

Clinical update

Review of surgical prosthetic paravalvular leaks: diagnosis and catheter-based closure

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Paravalvular leak (PVL) is an uncommon yet serious complication associated with surgical prosthetic valve implantation. Paravalvular leak can have significant clinical consequence such as congestive heart failure, haemolytic anaemia, and infective endocarditis. Recently, transcatheter therapy has been applied to the treatment of this disorder with reasonable procedural and clinical success. This review discusses the current state of PVLs, the utilization of multi-modality imaging in their diagnosis and treatment, and the available therapeutic options. Further aim of this review is to examine transcatheter therapy of PVLs including the principles, outcomes, and procedural-related complications.

Keywords

Paravalvular leak • Percutaneous closure • Valvular prosthesis • Congestive heart failure • Haemolytic anaemia
• Multi-modality imaging

Introduction

Paravalvular leak (PVL) is an uncommon yet serious complication associated with prosthetic valve implantation. Paravalvular leak refers to an abnormal communication between the cardiovascular chambers adjacent to a prosthetic valve. Paravalvular leaks occur in patients who have undergone surgical valve replacement, with an incidence of 2–10% in the aortic position and 7–17% in the mitral position.^{1,2} Although most PVLs are asymptomatic and have a benign clinical course, an estimated 1–5% of patients with PVLs can lead to serious clinical consequences.^{3–5}

Until recently, surgery has been the only available therapy for the treatment of clinically significant PVLs despite the significant mortality associated with re-operation.^{6,7} Percutaneous transcatheter closure, routinely applied in the management of various intracardiac defects, has been utilized for the treatment of PVLs using a variety of techniques.^{4,8–16} This review discusses the current understanding of PVLs, the utilization of multi-modality imaging in PVL diagnosis and treatment, and the available therapeutic options. We will examine the state of transcatheter therapy of PVLs including the principles, outcomes, and procedural-related complications.

Aetiology

Paravalvular leaks are the result of an incomplete seal between the sewing ring and annulus. This may arise from abnormal pressure or traction forces on the prosthesis occurring after surgery.^{17,18} Several factors are known to increase the risk of PVL formation.^{3,19} They include annular calcification, infection, suturing technique, as well as the size and shape of prosthetic implant. The early occurrence of PVLs is usually associated with the technical aspects of the surgical implant. Late PVLs are commonly a consequence of suture dehiscence caused by endocarditis or the gradual resorption of incompletely debrided annular calcifications.

Diagnosis

Clinical findings

Auscultation is a widely used method of screening for PVL. Cardiac murmurs when considered in a patient with prosthetic valve(s), increases concern. In mitral PVLs, the most striking finding is a pansystolic murmur heard over the left sternal border, with radiation dependent on the trajectory of the regurgitant jet. In aortic PVLs, a high-pitched decrescendo murmur at the left sternal border in

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diastole can be appreciated. However, auscultation lacks the specificity for diagnosis. Other imaging modalities, in particular echocardiography, should be readily performed to confirm or rule out the presence of PVL(s).

Patients with symptomatic PVLs present with congestive heart failure (CHF) from volume overload in ~90% of cases and haemolytic anaemia from shear stress on the red blood cells ranging from one-third to three-quarters of cases. A majority of patients presenting with CHF have a mean NYHA functional class of ≥ 3 .^{14,16} Severe haemolytic anaemia may even manifest as congestive heart failure. Furthermore, PVL, like any intracardiac defect creating a significant turbulent flow, is an important pre-existing condition in the context of bacteraemia to develop infective endocarditis.

Blood test

Haemolysis can be identified by a serum lactate dehydrogenase level >460 U/L and any two of the four following criteria: blood haemoglobin <13.8 g/dL for males or <12.4 g/dL for females, serum haptoglobin <50 mg/dL, and reticulocyte count $>2\%$.²⁰ In addition, plasma free haemoglobin levels >40 mg/dL are suggestive of haemolysis. Plasma N-terminal pro-brain natriuretic peptide is typically elevated (>400 pg/mL) in CHF and increases with a greater severity of aortic or mitral regurgitation, reflecting regurgitant volume, LV size and function, and symptomatic status.^{21,22}

Imaging techniques

Imaging techniques have an important role in diagnosis, procedural guidance, and evaluation of procedural results. The definitive diagnosis of PVL is made with echocardiography. At present, the two imaging modalities that are used to evaluate and guide closure of PVLs are echocardiography and computed tomography (CT).

Angiography

Initially, angiography was used to determine the location and size of PVLs, particularly in the aortic position.¹² Paravalvular leaks were profiled in multiple angles to document their geometry and proximity to the valve leaflets and coronary ostia. Test balloon

occlusion of the PVL helped to better determine the size of the PVL, its distensibility, and haemodynamic status with closure. However, there was risk associated with this technique including balloon entrapment and it is no longer recommended. The major challenge of angiography is the visualization of the three-dimensional (3D) anatomic and spatial characteristics of the defect.

Echocardiography

Transthoracic (TTE) along with transoesophageal echocardiography (TOE) can be utilized to determine these spatial characteristics along with prosthetic valve function. Three-dimensional TOE is superior to 2D-TOE for the evaluation of PVL regurgitation in that it provides improved localization and analysis of the PVL size and shape (Figure 1), especially in patients with multiple PVLs.^{23,24} Colour Doppler imaging can localize the paravalvular regurgitant jet as well as assess its severity. Although 3D-TOE may permit the planimetry of the regurgitant orifice(s), the resolution may be limited when the areas of dehiscence are slit-like.

The severity of aortic paravalvular regurgitation is defined by accepted aortic regurgitation criteria such as jet width (vena contracta), jet density, jet deceleration rate, and diastolic flow reversal in the descending aorta.²⁵ Quantitative methods such as regurgitant volume and fraction obtained by spectral Doppler are recommended when regurgitation is greater than mild.

To facilitate the communication between the interventionalist and echocardiographer, it is recommended that leak location be reported in a clock-wise format from a surgeon's perspective or 'surgical view' (Figure 2). Five o'clock is assigned to the commissure between the left and right coronary sinuses, 8 o'clock to the commissure between the right and non-coronary sinuses, and 11 o'clock to the commissure between the non-coronary and left coronary sinuses. Aortic PVLs are more commonly located in the right and non-coronary cusps.¹⁷

Similar to aortic valve assessment, qualitative parameters are used for mitral paravalvular regurgitation such as colour flow regurgitant jet area, jet density, and systolic pulmonary venous flow reversal, a specific sign of severe mitral regurgitation.²⁵ Because of jet eccentricity, jet area measurement may

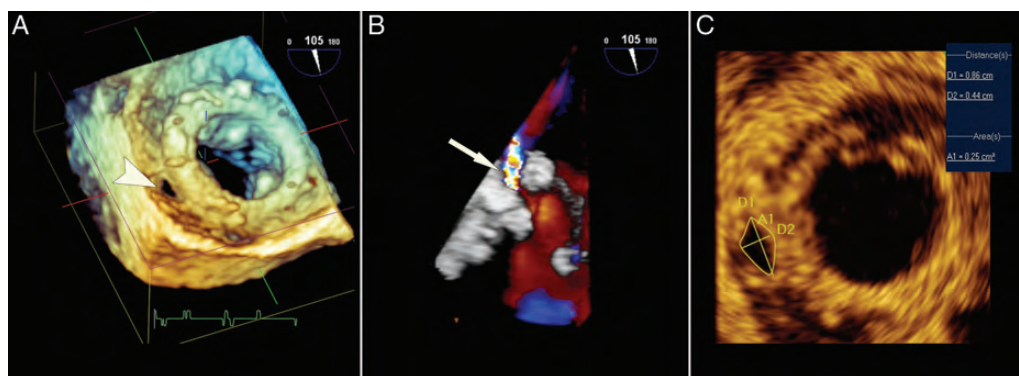


Figure 1 (A) Three-dimensional-transesophageal echocardiography with arrowhead identifying a mitral paravalvular leak. (B) Three-dimensional colour-Doppler imaging of the paravalvular leak with arrow identifying the regurgitant jet. (C) Measurements of length, width, and area can be performed. (Phillips QLab, Amsterdam, Netherlands).

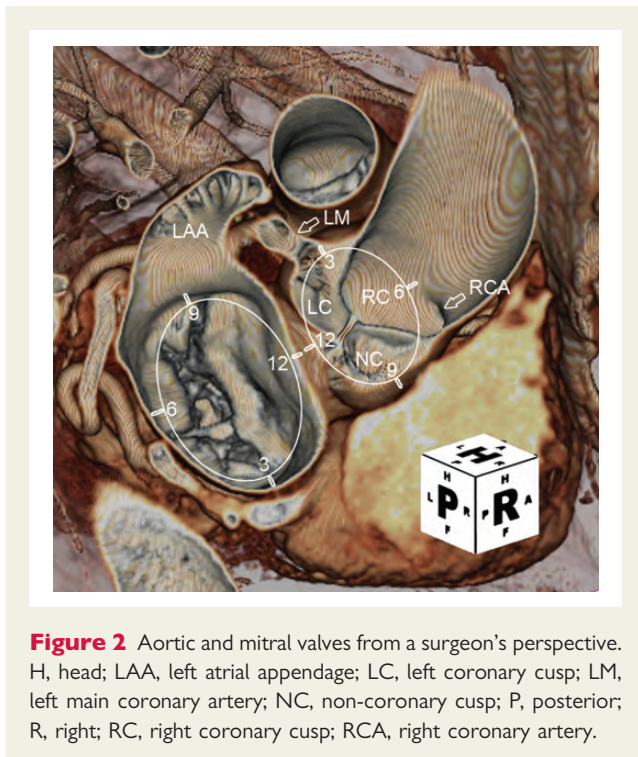


Figure 2 Aortic and mitral valves from a surgeon's perspective. H, head; LAA, left atrial appendage; LC, left coronary cusp; LM, left main coronary artery; NC, non-coronary cusp; P, posterior; R, right; RC, right coronary cusp; RCA, right coronary artery.

underestimate the severity of regurgitation due to the Coanda effect, spreading of the jet along the atrial wall. Quantitative parameters, such as vena contracta diameter and regurgitant volume and fraction, are helpful. Although the proximal isovelocity surface area (PISA) approach has not been validated in the setting of paravalvular regurgitation, the presence of a large PISA shell is consistent with more severe regurgitation.

Mitral PVL location can also be reported in a similar format as the aortic valve (Figure 2). By rotation of the echocardiographic image, the aortic valve is brought to a position at the top of the mitral ring, as viewed from the atrium. The mid-point of the anterior annulus (the aortic valve) is represented as 12 o'clock and the mid-point of the posterior annulus is represented as 6 o'clock.¹⁸ The postero-medial commissure and interatrial septum are at 3 o'clock and the antero-lateral commissure and atrial appendage are at ~9 o'clock. The most common locations for mitral PVLs are between 10 and 11 o'clock, corresponding to the aortic-mitral curtain, and 5 and 6 o'clock, corresponding to the posterior wall.^{14,18}

The quantification of severity in the case of multiple PVLs is a challenge. Colour-Doppler may be helpful in the initial assessment, but can be limited by jet eccentricity. Furthermore, the sum of multiple vena contracta widths or PISA radiuses has not been validated. Guidelines suggest that the proportion of regurgitant areas to the circumference of the prosthesis may be an appropriate semi-quantitative method, mild when it occupies <10% and severe when it occupies >20%.²⁵ Another possible method includes the calculation of regurgitant volume by comparing the volumes that pass through the reference valve with PVLs, to the non-regurgitant valve. Magnetic resonance imaging (MRI) is a reliable means for the quantification of regurgitant volume, but

there is limited evidence for the evaluation of paravalvular regurgitation and for comparison with echocardiography.^{26–28} Furthermore, many of the PVL patients have mechanical prostheses and/or implantable devices making MRI difficult to obtain. The use of 3D echocardiography will be useful in the evaluation of multiple defects, although currently its role remains to be determined.²³

Limitations of echocardiography

Assessment of paravalvular regurgitation is more difficult than native valve regurgitation, particularly in the presence of mechanical valves due to image distortion. Acoustic shadowing may misrepresent mild regurgitation when severe is present. When clinical suspicion is high, acoustic shadowing is a concern, and there is no significant transvalvular regurgitation, aortography, or ventriculography may aid in the diagnosis. Artefactual dropout of echoes may also occur, especially when the ultrasound beam is parallel to the area of interest. The use of colour Doppler is necessary to confirm the presence of the PVL. Furthermore for 3D TOE, there is a smaller field of view in real-time modes and the frame rates are slower when using the full-volume modality, lowering the temporal resolution. In addition, very fine structures are not well visualized. Improved spatial resolution will help to better define intracardiac anatomy, improving procedural planning and guidance.

Computed tomography

ECG-gated computed tomographic angiography (CTA) with 3D/4D-reconstruction using volume rendering techniques has become an increasingly utilized tool in PVL evaluation.²⁹ Helical CT acquisition is performed in multiple phases, usually 16 or more, with contrast injection protocols similar to that used for coronary CTA. Retrospective ECG-gated reconstruction of these phases is then processed for 4D-reconstruction using a dedicated CT workstation. With adjustment of opacity and colour and applying cut-planes, it is possible to visualize the PVL(s) in great detail. In addition, cardiac CTA can assist with technical planning for percutaneous PVL closure.^{14,30}

Limitations of computed tomography

Artefacts from dense structures such as prosthetic valves or extensive calcification may limit PVL size estimation. Furthermore, exposure to radiation and i.v. contrast media increases the risks associated with the procedure. Generally an increased radiation dose results in better tissue penetration and image quality. However, the benefits of acquiring images of diagnostic quality have to be weighed against the radiation risk for each individual patient, especially in females and younger patients.

Treatment

Medical therapy

Medical treatment of PVLs is in great measure palliative. Diuretics and afterload reduction are the cornerstones of heart failure therapy, but may be ineffective. If haemolysis is present, iron and folate supplementation, erythropoietin injections, and repeat

blood transfusions may be required to maintain haemoglobin > 10 mg/dL.³¹

Surgical corrective therapy

The gold standard and only available treatment, until recently, for severe PVL has been surgery. The choice of surgical correction involves either repair of the leak or re-replacement of the valve. This depends on the surgical findings related to the aetiology, condition of the native mitral annulus, location and size of the leak, and surgical exposure. Many techniques have been described to repair mitral PVLs, including direct suturing, patch closure, and incorporation of full-thickness autologous tissue.^{32–34} Both options have failure rates ranging from 12 to 35%, with mortality rates that increase with re-intervention.⁶ Paravalvular leak recurrence is common because the underlying pathologic process remains unchanged. Overall, surgical treatment offers improved survival and a reduction in symptoms in patients with severe PVL(s), when compared with conservative therapy.³⁵

Transcatheter therapy

Since the adaptation of transcatheter techniques for the treatment of PVLs, a less-invasive approach to PVL closure has become a potential option. The transcatheter closure of prosthetic PVL(s) is often a long, technically demanding procedure requiring access to a robust equipment inventory. General anaesthesia is often used for both patient comfort and airway protection. In addition, adequate anticoagulation is required throughout the procedure, especially if transseptal catheterization is performed, as prolonged equipment dwell times within the patient are common. Finally, the interaction with a multi-disciplinary team (MDT) is a key component in attaining procedural success. Important members of the MDT include the interventional cardiologist, echocardiographer, CTA reconstruction specialist, cardiovascular surgeon, and anaesthesiologist.

Equipment

A major challenge in the treatment of paravalvular regurgitation is the absence of dedicated delivery systems and devices designed for percutaneous closure. The devices currently being used have been designed for the closure of other cardiovascular defects, such as atrial septal defect, ventricular septal defect, and patent ductus arteriosus, and are used off-label for PVL closure. The initial devices used included umbrella devices, vascular occluders, and coils.^{12,36,37} These devices have been replaced by the Amplatzer family of occluders/plugs (St Jude Medical, St Paul, MN, USA), Amplatzer septal occluder (ASO), Amplatzer muscular VSD occluder (mVSD), Amplatzer duct occluder (ADO), and Amplatzer vascular plugs (AVP II and III). (Table 1).

The appropriate selection of closure device is critical for procedural success. The described device occluders are circular in shape, except for the AVP III (CE marked in Europe) which is oblong. Paravalvular leaks are variable in size and shape with many being crescentic, not cylindrical. Furthermore, PVLs may have serpiginous tracks making them difficult to cross with a wire. Successful treatment of these irregularly shaped defects with circular occluders may require relatively large devices that mold to the PVL. This practice can increase the risk of prosthetic

Table 1 Devices for percutaneous paravalvular leak closure

	Amplatzer septal occluder (ASO)	Amplatzer muscular VSD occluder (mVSD)	Amplatzer duct occluder (ADO)	Amplatzer vascular plug II (AVP II)	Amplatzer vascular plug III (AVP III)
Polyester cloth	Yes	Yes	Yes	No	No
Occlusive planes	4	4	3	6	4
Waist length	3–4 mm	7 mm	5–8 mm	6 mm	2–5 mm
Size difference between disc and waist	Proximal/distal disc: 8 mm/12 mm, (4–10 mm ASO), 10 mm/14 mm, (≥11 mm ASO)	8 mm	4 mm, (5/4–8/6 mm ADO), 6 mm, (10/8–16/14 mm ADO)	No difference	2 mm

Amplatzer family of occluders/plugs from St. Jude Medical (St. Paul, MN, USA).

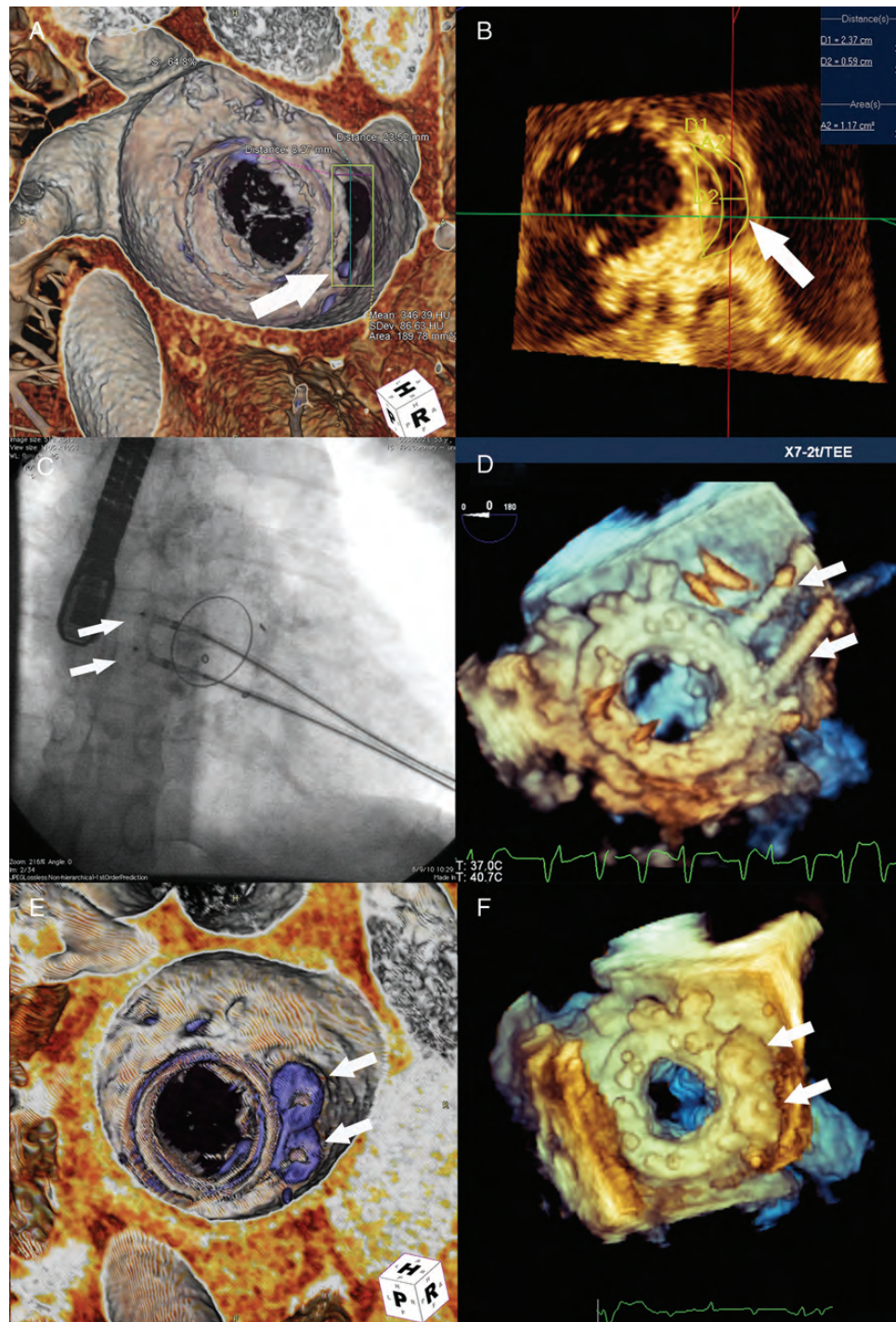


Figure 3 Computed tomography angiography (CTA) with 3D/4D-reconstruction and 3D transesophageal echocardiography (TEE) reveal a large mitral paravalvular leak (A and B). Measurements of length, width, area, and perimeter are used to determine device size. Decision for two smaller devices, instead of a single large device, prevents interference with prosthetic valve function. Simultaneous device delivery via two delivery systems and two transapical access sites are visualized under fluoroscopy and TEE (C and D). CTA and 3D TEE confirms the paravalvular position of the devices (E and F).

leaflet impingement particularly in mechanical prostheses. This may be overcome by the use of multiple smaller devices, which may conform better to the paravalvular space and potentially be the best option to avoid prosthetic valve dysfunction. In addition, the

oblong shape of AVP III may conform better to the shape of a crescentic PVL.

Typically, a rectangle is drawn on the imaging modality of choice encompassing the desired defect.³⁸ (Figure 3A and B) The

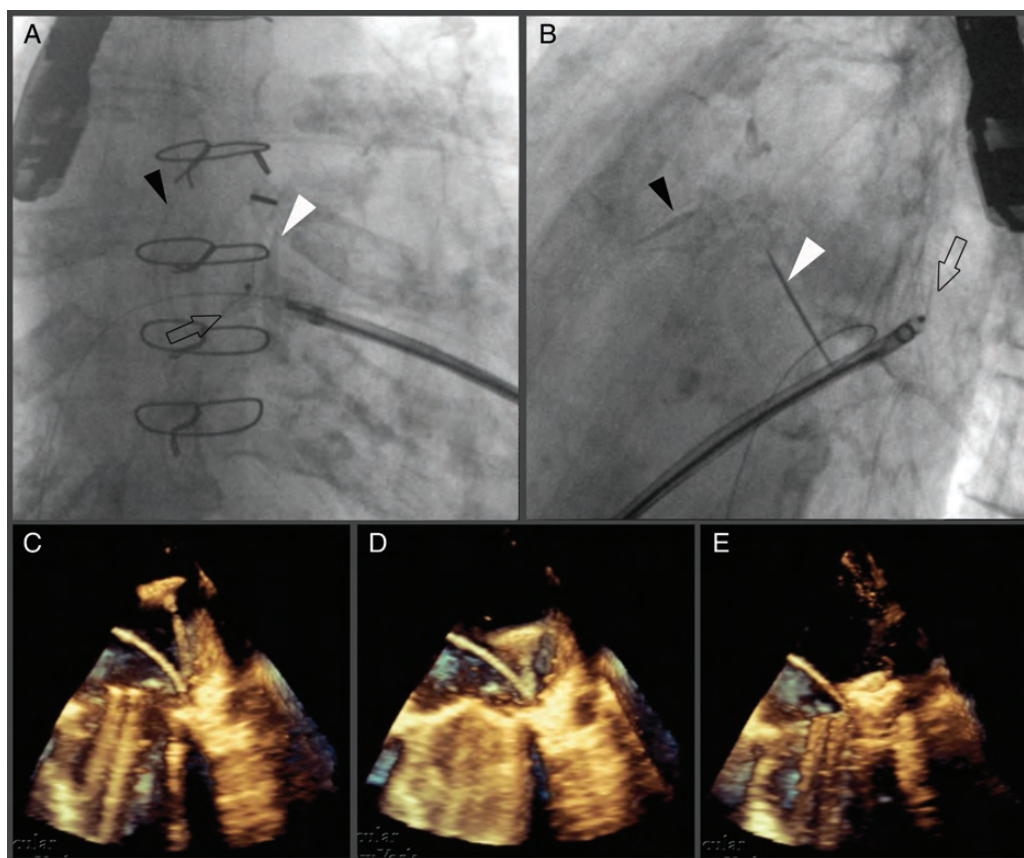


Figure 4 (A and B) Biplane fluoroscopy identifies the paravalvular position in two orthogonal views [mechanical aortic (black arrowhead) and mitral (white arrowhead) valves, amplatzer ductal occluder (outlined arrow)]. (C, D, and E) Three-dimensional-transoesophageal echocardiography guidance of paravalvular leak closure. An exteriorized safety wire (transapical to transseptal) and delivery sheath can be seen paravalvular to a bileaflet mechanical mitral valve. An Amplatzer Ductal Occluder is visualized within the left atrium and is being pulled back into the paravalvular leak.

measurements of the length and width of the PVL are used to determine the waist diameter of the device. Other measurements of area and perimeter can also be performed. To avoid impingement on adjacent structures, it is necessary to determine the distance between the PVL and the valve struts and leaflets.³⁹ This distance will establish the maximum disk size of the device that can be used. The ASO device has the greatest difference between the disk and the waist compared with the other devices. Devices with less of a difference are better suited when the distance between the PVL and adjacent structures is minimal. In patients with bileaflet mechanical valves, placement of the ADO retention disc on the LV side of an aortic PVL or on the atrial side of a mitral PVL prevents interference with the two semi-circular leaflets.

Multi-modality imaging guidance

Fluoroscopy

Fluoroscopy is a 2D planar imaging technique and is the hallmark modality for transcatheter therapy. Mono- or biplane fluoroscopy provides a high degree of mobility and flexibility for oblique and angulated projections, with biplane imaging providing two orthogonal views simultaneously. Biplane fluoroscopy is the preferred

modality for guidance in percutaneous PVL closure (Figure 4A and B).

Echocardiography

Transoesophageal echocardiography, both 2D- and 3D-, provides real-time guidance of transcatheter PVL closure. Transoesophageal echocardiography facilitates guidewire and catheter placement through the defect, assesses closure device position and residual paravalvular regurgitation, affirms prosthetic valve function, and detects procedural complications. (Figure 4C–E) When a transseptal approach is used, TOE can guide precise location of the transseptal puncture. Intracardiac echocardiography (ICE) may be helpful to image aortic PVLs that are located anteriorly.⁴⁰ Placement of the ICE catheter in the right ventricular outflow tract can provide visualization of the aortic valve prosthesis and aPVLs.

Computed tomography/fusion imaging

In recent years, CTA with 3D/4D reconstruction has also provided intra-procedural guidance.^{14,41,42} Pre-acquired 4D-CTA reconstructed images can be displayed in many catheterization laboratories either adjacent to or overlaid onto live fluoroscopy, also

known as fusion imaging. A single-phase, reconstructed image can be merged and co-registered with X-ray such that both images are congruent. Angulation and/or rotation of the fluoroscopy camera will subsequently adjust the CT image. Computed tomography overlay can identify important landmarks and allow for improved leak localization and crossing (Figure 5).

Volume status, patient positioning, and physiological variation that take place between pre-procedural imaging and the intervention may alter the cardiac anatomy and the ability to appropriately register images. In addition, cardiac motion can lead to inaccuracy. Future technology that allows the importation of multiple cardiac phases, improved registration methods, and the ability to fuse real-

time 3D TOE with fluoroscopy will enhance the utilization of fusion imaging.

Procedural principles

The transcatheter closure of PVLs is performed using transseptal, retrograde transaortic, and/or LV transapical approaches. The choice of approach depends on the valve involved, the location of the leak, the presence of mechanical valves hindering entry, and the vascular access difficulties of an individual patient. Other factors to be considered include the presence of paravalvular calcification and an orifice size differential on either side of the

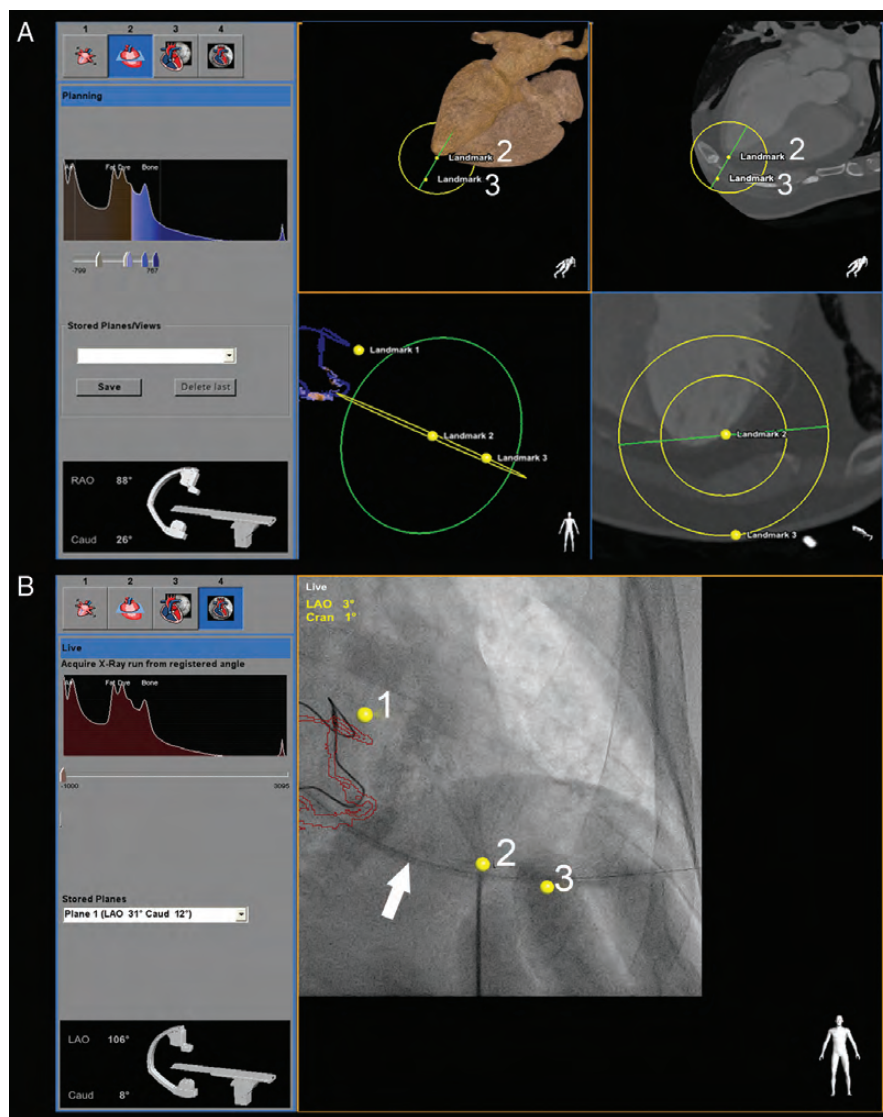


Figure 5 (A) Computed tomographic reconstructed images can be used to identify the paravalvular leak and other important landmarks for transapical access; 1, paravalvular leak; 2, left ventricular wall; 3, skin entry. (B) CT images are then co-registered with fluoroscopy (CT overlay) with angulation and/or figure rotation of the fluoroscopy camera moving congruently with the computed tomography image. (Phillips Heart-Navigator, Amsterdam, Netherlands).

prosthetic valve. Operator experience and preference also play an important role in the decision of approach.

Transapical access

Transapical access requires careful pre-procedural planning with CTA.³⁰ (Figure 6) The following structures are identified: cardiac apex or peri-apical segment away from the coronary arteries, papillary muscles, and extension of the lung parenchyma over the LV cavity. The entry sites for the skin and LV myocardium are selected such that they are in direct line with the PVL, away from any of the identified structures. Computed tomography/fluoroscopy fusion imaging with labelled skin entry, LV entry, and PVL location(s) facilitates access, improving procedural success, and reducing transapical complications. Simultaneous left coronary angiography may be necessary to confirm an entry location away from the coronary arteries, typically the left anterior descending.

Transapical puncture is performed using a 21-gauge micropuncture needle to minimize trauma or bleeding. For overweight patients with significant subcutaneous tissue, it is important to identify on CT the depth of the LV myocardium from the skin entry. Larger needles may be necessary to achieve adequate depth. Once entry into the LV is confirmed, 5F to 12F sheaths are used depending on the intended device(s) delivered. Transapical access closure is required for sheath sizes greater than 5F. Multiple devices can be used such as a ADO, mVSD, or AVP II.^{30,43}

Aortic paravalvular leaks

Most aortic PVLs can be successfully performed using a retrograde transaortic approach. A hydrophilic guidewire is used, supported by a 5F steerable catheter that will direct the wire towards the PVL. Once the wire is across the defect, paravalvular position is confirmed by echocardiography and fluoroscopy. The catheter is then advanced through the defect into the LV. The hydrophilic wire is exchanged for an extra-support, exchange-length wire. Careful precautions in wire exchange are used to reduce the risk of cardiac perforation, including the placement of a preformed loop and unsheathing of the catheter when the wire is at the catheter tip.

An appropriate French-size delivery sheath for the predetermined device(s) is introduced into the LV. The distal end of the device is exposed with caution not to entangle the mitral apparatus. Finally, the device is pulled back into the defect. Positioning is confirmed by TOE. For closure devices with a proximal disc, the location of the disc to the coronary ostia needs to be evaluated for risk of coronary obstruction.

The transapical approach permits direct access to the aortic valve and may be necessary in the presence of mechanical mitral and aortic prostheses, or when the retrograde transaortic approach is unsuccessful. For the antegrade transseptal approach, the creation of an exteriorized arteriovenous (AV) rail can provide complete control and support for sheath and device delivery. The AV rail is formed when the crossing wire is placed into the descending aorta, snared and then exteriorized through the femoral arterial sheath. Care must be taken not to have significant tension on the loop in LV that can cause severe mitral regurgitation by entrapping the anterior mitral leaflet.

Mitral paravalvular leaks

Mitral PVL closure, compared with aortic PVL closure, is technically more challenging. Approaches include retrograde transapical, antegrade transseptal, and retrograde aortic, in order of preference at our institution. Mitral PVLs located posteriorly or septally (1–6 o'clock positions) require a precise transseptal puncture and a high-degree of device flexion. Negotiation of the acute angle between the aortic valve and the PVL is needed when using a retrograde aortic approach, especially for leaks located along the aortic-mitral fibrous continuity (10–1 o'clock positions). A transapical approach provides direct access to the mitral valve and all of its associated PVLs.

For the transapical approach, access is obtained as above. A hydrophilic guidewire is used supported by a steerable catheter to direct the wire towards the PVL. Once across the defect and position is confirmed, the wire is exchanged for an Inoue wire. An appropriate French-size delivery sheath is advanced across the PVL. The distal end of the device is exposed in the left atrium and the device with the sheath is pulled back into the defect.

For the antegrade transseptal approach, transseptal puncture is performed under fluoroscopic and TOE guidance using standard techniques. Septally located mPVLs require a more posterior puncture to access the defect adjacent to the interatrial septum. The use of a deflectable left atrial sheath like the Agilis sheath (St Jude Medical, St Paul, MN, USA) is preferred and can allow easier manipulation and directional control within the left atrium.

Lastly, the retrograde aortic approach is rarely utilized. A guidewire and a support catheter are delivered across the aortic valve, with the wire directed to the mitral PVL. A retrograde aortic approach can be complicated by the presence of the mitral apparatus. The formation of an AV rail via transseptal access is necessary to support sheath and device delivery. Furthermore, the creation of an AV rail via snaring and exteriorization of the wire for either the transapical or transseptal approaches can provide further support, if necessary.

Deployment of multiple devices for closure

The deployment of multiple devices may be necessary for successful PVL closure (Figure 3C–E). Simultaneous device delivery requires the placement of two separate delivery systems. Another method is achieved by sequentially delivering devices. This approach utilizes an AV rail where the first closure device is placed through the delivery sheath, alongside the guidewire rail. The second delivery system and closure device is then positioned and deployed alongside the first device. Multiple devices can be deployed in this fashion with access maintained across the leak. A similar principal is achieved without an AV rail by maintaining access across the defect with an Inoue wire (for mitral PVLs) or Amplatz Extra-Stiff wire (for aortic or mitral PVLs, non-exteriorized).

Complications

There are several complications that can occur either during transcatheter closure or in follow-up. Complications include the need for emergent cardiac surgery in 0.7–2% and death in 1.4–2%.^{4,8–16} Access-site-related complications include vascular

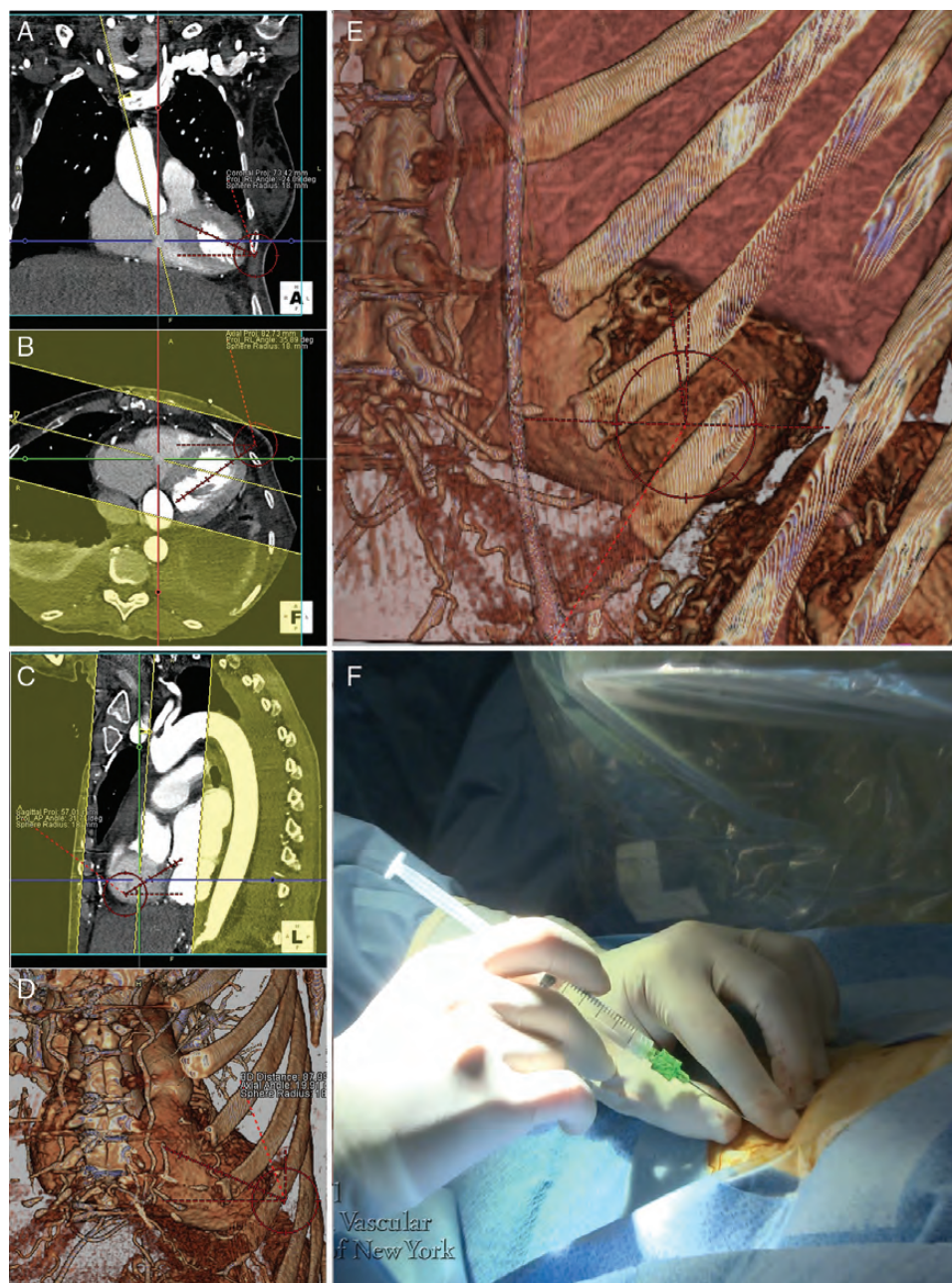


Figure 6 Computed tomographic angiography in (A) coronal, (B) cross-sectional, and (C) sagittal views, and (D) three-dimensional/four-dimensional-volume rendering reconstruction with the left anterior descending artery (white arrow) and left lung margin (black arrows) identified. (F) 21-gauge micropuncture needle with contrast used for left ventricular entry.

complications in 0.7–2% usually associated with common femoral arterial or venous access. Transapical access adds a further risk of haemothorax in 2.5–2.8%, together with more rare cases of coronary artery damage, acute myocardial infarction, cardiac tamponade, and pneumothorax.³⁰ Device-related complications include device embolization in 0.7–4%, device interference with the prosthetic valve in 3.5–5%, and the potential for device erosion. Device embolization outside of the LV typically bypasses the great vessels,

due to the size of device used, and lodges in the iliofemoral system where retrieval can be performed with a snare or biopptome.

Other complications include stroke, either haemorrhagic or embolic from thrombo- or air-embolism, endocarditis, and haemolysis. Post-procedural haemolysis, whether persistent or of new onset, can be attributed to residual leak around or through the device. Haemolysis from shunting through the device typically resolves within 6 months after complete endothelialization

Table 2 Published series of transcatheter closure of paravalvular leaks

Author (year)	Patients (aortic, mitral)	Devices	Technical success (%)	Clinical success (%)	Complications
Hourihan <i>et al.</i> (1992)	4 (4, 0)	Rashkind	3 (100)	2 (50)	Worsening haemolysis/device migration (1,25%)
Pate <i>et al.</i> (2006)	10 (1, 9)	ADO ASO Coils	7 (70)	4 (40)	Worsening haemolysis (2,20%) Device migration → surgery (1,10%) Retroperitoneal bleeding (1,10%)
Hein (2007)	21 (8, 13)	ADO mVSD ASO	20 (95)	14 (67)	Worsening haemolysis → surgery (2,9.4%) Endocarditis (1,4.7%) Valve interference → surgery (1,4.7%)
Shapira <i>et al.</i> (2007)	11 (2, 9)	ADO mVSD	10 (91)	6 (54)	Worsening haemolysis → surgery/death (2,18%)
Cortes <i>et al.</i> (2008)	27 (0, 27)	ADO	17 (63)	10 (37)	Cerebrovascular events (2,7.4%) Ventricular arrhythmia → cardioversion (1,3.7%) Transient asystole (1,3.7%) Pericardial effusion (1,3.7%) Bleeding events (5,1.9%)
Alonso-Briales <i>et al.</i> (2009)	8 (4, 4)	ADO	7 (88)	4 (50)	Residual shunts (3,37.5%) Residual shunt → surgery (1,12.5%)
Garcia-Barbolla <i>et al.</i> (2009)	8 (0, 8)	ADO	5 (63)	4 (50)	Massive stroke → death (1,12.5%)
Nietlispach <i>et al.</i> (2010)	5 (1, 4)	AVP III	5 (100)	5 (100)	Pericardial effusion (2,40%)
Sorajja <i>et al.</i> (2011)	115 (25, 90)	ADO mVSD ASO AVP II	88 (77)	77 (67)	Haemothorax (4,3.5%) IC haemorrhage/embolic stroke (3,2.6%) Death (2,1.7%) Valve interference → surgery (1,0.9%) Vascular complication (1,0.9%)
Ruiz <i>et al.</i> (2011)	43 (10, 33)	ADO mVSD ASO AVP II	37 (86)	33 (77)	Cardiac perforation (2,3.5%) Device migration (2,3.5%) Iliac artery dissection (1,1.8%) Procedure-related death (1,1.8%) Wire entrapped → surgery (1,1.8%)

ADO, Amplatzer duct occluder; ASO, Amplatzer septal occluder; AVP, Amplatzer vascular plug; mVSD, Amplatzer muscular ventricular septal defect occluder.

occurs. Acceleration of haemolysis with increased transfusion requirements has been noted on rare occasion, necessitating device exchange or removal. Overall, major adverse events associated with percutaneous PVL closure at 30 days (death, myocardial infarction, stroke, major bleeding, and emergent surgery) are 8.7%. Complications can be minimized with careful patient selection and appropriate procedural planning.

Results

Technical success can be defined as the correct deployment of an occlusive device through the PVL and the lack of significant residual regurgitation or new prosthetic valve malfunction. Clinical success, depending on the indication for intervention, is defined as an improvement in ≥ 1 NYHA-FC and/or improvement in mechanical haemolysis. Results of percutaneous PVL closure have been reported by a number of case series (Table 2).^{4,8–16} The largest experience of percutaneous PVL closure is derived from two centres, with 57 and 141 PVLs, respectively.^{14,16} Reported technical success ranged from 77 to 86% and clinical success ranged from 67 to 77%, with a median follow-up of 11 months. In our centre, increased utilization of the transapical approach has further improved the rates of technical success. Procedural failures were attributed to

an inability to cross the defect with either the guidewire or delivery sheath or interference of the device with prosthetic valve function.

The long-term follow-up of percutaneous closure has revealed survival rates at 6, 12, and 18 months of 91.9, 89.2, and 86.5%, respectively, for one series and at 1–2 years of ~70–75% with an estimated 3-year survival of 64.5% for another series.^{14,44} The limited life expectancy in the latter may be attributed to the high incidence of medical comorbidities associated with PVL patients. Furthermore significant residual paravalvular regurgitation was associated with a notably higher freedom from mortality or need for surgery (30.3% for moderate/severe vs. 58.3% for mild, 63.3% for none).⁴⁴ Early data for percutaneous PVL closure suggest similar survival curves compared with that observed in the surgical literature, with worse outcomes noted in patients treated with conservative medical management.

Conclusion

Symptomatic paravalvular prosthetic regurgitation is an uncommon, yet serious complication associated with surgical valve replacement. Percutaneous PVL closure is a technically challenging procedure requiring complex catheter techniques and a large interventional armamentarium. Multi-modality imaging, a MDT

approach to patient care, and a growing practice in transapical access have made possible the high procedural success rate associated with this therapy. When technically successful, the clinical outcomes are reasonable and are without the significant operative mortality rates associated with re-operation. Continued technological and procedural advances and increasing experience will further improve the success of transcatheter therapy, reduce its risk of complications, and in turn, may improve patient survival. For the high-risk symptomatic PVL patient, percutaneous closure is a viable therapeutic strategy to surgical PVL repair.

Conflict of interest: none declared.

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