh with a circular profile. AVP II has three lobes (Figure 3A), whereas AVP IV has two lobes (Figure 3B). The AVP II is the most commonly used device for percutaneous PVL treatment in the United States,[3,8] has a favorable delivery profile, and is generally the preferred device of expert operators.[18] However, the AVP IV has a smaller delivery profile, such that it is deliverable through any catheter than can accommodate a 0.038-inch wire, but it is only available in diameters smaller than the AVP II. PVL associated with surgical valves is often crescent-shaped (Figure 4), whereas PVL after TAVR is more often serpiginous and tubular. Thus, the AVP II is useful for closure of postsurgical PVL, particularly when

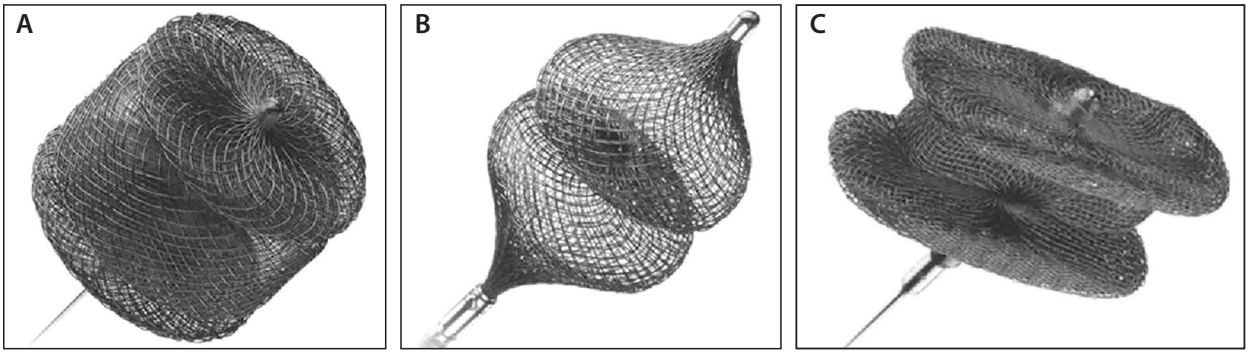

Figure 3. AVP II (A), AVP IV (B), and AVP III (C).

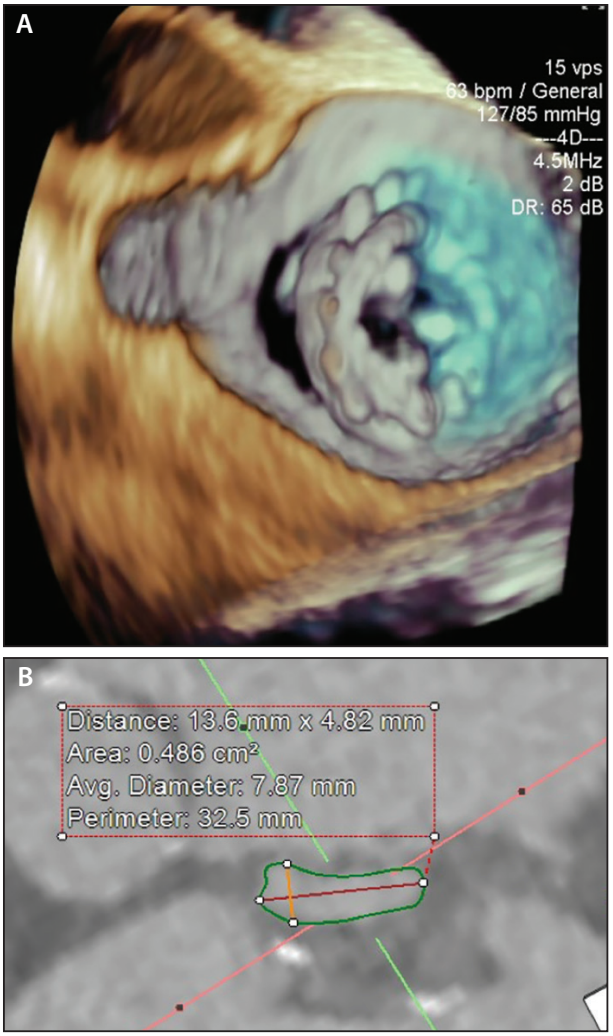

Figure 4. Anterolateral mitral PVL comprising 20% to 25% of the mitral annulus (A). CT reconstruction of the same mitral PVL demonstrating crescentic shape (B).

multiple stacked plugs are needed. AVP IV is most useful for post-TAVR PVL.

The AVP III (Abbott Vascular; Figure 3C) has the dual advantages of a tighter wire mesh that allows the device to seal more quickly as well as an oval design that allows the plug to form a shape more closely approximating noncircular PVLs.[19] The AVP III is not commercially available in the United States, but it is the most commonly used device in Europe for treating PVL and was used in > 60% of cases in the largest published series to date.[3] A variety of other devices, including Amplatzer septal occluders and ventricular septal occluders (Abbott Vascular), have been used in these procedures but are not typically recommended for standard PVL cases because they have a larger transcatheter delivery profile, bulkier design, and larger pores, which may result in suboptimal sealing.

PROCEDURAL TECHNIQUES

It is strongly recommended that before any transcatheter PVL procedure, operators review all available imaging, including CT and TEE, and have a detailed understanding of the patient's specific anatomy and PVL defect(s). Potential pitfalls (eg, the spatial proximity of the PVL to the coronary arteries) should be anticipated. If an imaging cardiologist or anesthesiologist is participating in the PVL procedure, it is important to establish a common nomenclature between the imagers and operators. For example, if the PVL is located at or near the left atrial appendage along the lateral wall of the left atrium in the "surgeon's view" (Figure 2), the interventional cardiologist and imager can communicate by referring to the mitral valve orifice as if it were the face of a clock (eg, "The PVL is located in the 10 o'clock position"). Communication between imagers and operators regarding the manipulation of equipment and wiring techniques should follow standard anatomic prompts, such as anterior versus posterior and lateral versus medial.

Aortic PVL

Transcatheter closure of aortic PVL is most commonly approached retrograde via femoral artery access.[18] General anesthesia can be used, but moderate procedural sedation without intubation is also acceptable. Echocardiography is

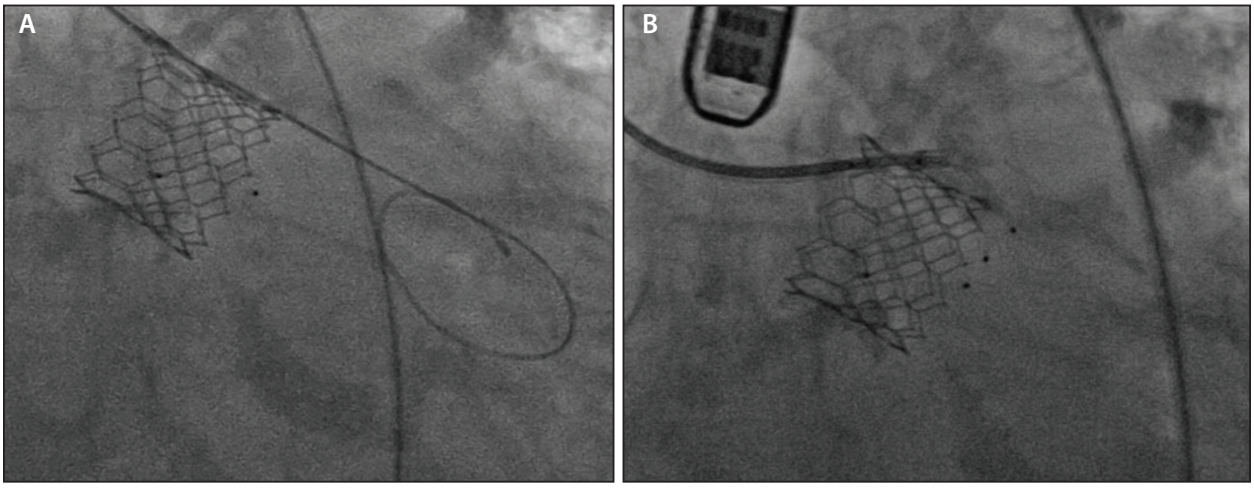

Figure 5. Closure of an aortic PVL after TAVR with a Sapien 3 valve (Edwards Lifesciences) (A). A stiff guidewire is advanced across the defect with a gentle ventricular curve to prevent injury to the left ventricle. Final image with three total AVP IVs (radiopaque dots) deployed across two separate aortic PVLs following TAVR (B).

essential to help guide the procedure, particularly as it pertains to assessing leaflet impingement of mechanical prostheses and assessing the severity of PVL. TEE can be used for posterior defects, but transthoracic echocardiography may be adequate or even superior to TEE when imaging anterior defects due to difficulty obtaining TEE images in the anterior position.[18]

With a catheter positioned in the ascending aorta, the PVL can typically be wired with a 0.035-inch angled hydrophilic guidewire within a 6-F guiding catheter—typically a 6-F multipurpose guidewire (for right coronary cusp or noncoronary cusp defects) or an Amplatz left 1 or 2 guidewire (for left coronary cusp defects). The defect can be crossed over the hydrophilic wire with a 5-F diagnostic multipurpose catheter or hydrophilic glide catheter, which is then used to introduce a stiff delivery wire with a ventricular curve (Figure 5A). Over the ventricular wire, a telescoping system consisting of a 5-F multipurpose catheter, a 6-F guiding catheter (typically a multipurpose shape), and, finally, a 6- to 8-F shuttle sheath (if needed) is advanced to the left ventricle. PVL closure devices are then introduced via the catheter or sheath, and the most distal lobe is deployed in the ventricle. Once the distal lobe is deployed, the device and sheath can be gently pulled back to the desired location, such that the more proximal lobes are deployed across the defect and the valve annulus (Figure 5B). TEE can be used to evaluate residual PVL severity and leaflet motion of the prosthetic valve once the closure device is deployed and before release of the device.

Mitral PVL

Closure of mitral PVL may be more complex than aortic PVL. There are three basic approaches to wire crossing: (1) retrograde via transapical puncture, (2) retrograde via femoral artery access using a diagnostic catheter in the left ventricle to redirect a wire across the PVL, or (3) antegrade via transseptal puncture, which is the preferred method.

For procedures in which antegrade wiring is chosen, the transseptal puncture can be performed per institutional practice with standard equipment. Electrocautery may be required if a previous interatrial septal repair has been performed or scar tissue is present. The transseptal puncture location is typically posterior and inferior in the fossa ovalis, which affords the most backup support when traversing the PVL with a catheter. Antegrade wiring is performed with a 0.035-inch stiff angled hydrophilic wire, facilitated by use of a steerable transseptal sheath (eg, an 8.5-F Agilis sheath, Abbott Vascular) with a telescoping 5-F multipurpose diagnostic catheter and 6-F multipurpose guiding system within it. This entire telescoping system can be manipulated in three dimensions to approach the PVL. Wiring of the defects is performed using both fluoroscopic guidance and TEE. Three-dimensional TEE is critical during this process to guide the operator steering the system, as well as to confirm the wire position across the defect rather than through the valve (Figure 6A). Once the PVL is crossed, the wire can be exchanged for a stiff ventricular wire (using a telescoping system as previously described) or used to create a transcatheter "wire rail," which produces optimal backup support. A transcatheter wire rail is created by directing the hydrophilic wire into the ascending aorta, which is then snared and externalized via femoral artery access, thus providing maximum support for catheter or sheath crossing (Figure 6B and 6C).

Once the defect is crossed with a guide or sheath, the plug is placed and released in a fashion similar to aortic defects, with TEE and fluoroscopic imaging used to rule

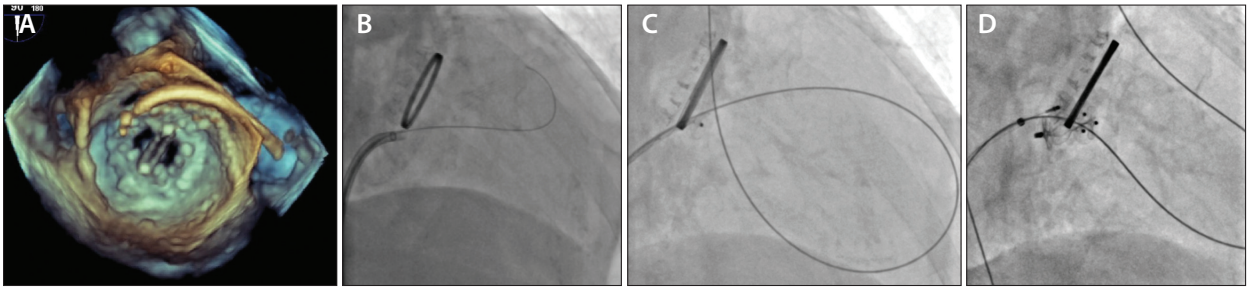

Figure 6. Three-dimensional TEE guiding a mitral PVL procedure for an anterolateral defect at the 10 o'clock position along the mitral annulus (A). The catheter and wire are shown crossing in the interatrial septum and approaching the defect. Panel B shows the formation of a transcatheter wire rail. A steerable guide catheter was used to guide a hydrophilic guidewire across the PVL into the left ventricle, which was then directed through the aortic valve and snared in the ascending aorta. A transcatheter wire rail is seen after the hydrophilic wire was snared in the ascending aorta and externalized via femoral artery access (C). Over the wire, a catheter was advanced across the PVL into the left ventricle, and the first AVP II was deployed across the defect. The wire was maintained in place after the device was deployed to allow access to the PVL for further devices. Panel D shows the final image of the mitral PVL case with three AVP IIs deployed.

out interaction with prosthetic valve leaflets. TEE is used to assess the degree of PVL reduction. If the defect is large and a single vascular plug does not provide adequate closure, placement of multiple plugs within the same defect may be necessary using an "anchor wire" technique. In this technique, the previously described single-catheter technique is adjusted by advancing a shuttle sheath across the defect and maintaining a stiff wire across the defect while the plug is deployed. The stiff wire is then maintained in place after the release of the plug, and then the shuttle sheath may be advanced alongside the plug over the stiff wire (Figure 6D). It is important to note that a larger access sheath size may be necessary to accommodate the passage of multiple devices and wires, and compatibility may be an issue.

OUTCOMES

Procedural success is excellent with modern techniques for transcatheter PVL closure. In the largest series to date, successful plug deployment was > 90%, and residual PVL of mild or less was 75% to 77%.[3,8] Complications of transcatheter PVL closure are infrequent, with < 2% incidence of stroke, device embolization, infection, valve leaflet impingement, and coronary occlusion.[3,14,15] In-hospital and 1-year mortality are lower following transcatheter PVL repair than after surgical repair in nonrandomized series, although the need for late reintervention may be higher after transcatheter repair.[15,20]

A consistent finding across all literature regarding PVL is that higher residual PVL severity is a marker of worse outcomes. In a comparison of surgical PVL repair versus medical therapy, mortality was higher in the latter group.[11] In the follow-up of patients after surgical repair, residual PVL and reintervention were associated with higher mortality.[12] Finally, in the largest series of PVL closure to date, mild or less PVL after percutaneous closure was associated with both improved survival and a greater reduction in symptoms of heart failure as compared with patients who had residual moderate or severe PVL.[3,8] This suggests that the goal of a successful PVL procedure should always be to achieve the maximal reduction in PVL severity, preferably to mild or no residual leak.

CONCLUSION

There are several unanswered questions regarding transcatheter PVL closure. First, the impact of device selection on procedural success and clinical outcomes is unknown. The ideal PVL closure device would allow for complete closure of a defect using only one device, thus optimizing time in the lab and minimizing procedural complexity. However, the use of multiple devices is common due to the complexity of PVL defects.[3,19] Although the acute procedural results with current AVP devices are favorable, there is certainly room for improvement, given that the devices are not specifically designed for PVL closure. It is unknown whether devices such as the AVP III, which may be more favorable in addressing large and/or crescentic PVLs, may result in improved procedural efficiency and long-term patient outcomes. In Ireland and the United Kingdom, where AVP II, III, and IV are all available, the AVP III was chosen in > 60% of cases, suggesting it is preferred by experienced operators in those countries.[3]

Finally, whether PVL closure is optimally performed in a small number of centers of excellence versus on-site at any center performing structural heart interventions is an unanswered question. However, as physicians gain additional procedural experience, the adoption of advanced procedural techniques—including transcatheter rails, TEE guidance, and use of an anchor wire—increase while

(Continued on page 48)

(Continued from page 46)

procedure time, length of hospital stay, and complications decrease.[21] How the learning curve with PVL closure affects the adoption of these procedures in a larger number of centers remains to be seen. ■

1. Hammermeister K, Sethi GK, Henderson WG, et al. 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;36:1152-1158.
2. Ionescu A, Fraser AG, Butchart EG. Prevalence and clinical significance of incidental paraprosthetic valvar regurgitation: a prospective study using transoesophageal echocardiography. Heart. 2003;89:1316-1321.
3. Calvert PA, Northridge DB, Malik IS, et al. Percutaneous device closure of paravalvular leak: combined experience from the United Kingdom and Ireland. Circulation. 2016;134:934-944.
4. Kodali SK, Williams MR, Smith CR, et al. Two-year outcomes after transcatheter or surgical aortic-valve replacement. N Engl J Med. 2012;366:1686-1695.
5. Leon MB, Smith CR, Mack MJ, et al. Transcatheter or surgical aortic-valve replacement in intermediate-risk patients. N Engl J Med. 2016;374:1609-1620.
6. Mack MJ, Leon MB, Thourani VH, et al. Transcatheter aortic-valve replacement with a balloon-expandable valve in low-risk patients. N Engl J Med. 2019;380:1695-1705.
7. Popma JJ, Deeb GM, Yakubov SJ, et al. Transcatheter aortic-valve replacement with a self-expanding valve in low-risk patients. N Engl J Med. 2019;380:1706-1715.
8. Sorajja P, Cabalka AK, Hagler DJ, Rihal CS. Long-term follow-up of percutaneous repair of paravalvular prosthetic regurgitation. J Am Coll Cardiol. 2011;58:2218-2224.
9. Thourani VH, Kodali S, Makkar RR, et al. Transcatheter aortic valve replacement versus surgical valve replacement in intermediate-risk patients: a propensity score analysis. Lancet. 2016;387:2218-2225.
10. Sponga S, Perron J, Dagenais F, et al. Impact of residual regurgitation after aortic valve replacement. Eur J Cardiothorac Surg. 2012;42:486-492.
11. Genoni M, Franzen D, Vogt P, et al. Paravalvular leakage after mitral valve replacement: improved long-term survival with aggressive surgery? Eur J Cardiothorac Surg. 2000;17:14-19.
12. Taramasso M, Maisano F, Denti P, et al. Surgical treatment of paravalvular leak: Long-term results in a single-center experience (up to 14 years). J Thorac Cardiovasc Surg. 2015;149:1270-1275.
13. Hourihan M, Perry SB, Mandell VS, et al. Transcatheter umbrella closure of valvular and paravalvular leaks. J Am Coll Cardiol. 1992;20:1371-1377.
14. Sorajja P, Cabalka AK, Hagler DJ, Rihal CS. Percutaneous repair of paravalvular prosthetic regurgitation: acute and 30-day outcomes in 115 patients. Circ Cardiovasc Interv. 2011;4:314-321.
15. Wells JA 4th, Condado JF, Kamioka N, et al. Outcomes after paravalvular leak closure: transcatheter versus surgical approaches. JACC Cardiovasc Interv. 2017;10:500-507.
16. Nishimura RA, Otto CM, Bonow RO, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. Circulation. 2014;129:2440-2492.
17. Motwani M, Burley O, Luckie M, et al. 3D-printing assisted closure of paravalvular leak [published online March 26, 2019]. J Cardiovasc Comput Tomogr.
18. Eleid M. Interventional management of paravalvular leak. Heart. 2018;104:1797-1802.
19. Sorajja P. Round pegs for not round holes: the challenge of percutaneous repair of paravalvular regurgitation. Catheter Cardiovasc Interv. 2011;78:331-332.
20. Alkhouli M, Rihal CS, Zack CJ, et al. Transcatheter and surgical management of mitral paravalvular leak: long-term outcomes. JACC Cardiovasc Interv. 2017;10:1946-1956.
21. Sorajja P, Cabalka AK, Hagler DJ, Rihal CS. The learning curve in percutaneous repair of paravalvular prosthetic regurgitation: an analysis of 200 cases. JACC Cardiovasc Interv. 2014;7:521-529.

John T. Saxon, MD
Saint Luke's Mid America Heart Institute
University of Missouri-Kansas City
Kansas City, Missouri
jsaxon@saint-lukes.org
Disclosures: None.

Adnan K. Chhatriwalla, MD
Saint Luke's Mid America Heart Institute
University of Missouri-Kansas City
Kansas City, Missouri
Disclosures: Speaker's bureau for Edwards Lifesciences, Medtronic, and Abbott; proctor for Medtronic and Edwards Lifesciences.