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iREVIEWS

STATE-OF-THE-ART PAPER

Echocardiography in Percutaneous Valve Therapy

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Echocardiography has played a critical role in valve reconstructive surgery and more recently in developments in percutaneous techniques for mitral valve repair and aortic valve implantation. A combination of transthoracic echocardiography and transesophageal echocardiography (TEE) provide diagnostic and screening data pre-procedure, intraprocedural guidance, and assessment of valve function and left ventricular reverse remodeling post-percutaneous valve procedures. The role of intracardiac echocardiography and live 3-dimensional TEE in percutaneous valve interventions is evolving. This review summarizes the role of echocardiography during percutaneous device-based valve procedures. (J Am Coll Cardiol Img 2009;2:1226–37) © 2009 by the American College of Cardiology Foundation

Proliferation of percutaneous technology for treatment of structural heart disease has led to a demand for online imaging with high spatial and temporal resolution and has placed echocardiography in the forefront as a diagnostic and therapeutic imaging modality. Recent developments in successful percutaneous aortic valve implantation (1,2), pulmonic valve implantation (3), coronary sinus stent placement for tightening of mitral annulus (4), as well as percutaneous edge-to-edge repair of the mitral valve (MV) (5) in patients with mitral regurgitation (MR) promise a proliferation of percutaneous catheter-based techniques for treatment of valvular heart disease (6). This therapy has a role especially in patients who are poor surgical candidates due to advanced age, poor cardiac function, or multiple comorbidities.

This paper focuses on the role of echocardiography during recently developed percutaneous MV repair and aortic and pulmonic valve implantation procedures. Three-dimensional (3D) echocardiography and intracardiac echocardiography (ICE) during established procedures such as balloon mitral valvuloplasty as well as their evolving role in recently introduced percutaneous valve interventions are briefly discussed.

Although fluoroscopy and contrast cineangiography have been used successfully for interventions within the coronary arteries, poor soft-tissue contrast resolution limits their ability to visualize intracardiac anatomy that is necessary for percutaneous valve procedures, demanding alternative imaging modalities for procedural guidance. Fluoroscopy and angiography can provide reliable guidance during percutaneous aortic valve implantation and coronary sinus stent placement; however, most centers also use transesophageal echocardiography (TEE) for aortic valve implantation. Percutaneous repair of complex structures such as the MV requires a clear delineation of intracardiac anatomy in multiple dimensions to facilitate catheter manipulation relative to cardiac chambers and valves, to guide the device to the desired target site on the valve, and to

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evaluate valve anatomy, valve gradients, and regurgitation after device deployment and is heavily dependent on TEE guidance during repair. Although other imaging modalities such as magnetic resonance imaging (7) are undergoing rapid evolution, and data are emerging on its potential role as online imaging, at present, echocardiography is the most readily available, portable, online imaging guide during percutaneous interventions. Please refer to the Online Appendix for an overview of the echocardiographic imaging modalities.

Echocardiography in balloon mitral valvuloplasty. Echocardiography, both transthoracic echocardiography (TTE) and TEE, has an established role in MV percutaneous balloon valvuloplasty (8,9). TTE can be used as a stand-alone imaging modality with minimum use of fluoroscopy during mitral valvuloplasty (10). TEE is superior to TTE in evaluation of the left atrial (LA) appendage; guidance for transseptal puncture; evaluation of MV leaflets, commissures, and chordae; and assessment of residual atrial septal defect. TEE should be used for exclusion of LA thrombus and/or with an inexperienced interventionalist. Live 3D TEE can provide excellent patient selection and guidance by providing surgical views of the LA appendage, LA, interatrial septum, MV, and chords and provides a MV model depicting leaflet and annular geometry, leaflet angles, and surface area (Online Fig. E1, Fig. 1, Online Videos 1A, 1B, and 2). Three-dimensional TTE and TEE provide more accurate assessment of MV area (Online Video 2) than the planimetered MV area derived from 2D images, whereby the ultrasound beam may not transect the valve in the correct plane, or by the pressure half-time Doppler method, which is unreliable in the immediate post-valvuloplasty phase (11). During MV balloon valvuloplasty, 3D TEE can evaluate leaflet tear and its extent better than TTE, 2D TEE, or ICE (12). ICE has been used successfully in conjunction with TTE during percutaneous mitral valvuloplasty (13); however, it does not provide multiplanar assessment of the MV.

Echocardiography in paravalvular leak repair. Paravalvular (PV) regurgitation is seen with mechanical and bioprosthetic valves. Interrogation in multiple angles including off-axis views is required to determine the location and severity of the regurgitation. PV regurgitation (or leak) is characterized by Doppler flow outside the sewing ring of the valve, often in an eccentric direction. TTE may be adequate for most of the qualitative and quantitative information needed to evaluate aortic PV leaks. TEE complements TTE in technically difficult studies and in evaluating posterior aortic PV leaks. Because of artifacts and reverberations, prosthetic MV PV regurgitation, however, may be missed on TTE, and TEE is required for diagnosis, location, and assessment of severity. The proportion of the circumference of the sewing ring occupied by the jet gives an approximate guide to severity. MR jet width at origin of 1 to 2 mm, 3 to 6 mm, and >6 mm, respectively, defines mild, moderate, and large PV leak (14). A combination of semiquantitative and quantitative parameters similar to those used for native valve regurgitation may be used although eccentric jets may make quantitation difficult. Three-dimensional color Doppler may improve quantitation of PV regurgitation. TEE helps evaluate contraindications to percutaneous closure of PV leaks, such as mechanical instability of the prosthetic valve, intracardiac thrombus, and endocarditis (15). Real-time 3D TEE is far superior to 2D TEE in evaluation of location and extent of PV leak (Fig. 2, Online Videos 3A, 3B, and 4). TEE plays a critical role in the percutaneous closure of PV leaks by providing guidance on location of transseptal puncture, particularly in patients with calcified interatrial septum not uncommon with multiple prior valve surgeries (Figs. 3A and 3B), facilitating placement of the guidewires across the PV defect (Figs. 3C and 3D), providing guidance on catheter and guide manipulation to approach the defect perpendicularly, confirming adequate seating of the device across the defect before deployment, verifying normal prosthetic valve leaflet motion (Online Video 5A), assessing severity of residual PV regurgitation (Figs. 3F to 3I), evaluating residual atrial septal defect after device deployment, and detecting procedural complications promptly, such as development of thrombus on catheters and development of pericardial effusion. Using more than 1 Amplatzer septal occluder device (atrial septal defect closure device used off-label for PV closure) potentially increases the risk of device dislodgement with embolization, and lead to interference with prosthetic leaflet motion (Online Video 5A) and disruption of the prosthetic valve. Isolated reports on use of 3D TEE during closure of PV leak exist (16). Although the incremental value of 3D over 2D TEE during device closure of PV leak is not established, 3D TEE may allow procedure planning, including procedure feasibility by better assessment of location and extent of PV leak, and may shorten procedure time by

ABBREVIATIONS AND ACRONYMS

3D = 3-dimensional

ICE = intracardiac echocardiography

LA = left atrial, left atrium

LV = left ventricular

MR = mitral regurgitation

MV = mitral valve

PV = paravalvular

TEE = transesophageal echocardiography

TTE = transthoracic echocardiography

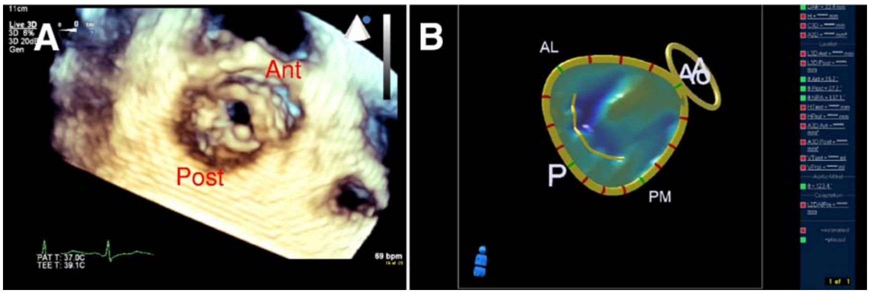

Figure 1. 3D TEE of the MV in Mitral Stenosis

Three-dimensional (3D) volumetric transesophageal echocardiography (TEE) view showing mitral valve (MV) orifice visualized from the left ventricular (LV) side in a patient with mitral stenosis in **A** and the corresponding model reconstructed from 3-dimensional (3D) image dataset in **B**. Mitral annular shape, circumference, mitral leaflet surface area, and aorto-mitral angle are displayed in **B**. **Curved yellow line in B** is the mitral coaptation line. Also see Online Videos 1A, 1B, and 2. A = anterior; Ao = aortic root; Ant = anterior; AL = anterolateral commissure; P = posterior; PM = posteromedial commissure; Post = posterior.

facilitating catheter manipulation, device sizing and positioning.

Echocardiography in MV repair. TTE provides accurate quantification of MR severity and is able to determine etiology of MR as degenerative, ischemic, or functional. Quantitative assessment of MR by vena contracta (width of MR jet at its origin) and measurement of effective regurgitant orifice area and regurgitant volume is now the gold standard for MR quantitation (17) (Online Fig. E2) and has been used for the first time in a multicenter setting in Phase I and Phase II EVEREST (Endovascular Valve Edge-to-Edge REpair STudy) trials (6). TTE often provides limited information on valve reparability. Three-dimensional TTE may improve MV assessment although resolution of 3D TTE remains an important limitation (Online Fig. E3). At present, percutaneous MV repair technique by the edge-to-edge technique aims to repair MR originating from the A2 and P2 scallops of MV rather than commissures or posteriorly or anteriorly located MV scallops. TEE evaluates location of diseased mitral scallop/s by using 2D and color Doppler in multiple imaging planes (Online Fig. E4), by location of flow convergence (Online Figs. E4 to E7), and by assessment of site of origin of MR jet. MR jet origin in the short-axis view is critical to

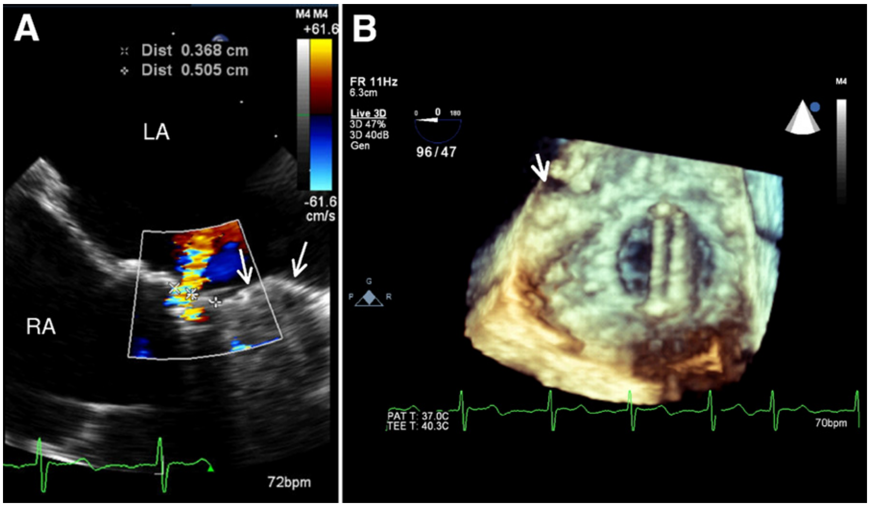

Figure 2. 2D and 3D TEE in PV Leak

Mid-esophageal 2D TEE view at 0° showing paravalvular (PV) leak located anteromedially between St. Jude's aortic and mitral prostheses. St. Jude's mitral valve disks in the closed position are shown by **white arrows in A**. **B** is the 3D TEE view showing St. Jude's mitral valve disks in the open position from the atrial aspect. A PV hole is seen at the 10 o'clock position (**white arrow**). The location of the PV leak made percutaneous repair nonfeasible. Also see Online Videos 3A, 3B, and 4. LA = left atrium; RA = right atrium; other abbreviations as in Figure 1.

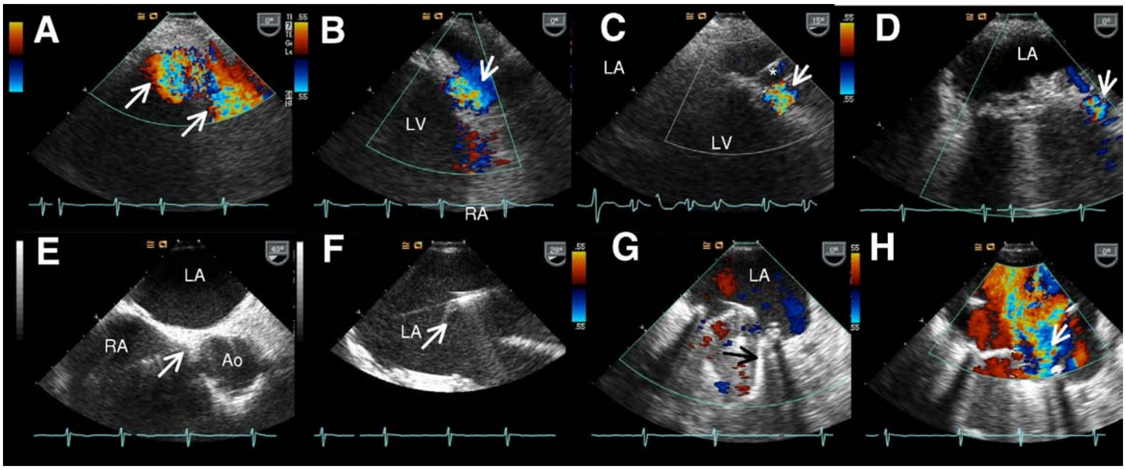

Figure 3. TEE During Percutaneous Closure of PV Leak

A to D show PV leaks by **white arrows** in a 72-year-old female with 4 prior MV surgeries. Paravalvular leak is shown by **white arrows**. Large leak is shown at baseline **(A)**, moderate leak after first device deployment **(B)**, mild leak after balloon **(*)** dilation lateral to the first device **(C)**, and after 2 Amplatzer devices **(D)**. **E to H** show detection of potential complications with TEE during procedure, shown by **arrows**. **E** shows direction of Brockenbrough needle towards the aortic root, **F** shows atrial tissue attached to the sheath (withdrawn subsequently with the sheath), **G** shows passage of wire across the St. Jude's mitral valve **(black arrow)**, and **H** shows resulting severe MR **(white arrow)**. Also see Online Videos 5A and 5B. Ao = aorta; other abbreviations as in Figures 1 and 2.

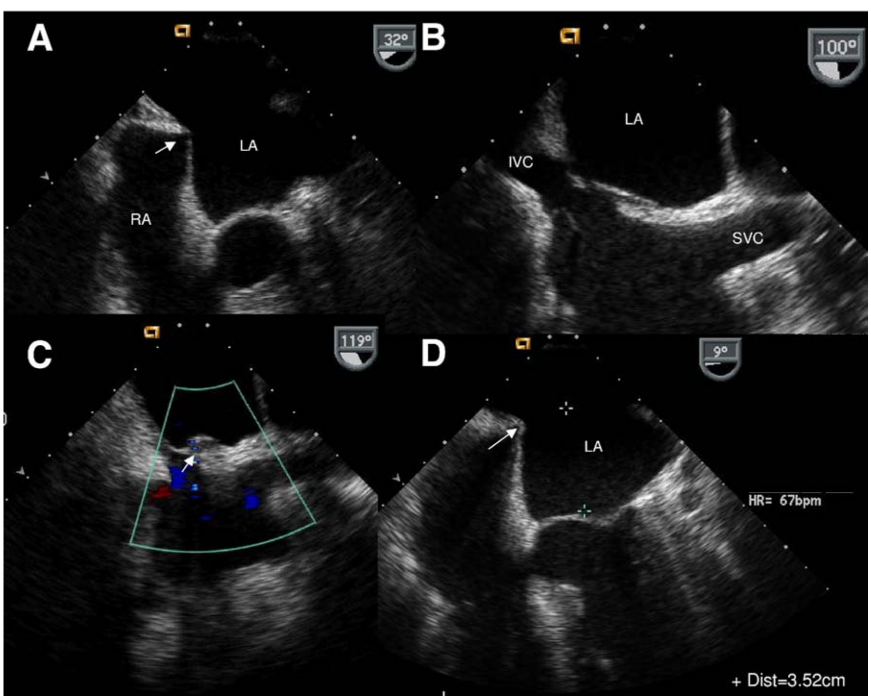

Figure 4. TEE During Initial Stages of Percutaneous MV Repair by Evalve Clip

Mid-esophageal transesophageal views used for guided transseptal puncture during percutaneous edge to edge MV repair. **(A)** Short-axis view at the base (showing the anterior–posterior portion of the interatrial septum with tenting **(white arrow)** at the junction of septum primum with septum secundum or the edge of the fossa. **(B)** Bicaval view showing the superior–inferior portion of the interatrial septum. **(C)** Bicaval view with tenting at the junction of ostium primum with ostium secundum **(white arrow)**. **(D)** Mid-esophageal 4-chamber view (for assessing height of the tenting site above the MV plane) to allow perpendicular approach of the guide and device catheter towards the MV. Also see Online Videos 6A, 6B, and 6C. IVC = inferior vena cava; SVC = superior vena cava; other abbreviations as in Figure 2.

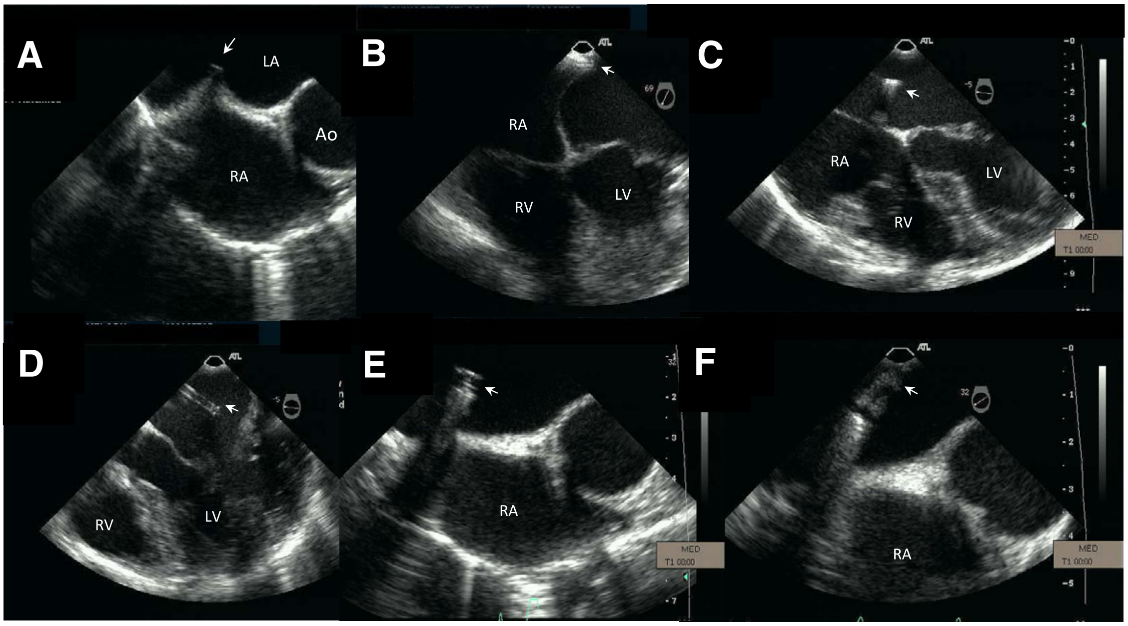

Figure 5. TEE During Early Stages of Percutaneous MV Repair by Evalve Clip

TEE views at the mid-esophageal level used to guide early stages of Evalve edge-to-edge repair. Transseptal puncture at the superoposterior interatrial septum is shown in the mid-esophageal short-axis view at the base of the heart in **A** and 4-chamber view in **B (white arrowhead)**. Note the needle tip in the LA in **C (white arrowhead)**, 22-F guide delivery sheath in the LA in **D (white arrowhead)** and tip of the device delivery guide and of the therapy catheter in **E and F (white arrowheads)**. Also see Online Videos 6A, 6B, and 6C. Ao = aorta; other abbreviations as in Figures 1 and 2.

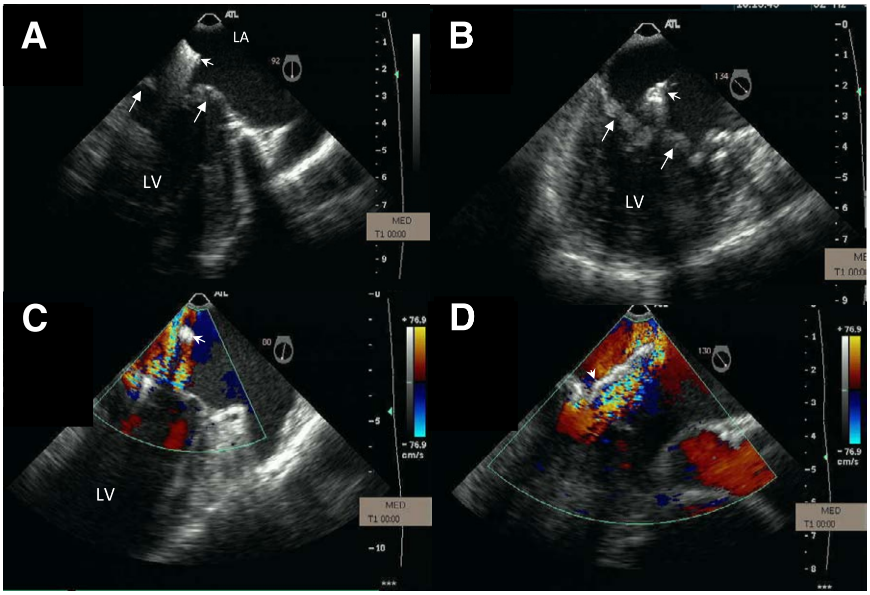

Figure 6. TEE During Mid-Stages of Percutaneous MV Repair by Evalve Clip

TEE views at the mid-esophageal level used to guide middle stages of Evalve edge-to-edge repair. 2-chamber **(A)** and 3-chamber views **(B)** are used to navigate the tip of the device **(arrowheads)** toward the middle of the MV in the mediolateral **(A)** and anteroposterior plane **(B)**. **White arrows** in **A and B** point to the MV leaflets. Device tip is shown in the middle of MR jet in **C and D** by **white arrowheads**. Also see Online Videos 6A, 6B, and 6C. Abbreviations as in Figures 1 and 2.

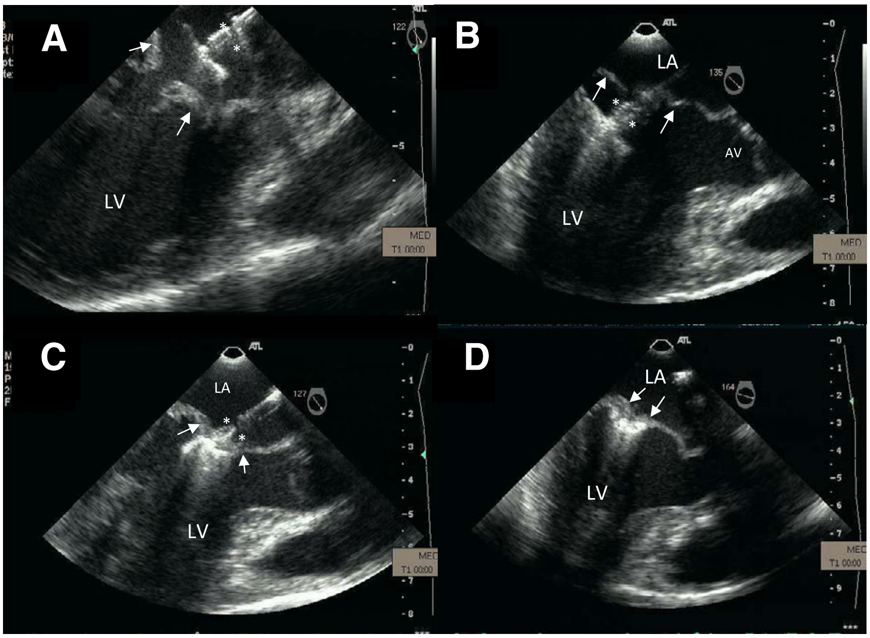

Figure 7. TEE During Mid- to Late Stages of Percutaneous MV Repair by Evalve Clip

TEE views at the mid-esophageal and deep transgastric level used to guide middle to later stages of Evalve edge-to-edge repair. Anterior leaflet is on the **right** and posterior leaflet on the **left**. Open clip is shown in the LA above the MV leaflets **(white arrows)** in **A**. The corrugated surface of the grippers and the open Dacron arms are shown **(white asterisks)**. Open clip advanced into the LV through the MV is shown in **B**. Grippers are shown folded upward and the Dacron arms opened horizontally **(white asterisks)**. **C** shows that posterior and anterior leaflets well within the grippers and the closed Dacron arms of the clip. **D** shows the clip along with the captured anterior and posterior leaflets after release of the clip from the device assembly. Also see Online Videos 6A, 6B, and 6C. AV = aortic valve; other abbreviations as in Figures 1 and 2.

evaluate location and severity of pathology and complements information obtained by long-axis views (Online Fig. E8).

The first approach to percutaneous MV repair is the edge-to-edge technique, which creates a double MV orifice replicating the surgical intervention pioneered by Alfieri et al. (18). Preliminary clinical results obtained in over 100 patients from percutaneous edge to edge repair using a clip (Evalve, Inc., Menlo Park, California) in Phase I (6) and II (19) studies suggest that in expert hands, the success rate of the technique is high (80% to 90%), and the degree of MR can be reduced to mild in two-thirds of cases. The risk is low in experienced centers. In patients in whom the procedure was successful, two-thirds of the cases remained event-free after 3 years. Besides assessment of involved scallops, screening by echocardiography involves measurement of coaptation depth and coaptation length in ischemic MR (Online Fig. E8) and of flail gap (Online Fig. E9) and flail width (Online Fig. E10) in degenerative MR.

In the catheterization laboratory, TEE is the primary imaging modality used for procedural guidance of MV repair using the Evalve clip. TEE is able to visualize all components of the clip delivery system (Figs. 4 to 9, Online Videos 6A, 6B, and 6C). TEE guides puncture of the posterior and superior portion of the interatrial septum, thereby allowing perpendicular alignment of device in the plane of the posteriorly located MV (Fig. 4). By visualization of guide and device catheter tips, TEE helps steer these devices in the appropriate direction and ensures minimal device–endocardial contact. TEE guides advancement of the therapy catheter towards the center of pathology by placing it within the center of maximum MR jet. Steering of the device assembly is performed in the mediolateral and anteroposterior planes using 2- and 3-chamber views, respectively (Fig. 6). The actual procedure of opening the clip in the LA, its advancement into the LV, its correct alignment so the device arms are at right angles to the MV coaptation, and actual leaflet capture are all guided by TEE (Online Videos 6A, 6B, and 6C). TEE directs the decision to release the clip in case of suboptimal MV leaflet capture or whether the procedure should be abandoned in cases of minimal MR reduction once

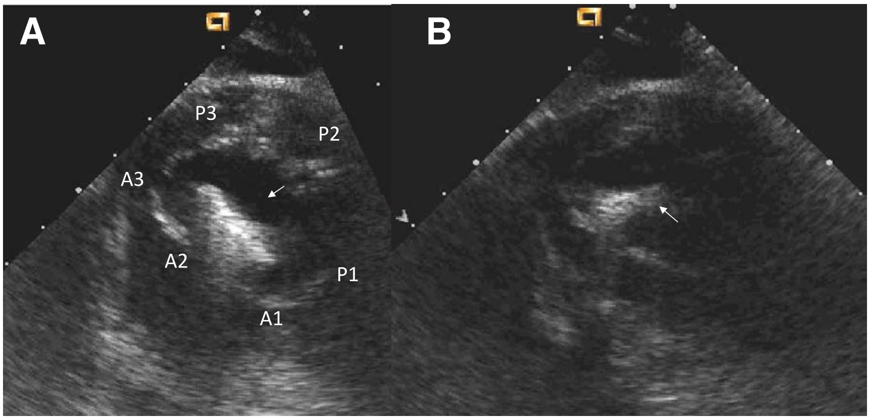

Figure 8. TEE During Late Stages of Percutaneous MV Repair by Evalve Clip

A transgastric short-axis view at the mitral valve (MV) level showing clip arms parallel to the plane of coaptation of anterior and posterior MV leaflets **(white horizontal arrow)** in **A**. **B** shows a 90° rotation of the clip arms so these are perpendicular to MV coaptation (**white vertical arrow)** before the clip is pulled back for mitral leaflet capture. MV scallops are labeled in diastole in **A**. Also see Online Videos 6A, 6B, and 6C.

leaflets are grasped. TEE confirms an adequate result by reduction in the MR grade to less than moderate and by visualizing anterior and posterior MV leaflet anatomy. TEE is able to determine the immediate effect of MR reduction on cardiac physiology, including MV gradients, pulmonary venous flow pattern, right ventricular systolic pressure, and residual MV area before the clip is finally deployed

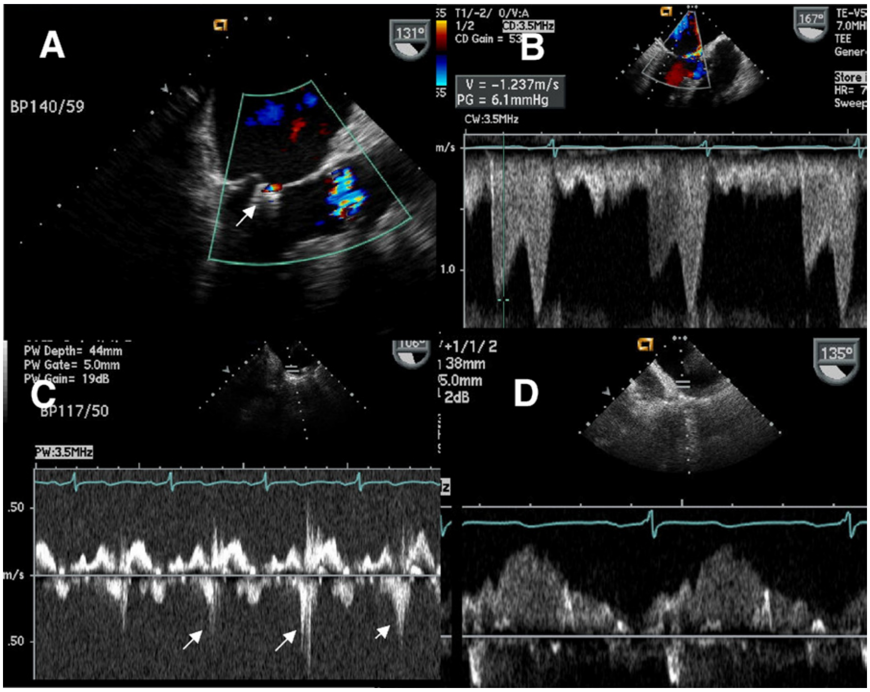

Figure 9. TEE Doppler Evaluation During Evalve Clip Deployment

Mid-esophageal views showing 2D and Doppler evaluation performed after the clip is released before decision on the adequacy of capture or the need for a second clip is made. Multiple views and angulation are used to ensure that eccentric jets are not missed. **A** shows apical 3-chamber view with color Doppler. No color Doppler evidence of residual MR after clip deployment **(white arrow)** is shown in **A**. **B** shows continuous wave Doppler of mitral inflow to evaluate peak and mean MV gradients to ensure lack of mitral stenosis. **C and D** are pulsed wave Doppler signals obtained from the left inferior pulmonary vein showing systolic flow reversal **(white arrows)** pre-clip deployment in **C** and systolic (S) dominant flow pattern in the same pulmonary vein post-clip deployment in **D**. Also see Online Videos 6A, 6B, and 6C.

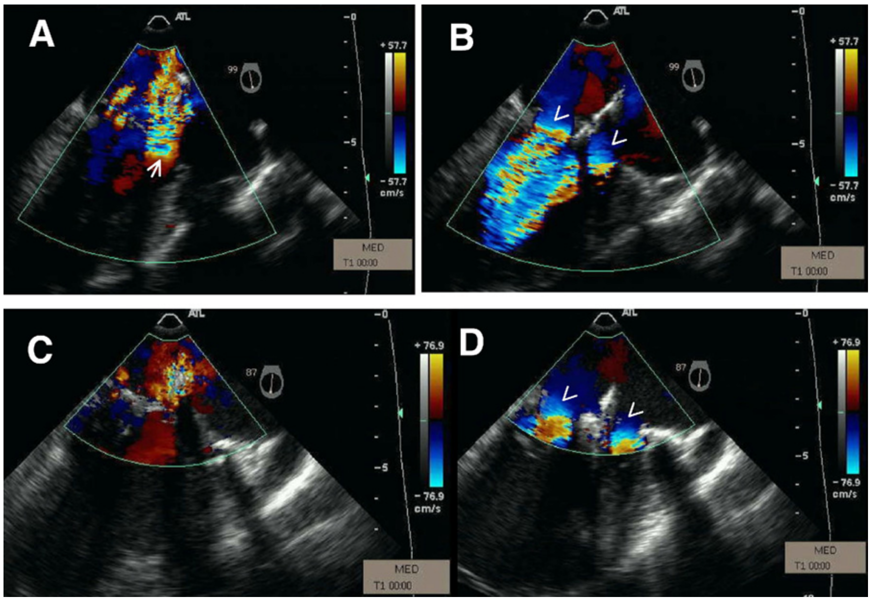

Figure 10. TEE Evaluation of Residual MR After Evalve Clip Deployment

Mid-esophageal TEE views in the mediolateral plane showing significant residual MR jet **(white arrow)** lateral to the Evalve clip in **A**. Two trivial MR jets medial to the clip are also shown. **B** shows a diastolic frame with a double orifice mitral inflow **(white arrowheads)**. **C** is obtained after second clip deployment and shows no residual MR jet lateral to the second clip, and **D** shows double mitral inflow with 2 orifices (shown by **white arrow heads**) separated by a wider distance due to 2 clips in **D** versus 1 clip in **B**. Also see Online Videos 7A and 7B.

(Fig. 9). TEE determines the need for a second clip by assessing the severity of residual MR and guides placement of the guidewire and therapy catheter in the correct orifice of a double orifice MV (Fig. 10, Online Videos 7A and 7B). TEE confirms the final MR grade and size of residual atrial septal defect before the completion of the procedure. TEE allows immediate detection of procedural complications such as development of thrombus on catheters, pericardial effusion, and tangling of device with chordae. Finally, echocardiography evaluates MR severity during follow-up, device stability and effect on LV size and function, and pulmonary artery pressure. Isolated case examples on the use of live 3D TEE during MV repair are beginning to emerge (16). The incremental value of 3D TEE in this procedure has not been examined, but it may guide perpendicular alignment of therapy catheter to the MR jet in patients with markedly dilated LA and may significantly shorten procedure time by providing surgical-type views of mitral apparatus.

The second possible approach of mitral annuloplasty, which is achieved by introducing a constraining device in the coronary sinus located in the vicinity of the mitral annulus can be accomplished by fluoroscopy and coronary sinus angiography. Preliminary efficacy data suggest some reduction in the degree of MR in animals (20) and humans (5). Although TEE can show the coronary sinus ostium and its diameter in the proximal and mid- to distal course for stent sizing, assessment of coronary sinus length and its relation to the mitral annulus and to the circumflex coronary artery remains difficult by TEE. TTE and TEE can nevertheless determine acute or chronic mitral annular diameter reduction with coronary sinus stent placement and its effect on MR severity.

ICE during percutaneous MV repair. There is no published human experience with ICE during percutaneous MV repair or aortic valve implantation. This author's experience with ICE in animal experiments suggests that ICE can be an adjunctive if not a sole imaging modality during percutaneous valve interventions (21) (Fig. 11, Online Video 8). ICE along with TEE may facilitate edge-to-edge MV repair procedure by visualizing intracardiac structures that may be difficult to delineate due to shadowing from calcification or prosthetic material during TEE.

Echocardiography in percutaneous aortic valve implantation. Percutaneous aortic valve implantation is an emerging alternative for inoperable patients with severe aortic stenosis and can be deployed using an antegrade (1) or retrograde (2,22) approach. Presently, there are 2 catheter-based treatment systems (the Cribier-Edwards Aortic Bioprosthesis [2] and the CoreValve ReValving System) utilizing either a balloon-expandable or a self-expanding frame that

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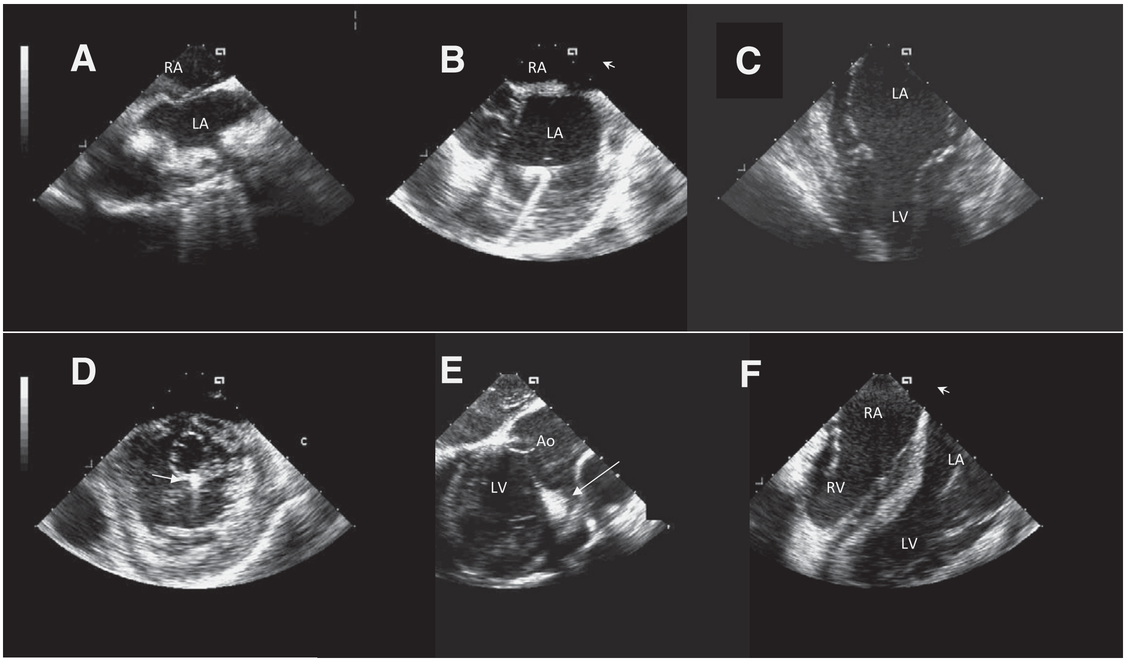

Figure 11. Intracardiac Echocardiography During Percutaneous MV Therapy

Intracardiac views obtained by Acunav catheter in the right atrium of a swine. **A** shows tenting of the interatrial septum **(white arrow)** by the Brockenbrough needle. **B** shows J-shaped tip of guidewire in the LA after transseptal puncture. **C** shows anterior and posterior leaflets of the MV with the ICE catheter advanced across the interatrial septum into the LA and the transducer facing down. **D** shows a short-axis view of the MV at the base with a central suture and clip **(white arrow)** and a double orifice MV created after the deployment of suture and clip (Edwards Lifesciences, Irvine, California). The SAX view was obtained by advancing the ICE catheter across the tricuspid and pulmonic valves. **E** shows aortic root, left main coronary artery **(white arrow)**, and LV, and **F** is a 4-chamber view obtained by advancing the ICE catheter tip into the right ventricle. Also see Online Video 8. Abbreviations as in Figures 1 and 2.

unfolds a pericardial tissue valve within the displaced diseased aortic valve. Current Edwards Sapien series and CoreValves have CE mark approval in Europe. Compared with surgical aortic valve replacements, percutaneous valve implantation leads to lower mean gradients but increased incidence of mild or moderate PV leak (23). TTE is essential for pre-procedure screening. Although the procedure can be performed under fluoroscopic guidance alone, TEE can accurately measure aortic valve annulus, LV outflow tract, and ascending aorta to assist in selection of prosthetic valve size. A difference of up to 4 mm between the TTE and the TEE annulus measurements can occur and may lead to a change in valve size (24). TEE provides assessment of LV and valve function and thoracic aortic anatomy. Severe, mobile plaque supports utilization of the transapical approach, which avoids manipulation of large catheters in the aorta. Three-dimensional TEE is particularly invaluable in evaluating aortic atheroma (Online Fig. E11).

During implantation, TEE evaluates the exact position of the deployment catheter and valve, which is critical for valve function. The 14- or 16-mm long Edwards prosthesis relies on traction with the native annulus for post-deployment stability. Although the prosthesis must be positioned distal enough to permanently stent open the native aortic valve cusps, slightly more than one-half of the prosthesis should remain on the LV side of the aortic valve annulus. Deployment of the apparatus at the level of the sinuses of Valsalva is too distal, may lead to aortic regurgitation, and risks valve embolization. Ascending aortic dilation is therefore not a contraindication for the Edwards valve since the valve sits inside the native aortic annulus (25). Early assessment of PV regurgitation is crucial. Significant transvalvular aortic regurgitation suggests overexpansion of the prosthesis, which may require deployment of a second prosthetic valve within the first. Following prosthetic valve deployment, TEE can immediately assess prosthetic valve position, in relation to the LV outflow tract and aortic valve plane, prosthetic valve leaflet mobility, valve area, and gradients and presence of central and PV regurgitation. Multiple views are essential to

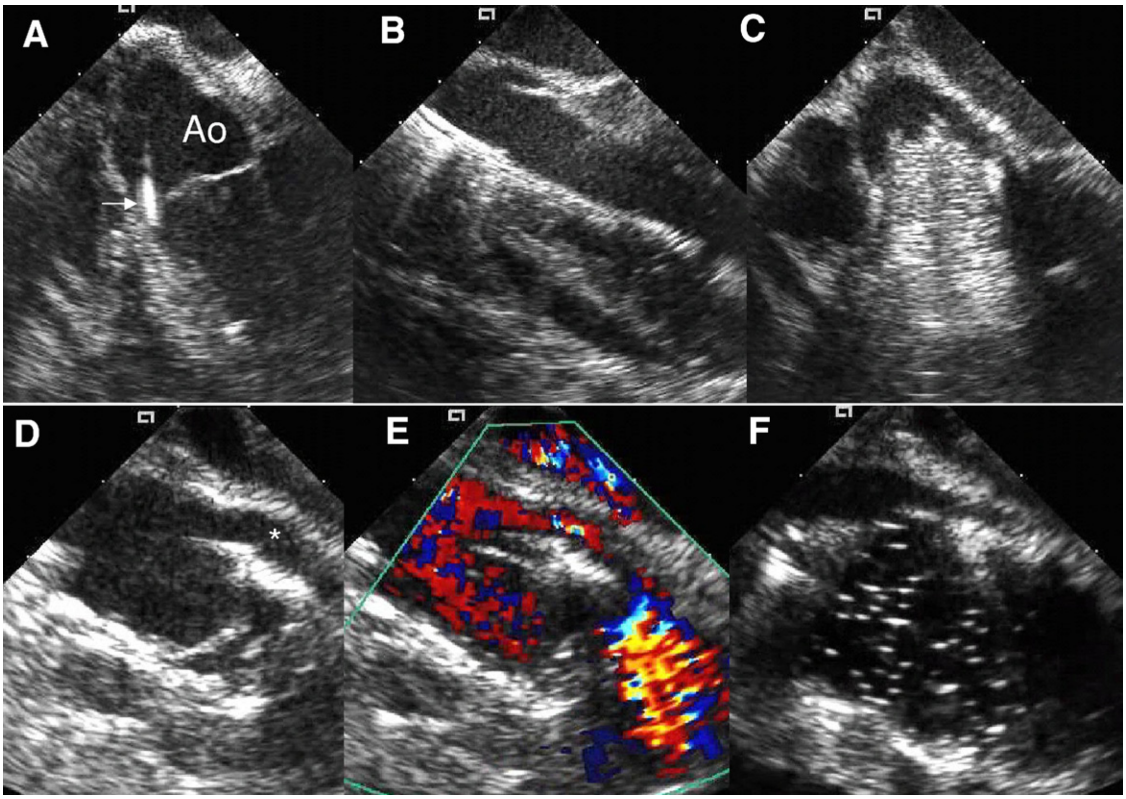

Figure 12. Intracardiac Echocardiography During Percutaneous AV Therapy

ICE imaging during percutaneous aortic valve (Edwards Lifesciences) replacement obtained in a pig with the ICE catheter tip placed in the right atrium. Wire across the aortic valve **(white arrow)** placed via a retrograde approach in **A**, delivery sheath advanced across the aortic valve and into the LV outflow tract in **B**, balloon expansion of the stent at the level of the aortic valve in **C**, incomplete stent deployment with a space between the stent post and the posterior aortic root **(white asterisk)** and flow through this space in **D**, further balloon inflation for stent expansion in **F**. Also see Online Videos 9A, 9B, and 9C. Ao = aortic root.

determine the site and degree of aortic regurgitation post-implant and the need for further balloon dilation. Acoustic shadowing off the stent may make evaluation of PV leak difficult. The short-axis view most reliably distinguishes PV from transvalvular aortic regurgitation. This distinction is difficult to make by fluoroscopy and aortic root contrast injection. TEE greatly facilitates detection of procedural complications such as presence of thrombi on catheters, development of pericardial effusion, any interference of the procedure with MV motion, development of MR, possible compression of coronary ostia by native aortic valve leaflets (by showing new wall motion abnormalities), and aortic hematoma or dissection during or after the procedure. Real-time 3D TEE may provide superior spatial visualization of the cardiac structures and facilitate the detection of procedure-related complications that might improve patient outcome (26). It may be helpful in evaluating coronary ostia in relation to the stented valve (Online Fig. E12).

Intracardiac echocardiography in percutaneous aortic valve implantation. This author has used ICE as an imaging guide in swine during the development of a percutaneous aortic valve (27). ICE allowed accurate measurement of aortic annulus, assisted with placement of the device within the aortic annulus, helped in assessment of PV leak post-valve deployment and the need for further balloon expansion, and in assessment of post-deployment gradients (Fig. 12, Online Videos 9A, 9B, and 9C).

Echocardiography in pulmonic valve implantation. Currently available percutaneous pulmonic valve is a balloon-expandable valve stent composed of a bovine jugular valve mounted in a platinum/iridium stent (Medtronic Corp./NuMED Inc., Medtronic Inc., Minneapolis, Minnesota) and is largely implanted in children with complex congenital heart disease and prior right ventricular to pulmonary

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artery valved conduits with conduit valve stenosis and/or regurgitation (28). The major drawback in pulmonary valve replacement is limitation in bovine jugular venous valve size, which rarely exceeds 18 to 22 mm in diameter. Echocardiography plays a diagnostic role pre-procedure and post-procedure to evaluate implanted pulmonic valve function. Fluoroscopy and cineangiography remain key imaging modalities during valve deployment. ICE has been used in isolated case reports and provides adequate anatomic and physiologic information to guide percutaneous pulmonic valve placement (29).

Conclusions

Recent studies have shown successful percutaneous MV repair by edge-to-edge procedure and stent-mounted aortic and pulmonic valve implantation. The real-time guidance of this procedure requires a unique and intense collaboration between echocardiologist and interventionalist not hitherto seen in other catheterization lab procedures or intraoperative TEE (30). This collaboration includes use of common vocabulary, training of the interventionalist on basic echocardiographic views critical for the procedure, and possession of unique interventional imaging skill by the echocardiologist. Besides conventional diagnostic echocardiography, hybrid views showing endovascular devices and their relationship to cardiac structures and command on 3D reconstruction of cardiac anatomy from 2D images is required. Limitations of 2D TEE imaging include shadowing from devices, loss of imaging plane from respiratory motion in an intubated patient, and suboptimal images, especially later in the procedure due to stomach air, poor contact of probe with the stomach wall due to secretions, and reduction in heart size from blood loss. Further developments in delivery technology, valve design improvements, and availability of follow-up data will lead to proliferation of percutaneous valve technology and in turn development of interventionists dedicated to treatment of structural heart disease and echocardiologists dedicated to interventional echocardiography.

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Key Words: percutaneous valve repair ■ percutaneous valve implantation ■ transesophageal echocardiography ■ transthoracic echocardiography ■ intracardiac echocardiography ■ 3-dimensional echocardiography.

APPENDIX

For an overview of the echocardiographic imaging modalities, accompanying Figures E1 to E12, and accompanying Videos 1A to 9C with their legends, please see the online version of this paper.