Echocardiography in Transcatheter Aortic Valve Implantation and Mitral Valve Clip

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Transcatheter aortic valve implantation and transcatheter mitral valve repair (MitraClip) procedures have been performed worldwide. In this paper, we review the use of two-dimensional and three-dimensional transesophageal echo for guiding transcatheter aortic valve replacement and mitral valve repair.

Keywords: Aortic valve stenosis; Mitral valve insufficiency; Percutaneous; Catheterization; Valvuloplasty

INTRODUCTION

Transcatheter valve repair and replacement is a very promising approach for replacement of stenotic aortic valves and repairing regurgitant mitral valves (MVs). Previously, percutaneous valve intervention comprised balloon valvuloplasty for congenital aortic and pulmonic stenosis as well as rheumatic mitral stenosis. Fluoroscopy, angiography, and transthoracic and transesophageal imaging have often been used as adjunctive imaging modalities during balloon valvuloplasty. However, more detailed information regarding valve pathology, morphology, and annular dimensions as well as information about structures adjacent to the valve itself are required to guide valve repair and replacement. Fluoroscopy provides little information about the severity of valve disease or the cardiac chambers. Moreover, it is not adequate to define valve structures or the location of catheters or devices. Two-dimensional (2D) transesophageal echocardiography (TEE) is useful for transcatheter procedures. Three-dimensional (3D) im-

aging provides additional information as well as spatial relationships that cannot be appreciated using 2D TEE alone. This paper focuses on the role of 2D and 3D TEE for transcatheter aortic valve implantation (TAVI) in patients with severe aortic stenosis using the Sapien aortic bioprosthetic valve (Edwards Lifesciences, Irvine, CA, USA) and MitraClip (Abbott Vascular, Redwood City, CA, USA) placement in patients with significant MV regurgitation.

VALVULAR AORTIC STENOSIS

Severe aortic stenosis has been defined as the presence of a maximum Doppler velocity across the aortic valve of > 4 m/sec, a valve area of < 1 cm^2, and a mean aortic valve gradient of > 40 mmHg [1]. The prevalence of aortic valve stenosis increases with age, from 2% of people 50 years of age to at least 4% of individuals 85 years of age or older. The average rate of progression of aortic valve stenosis is 0.1 cm^2/yr [2-4]. Indications

for surgical intervention in patients with severe aortic stenosis are the development of symptoms such as chest pain, syncope, shortness of breath, or other symptoms related to heart failure, or evidence of left ventricular dysfunction (left ventricular ejection fraction [LVEF] of < 50%). Several studies have found that one-third of older patients with symptomatic aortic stenosis are denied aortic valve replacement (AVR) surgery because of significant comorbidities [1,5,6]. We have experienced a similar rate of surgical denials at our institution [6]. In a study recently performed at our institution, we found that the 1-year survival rate of unoperated aortic stenosis was 62.4%. One-year survivors had a slightly higher LVEF than that of nonsurvivors (55 ± 15 vs. 50 ± 16; p = 0.042). However, a Doppler MV inflow E velocity over the myocardial E´ velocity (E/E´) of > 15 was the single most accurate parameter in the determination of 1-year mortality. It was superior to LVEF, brain natriuretic peptide level, and age in identification of 1-year mortality. Of note, patients with an LVEF of < 50% and E/E´ of > 15 had only a 22.3% 1-year survival. As result, a number of patients with aortic stenosis with a very poor survival rate are denied surgical intervention because of comorbidities. Many of the surgical comorbidities are not a contraindication for TAVI because this is a much less invasive approach to AVR.

Since TAVI was first performed in 2002, more than 25,000 Sapien aortic valves (Edwards Lifesciences) have been implanted worldwide [7]. This procedure has evolved considerably from an equine valve to the traditional bovine pericardial valve. As shown in Fig. 1 [8], two TAVI devices are being used commercially outside of the United States or in clinical trials within the United States: the CoreValve (Medtronic, Luxembourg, Luxembourg) and the Sapien valve (Edwards Lifesciences). The CoreValve (Medtronic) is implanted under fluoroscopic guidance; thus, its implantation will not be discussed. Placement of the Sapien valve involves echo for prevalve implantation assessment, during valve implantation, and for postprocedure evaluation.
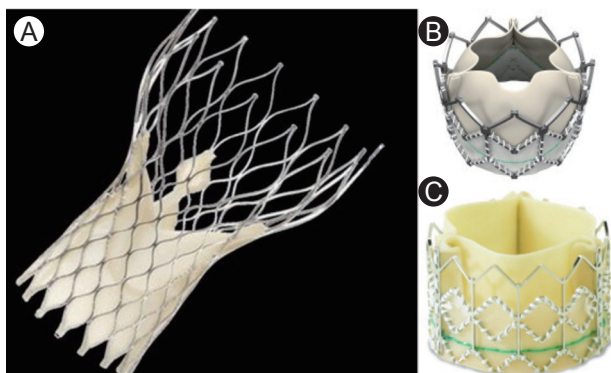
A multicenter study involving the Sapien valve in 358 patients with severe aortic stenosis who were at a too-high risk to undergo surgical heart valve replacement was recently reported [9]. The average age of the patients was 83 years, and 20% were 90 years of age or older. The medically treated patients had a 50.7% mortality compared with 30.7% in the TAVI group at 1 year. However, it should be noted that the risk of major stroke and vascular complications was higher in the TAVI group. The risk of undergoing rehospitalization in the ensuing year was substantially reduced (22.3% vs. 44.1%). Quality-of-life scores were markedly improved in the TAVI group compared with the control group [9]. At 2 years, the survival advantage persisted with a mortality rate of 68% in the medical therapy group and 43% in the TAVI group (p < 0.001). The rehospitalization rate was also reduced in the TAVI group from 72% in the medical arm to 35% in the TAVI arm (p < 0.001). Echo analysis of the TAVI group revealed a mean bioprosthetic valve pressure gradient of 9.7 mmHg, peak pressure gradient of 18.7 mmHg, and aortic valve area of 1.53 cm^2. These findings are consistent with a good hemodynamic profile of TAVI at 2 years. Many patients had trace or mild aortic regurgitation (AR); 9% had moderate AR (4.5% paravalvular and 4.5% transvalvular) [10]. In another study that compared TAVI with surgery in high-risk patients, the mortality rate at 6 months was 3.4% for TAVI and 6.5% for surgery (p = 0.07); however, at 1 year, there was no difference in mortality between the groups [11].

Transfemoral TAVI entails passing a catheter from the femoral artery retrograde up the aorta and across the aortic valve. Aortic balloon valvuloplasty is then performed to pre-dilate the calcific, stenotic aortic valve. TEE is used to size the aortic valve annulus; concomitant TEE and fluoroscopy are used to position and deploy the valve. If the femoral arteries are too tortuous or too small, a transapical approach can be used for TAVI,

Figure 1. (A) CoreValve (courtesy of Medtronic). (B) SAPIEN XT 9300 TFX and (C) SAPIEN 9000 TFX valves (courtesy of Edwards Lifesciences Inc.). Adapt from Jayasuriya et al. J Am Soc Echocardiogr 2011;24:15-27, with permission from Mosby Inc. [8].

in which the catheter system is inserted percutaneously through the chest wall and into the LV apex.

ROLE OF ECHOCARDIOGRAPHY IN TAVI

Assessment of the anatomy of the aortic annulus and ascending aorta

Precise delivery of the valve prosthesis is mandatory for successful TAVI. A stent-valve prosthesis that is placed too deep in the LV can restrict anterior mitral leaflet opening. A prosthesis that is delivered excessively antegrade toward the aortic sinuses of Valsalva can obstruct either the coronary ostia or embolize distally into the aorta. A preprocedural understanding of the anatomy of the aortic annulus and intraprocedural 2D and/or 3D TEE allow interventional cardiologists and echocardiologists to carefully evaluate the pathologic anatomy of the aortic valve and annulus in patients undergoing TAVI.

Poh et al. [12] demonstrated that the left ventricular outflow tract (LVOT) was circular in shape in only 43% of 68 patients with aortic stenosis. More recently, a 3D TEE study from our laboratory found that the LVOT is oval in shape in 90% of patients [13]. Three-dimensional TEE has also been shown to improve the assessment of LVOT dimension, as well as aortic valve area in aortic stenosis associated with upper septal hypertrophy. This is due to the prevalence of nonsymmetric LVOT geometry in some patients with aortic stenosis. Three-dimensional TEE is associated with less underestimation of annular size and narrower limits of agreement than 2D TEE when compared with 3D computed tomography (CT) measurements. Aortic stent-valves (Sapien valves) are circularly shaped when they are implanted. Underestimation of aortic valve annular diameter due to an oval shape can cause postprocedural paravalvular AR.

The aortic annulus, aortic valve cusps, calcium, and shape of the LVOT can be seen by 2D and 3D TEE. The presence of a protruding sigmoid septum can cause subvalvular gradients, as well as make it more difficult to successfully deploy the transcatheter aortic stent-valve. Fig. 2 [14] demonstrates a 2D TEE preprocedural image using X-plane imaging to show the aortic valve in cross-section as well as in the long axis view in a patient undergoing TAVI.
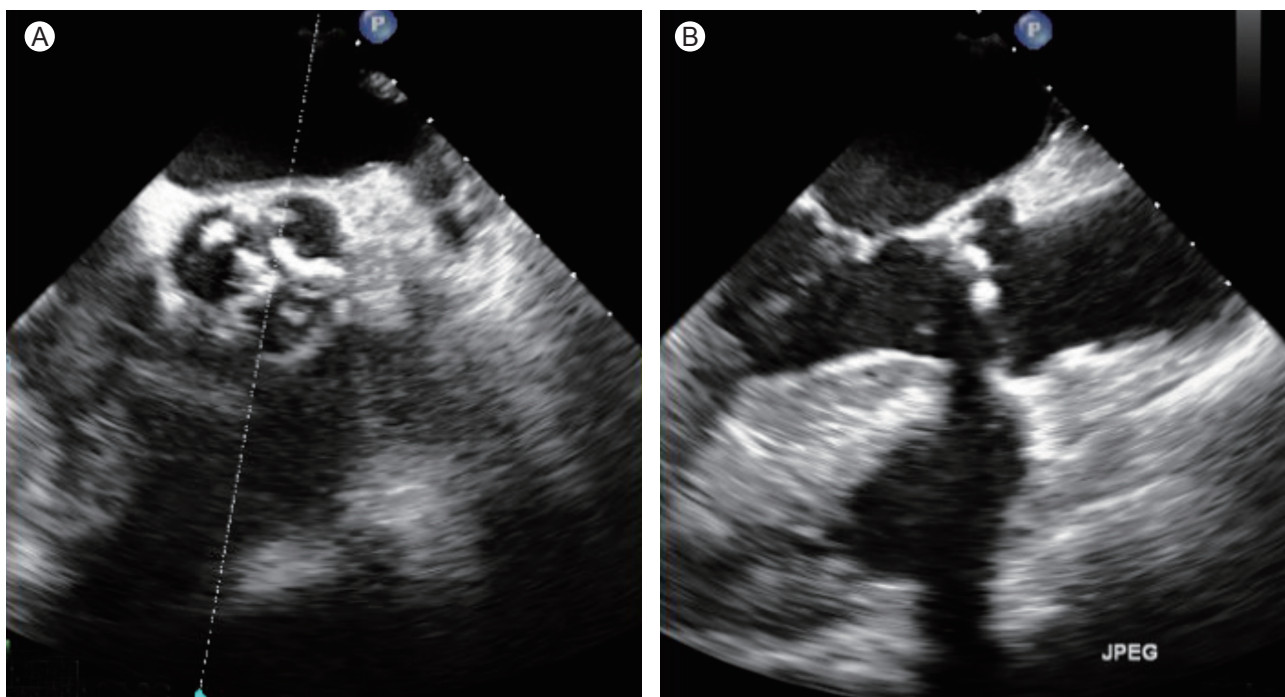

Figure 2. X-plane from the three-dimensional transesophageal echocardiography system. (A) Cross section of the aortic valve in a short-axis view at the level of the aortic annulus. (B) Long-axis view of the left ventricular tract and aorta. Dimensions of the aortic annulus are different in the short-axis and long-axis planes. Adapt from Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission from Springer-Verlag Dordrecht [14].

During TEE, the distance from the open left aortic cusp to the left main coronary ostium should be noted. As shown in Fig. 3 [15], with multiple TEE as well as 3D TEE, the short-axis view at the aortic level at 30° to 60° often delineates the left main coronary artery, and the long-axis view at the level at 110° to 140° often shows the right coronary artery ostium clearly. Annular remodeling in aortic stenosis has been reported to cause the distance between the aortic annulus and coronary ostia to decrease. The ostia of the coronary arteries are often distinctly visualized in the X-plane 3D TEE mode, allowing assessment of their distance from the native and prosthetic valves. In our experience, 3D TEE is useful for further assessment of the left and right coronary ostia and assists judgment of the distance from the aortic annulus to the ostia. This approach facilitates safer delivery of the stent valve, helping to prevent oc-clusion of the coronary ostia. If the valve is deployed too low in the LVOT, it can be released into the LV and subsequently be embolized distally into the aorta. In addition, deployment that is too low can result in the prosthetic valve impinging on the anterior mitral leaflet. On the other hand, if the valve is deployed too high in the aortic root, it can obstruct the coronary artery ostia or embolize into the aorta. An undersized valve may have significant regurgitation and may embolize because it is not well seated. A valve that is oversized can cause aortic annular rupture, which can cause aortic AR, cardiac tamponade, and death.

Sizing the aortic annulus

One of the primary roles of preprocedural and intra-procedural TEE for TAVI is defining the diameter and size of the aortic annulus. Prior to the procedure, CT is
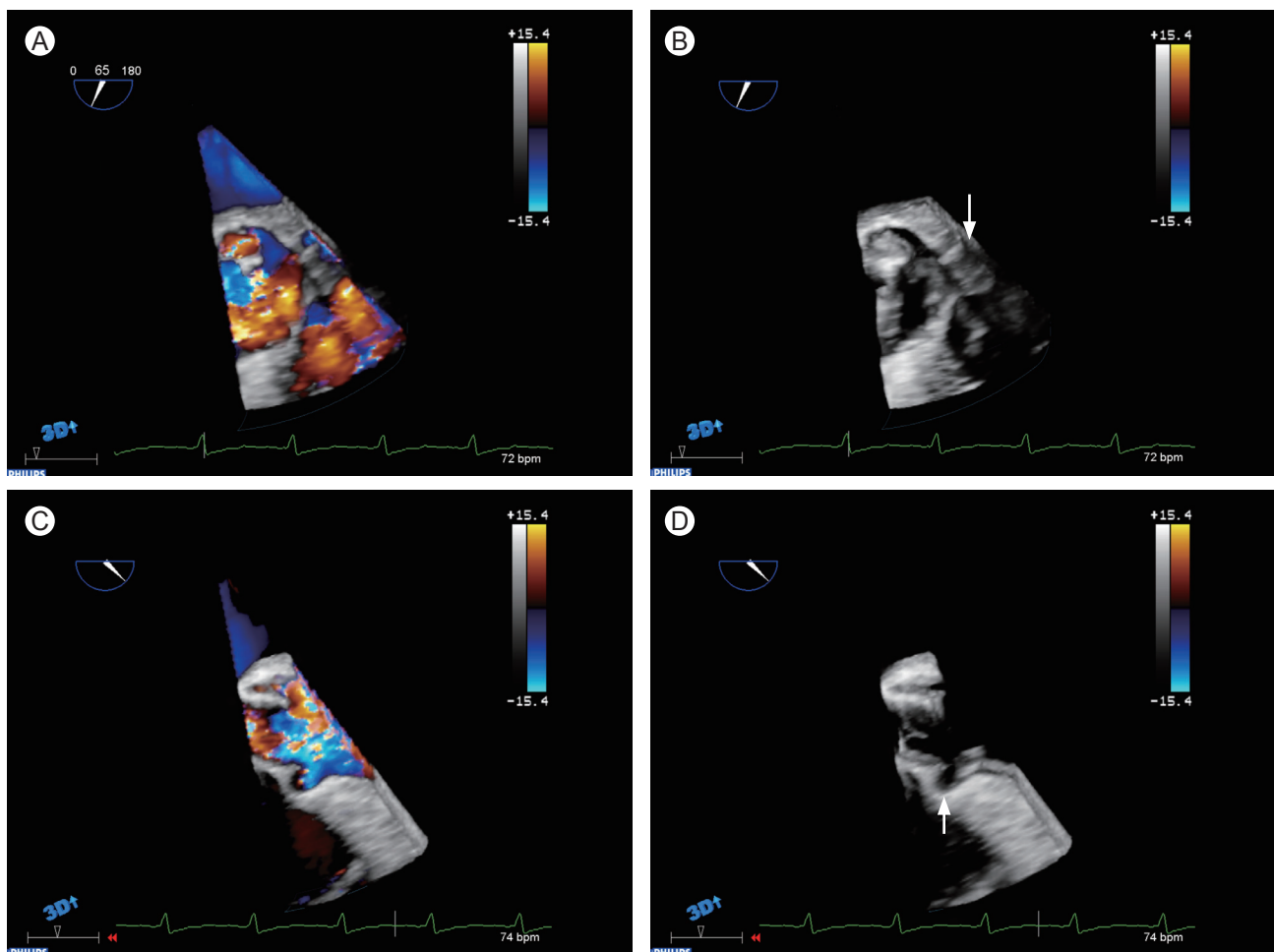

Figure 3. Assessment of the relationship of the left (A, B) and right (C, D) coronary artery ostia (arrows) to the implanted stent valve following transcatheter aortic valve implantation using three-dimensional transesophageal echocardiography. Adapt from Fig. 6, Siegel et al. Curr Cardiovasc Imaging Rep 2011;4:335-348, with permission from Current Medicine Group LLC [15].

also often used to measure the aortic annulus. During the TAVI procedure, TEE is used to corroborate the procedural measurements. With 2D TEE, a long-axis view (120° to 140°) is used to measure the aortic annulus size and determine the appropriate valve size. If the aortic annulus is 18 to 23 mm, a 23-mm aortic bioprosthesis is used. If the annulus is 23 to 36 mm, a 26-mm prosthesis is employed. The diameter of the aortic annulus is measured by echo at the lowest portion of the hinge point of the aortic valve cusps. As discussed above, it has been shown that the aortic annulus is frequently not circular when assessed by CT, 3D echo, or MRI [6]. Thus, the aortic annular diameter differs depending on whether it is measured in a coronal or sagittal plane. In addition to the aortic annulus dimension, we also measure the size of the sinus of Valsalva, the sinotubular junction, and the ascending aorta. As demonstrated in Fig. 4 [15], X-plane imaging from a 3D TEE system allows measurement of the aortic valve annulus on orthogonal views. From a TEE mid-esophageal long-axis view (110° to 140°), we measure the distance between the basal attachments of the right and non-coronary cusps during systole. Using the X-plane, an orthogonal dimension can also be measured. As shown in Fig. 4B [15], 3D TEE imaging also reveals that the aortic annulus in this case is not circular, but oval.

Echo during TAVI

During TAVI, both 2D and 3D TEE help to identify intracardiac catheters, the valvuloplasty balloon, the valve, and the catheter tip. Three-dimensional TEE yields better imaging of the catheter across the calcified aortic valve in the aorta and LV, as seen in Fig. 5 [14]. To implant the prosthetic valve, the stenotic native aortic valve must be predilated using a balloon catheter. During balloon inflation, rapid right ventricular pacing is induced at a rate ≥ 160 bpm, which reduces cardiac motion. Fig. 6A [14] shows an image of the procedure during balloon inflation. After balloon deflation, echo is used to assess complications, including hypotension. As seen in Fig. 6B [14], 3D color is also useful for assessment of the effect on the valve after balloon dilation as well as the amount of AR postvalvuloplasty. Next, the bioprosthetic Sapien aortic valve, which has been crimped on a catheter (Fig. 7) [16], is inserted across the predilated, stenotic aortic valve and into the LVOT. The aortic and ventricular edges of the crimped valve can be seen by 2D and 3D TEE, but 3D seems to enhance edge detection. The valve should be coaxially aligned in the LVOT and at the correct level before deployment. If the catheter is not coaxial, the valve deployment angulation could cause paravalvular regurgitation due to poor alignment between the bioprosthetic valve and the aortic annulus and aorta. Prior to valve deployment, the
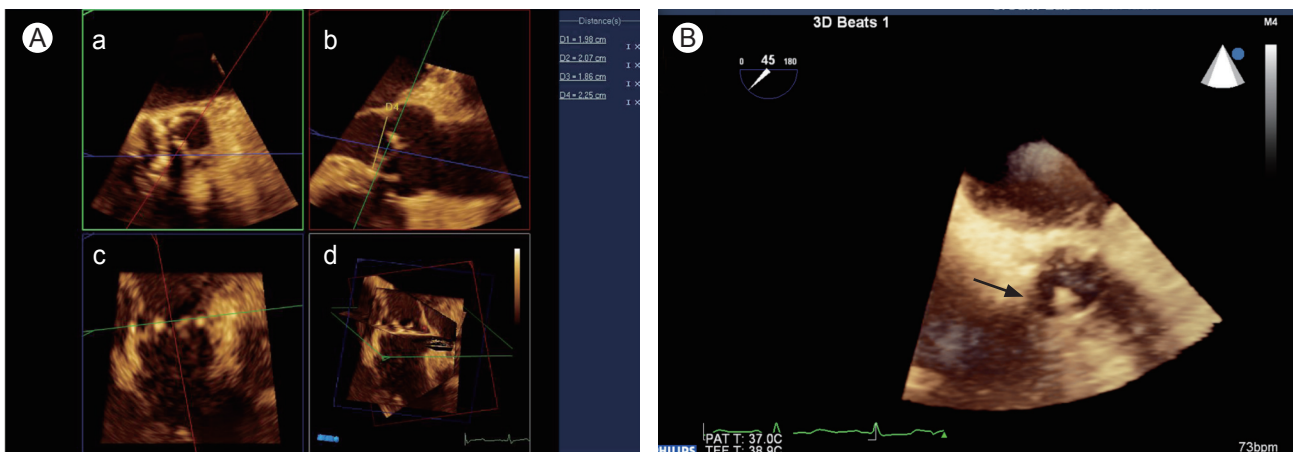
Figure 4. (A) Multiplanar assessment of the aortic annulus using three-dimensional (3D) transesophageal echocardiography (TEE). (Aa) The top left panel shows short-axis assessment of the aortic valve. (Ab) The top right panel shows a left ventricular outflow tract (LVOT) view with measurement of the aortic annulus diameter. (Ac) The bottom left panel shows an orthogonal measurement of the aortic annulus. (Ad) The bottom right panel shows a composite of the other three panels. The use of 3D TEE facilitates measurements of the aortic annulus from multiple angles (Adapt from Fig. 3, Siegel et al. Curr Cardiovasc Imaging Rep 2011;4:335-348, with permission from Current Medicine Group LLC) [15]. (B) A short-axis view of the LVOT by 3D TEE shows the shape of the LVOT to be oval in this patient with severe aortic stenosis undergoing transcatheter aortic valve implantation. A catheter (arrow) is present in the LVOT. Adapt from Fig. 4, Siegel et al. Curr Cardiovasc Imaging Rep 2011;4:335-348, with permission from Current Medicine Group LLC [15].

ventricular edge of the valve should be aligned as shown in Fig. 8 [16] so that it is to 4 mm below the aortic cusps because the bioprosthetic valve will move further antegrade into the LVOT and aorta when deployed. In Fig. 8B [16], the heart valve stent is placed too far into the aorta relative to the aortic cusps. As shown in Fig. 8C [16], the bioprosthetic valve must be carefully adjusted to the proper level across the aortic valve between the LVOT and aorta. Fig. 9 [14] was obtained during rapid right ventricular pacing while the balloon inflation was performed, and the aortic valve was deployed while imaging with real-time 3D TEE. Ideally, after implantation, the valve should be 1 to 2 mm below the insertion
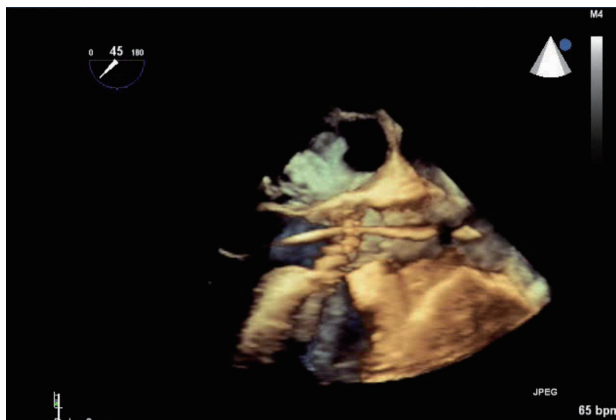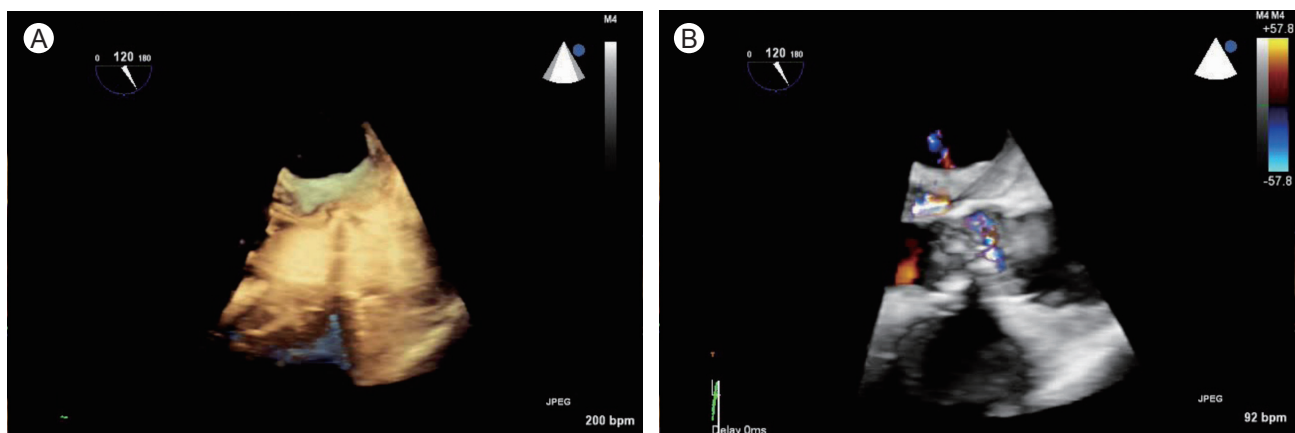
parts of the native aortic valve cusps.

As shown in Fig. 10A [14], 3D imaging documents how well the valve is seated. Color-flow 3D echocardiography (Fig. 10B) [14] allows assessment of the severity of AR, the precise origin of the regurgitation (paravalvular or central), and whether the AR is coming from more than one site.

For TAVI, 3D TEE for catheter-based AVR is adjunctive to 2D TEE. Real-time 3D TEE is useful in TAVI for assessment of the annulus and guidance of the TAVI procedure [17,18]. As noted in Table 1, real-time 3D TEE is especially useful during TAVI to ensure coaxial catheter alignment in the LVOT and the aortic root, position the valve correctly in relation to the aortic cusps, assess AR after valve deployment, and identify postprocedural complications.

POST-TAVI DEPLOYMENT

Aortic valve regurgitation

Aortic valve regurgitation has been reported in 88% of post-TAVI cases [13]. It manifests most commonly as paravalvular regurgitation and is generally along the posterior (MV) side of the aortic stent valve. The degree of regurgitation can range from trivial to severe. Paravalvular regurgitation should always be assessed by color flow Doppler interrogation of the aortic annulus immediately postprocedure. The location of the regurgitation may be variable, and the directionality of the regurgitant jet may be challenging to precisely identify

Figure 5. Real-time three-dimensional transesophageal echocardiography long-axis view through mitral valve, left ventricular outflow tract, and aorta. View of a length of catheter from the aorta traversing the stenotic aortic valve and entering the left ventricular. Adapt from Fig. 4, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].

Figure 6. (A) Three-dimensional (3D) view of balloon inflation during balloon valvuloplasty. (B) Full-volume 3D color flow showing severe aortic regurgitation after balloon valvuloplasty. Adapt from Fig. 5, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].

using 2D TEE. Less commonly, the regurgitation can be transvalvular. It has been reported in 1.3% of cases [19], and this often diminishes over time. Occasionally, it results from a bioprosthetic aortic cusp that is under-deployed, and simple catheter manipulation may reduce this form of postprocedural AR by causing expansion of the cusp into an open position. An example of moderate AR caused by transvalvular and paravalvular AR post-TAVI is shown in Fig. 11 [15]. In one report on the Place-ment of Aortic Transcatheter Valves Trial valve, moder-ate or severe paravalvular AR was present in 11.8% of the patients in the TAVI group at 30 days and in 10.5%

at 1 year [10]. There were no substantial changes in paravalvular AR in the TAVI group during the 1-year follow-up period. The presence of moderate or severe paravalvular regurgitation after TAVI has been reported to have a 3.79-fold higher risk of 1-year postprocedural mortality [20].

Valve embolization and valve malposition

Distal embolization of the aortic stent valve is a po-tentially serious complication that can lead to stroke or peripheral embolism. If this complication occurs, the valve should be advanced into the descending aorta, and balloon inflation should be used to compress the prosthesis and leaflets into the wall of the aorta. This should allow the valve to remain wide open throughout the cardiac cycle.

Other complications that may occur during TAVI are rupture of the aortic annulus and cardiac tamponade, transient LV dysfunction, coronary obstruction due to the prosthesis or displaced stenotic aortic valve, and varying degrees of mitral regurgitation (MR). Fig. 12A [15] shows severe MR by 2D TEE that was associated with transient LV dysfunction. The 3D TEE (Fig. 12B) [15] demonstrates that the severe MR was due to the lack of MV leaflet coaptation, causing a central regurgi-tant orifice. As has been reported after traditional AVR, when LV function post-TAVI is hyperdynamic, severe MR can occur due to systolic anterior motion of the MV.
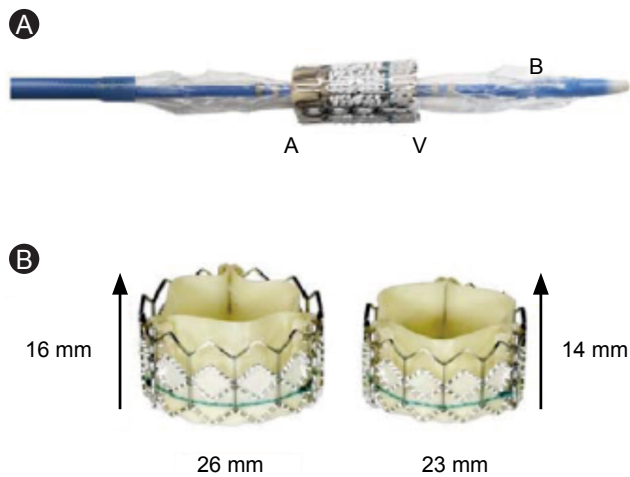
Figure 7. (A) Photograph of Edwards-Sapien bioprosthetic valve crimped on a delivery catheter. (B) The 26- and 23-mm valves and their respective height in mm are shown. The aortic end of the stent valve is labeled A, and the ventricular aspect is labeled V. The col-lapsed balloon on the catheter used to deploy the valve is labeled B. Adapt from Fig. 1, Lerakis et al. JACC Cardiovasc Imaging 2010;3:219-221, with permission from Elsevier Science [16].
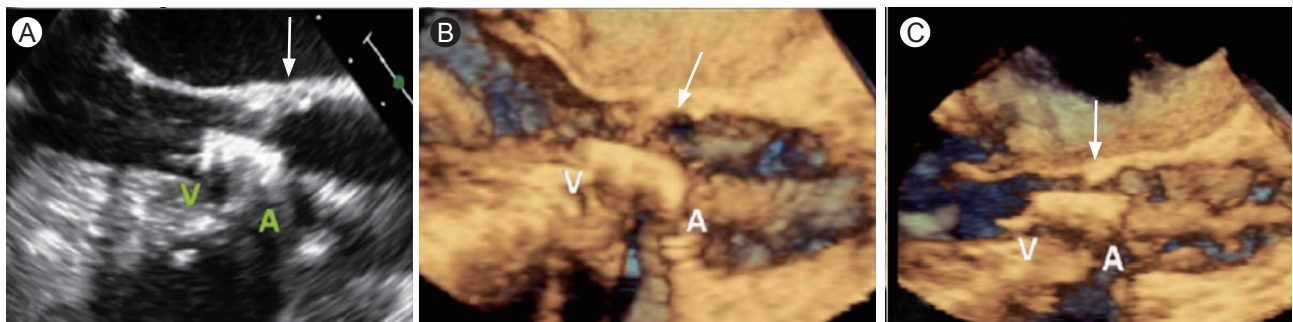
Figure 8. The 23-mm valve. (A) Two-dimensional transesophageal echocardiography (TEE) long-axis view. (B) Three-dimensional TEE long-axis view; the stent length is too aortic and needs to be lower (further toward the left ventricular outflow tract). (C) The valve is now perfectly aligned. V, ventricular aspect of Sapien bioprosthetic valve; A, aortic aspect of Sapien bioprosthetic valve. Adapt from Fig. 3, Lerakis et al. JACC Cardiovasc Imaging 2010;3:219-221, with permission from Elsevier Science [16].
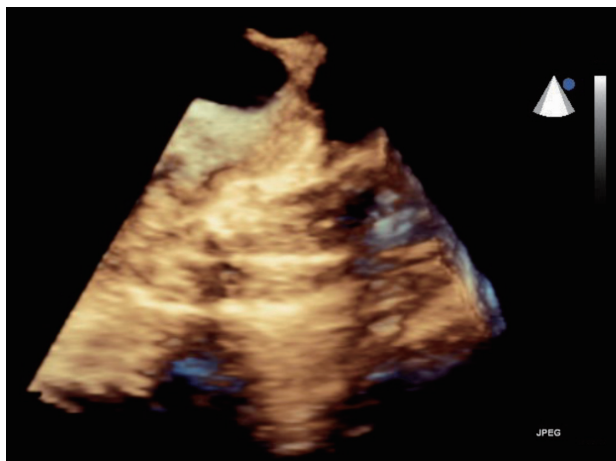
Figure 9. Three-dimensional imaging during balloon inflation deploying the Sapien bioprosthetic valve. Adapt from Fig. 7, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].

ECHOCARDIOGRAPHY IN PATIENTS WITH SEVERE MR UNDERGOING PERCUTANE-OUS MV REPAIR WITH THE MITRACLIP

The first MitraClip for severe MR was implanted in 2003 [21]. Since that time, more than 5,000 patients with MR have been treated with the MitraClip (Ted Feldman, M.D. from Evanston Hospital, Evanston, IL, USA. Personal communication 2011). A number of important inclusion and exclusion criteria that need to be fulfilled prior to clip placement (Ted Feldman, M.D.). These are listed in Table 2 and shown in Fig. 13. The largest study to-date of the MitraClip involved 279 patients and compared the MitraClip with surgery in terms of efficiency and safety [22]. While the MitraClip was effective in reducing MR, surgical treatment was more effective in reducing MR grade. However, the
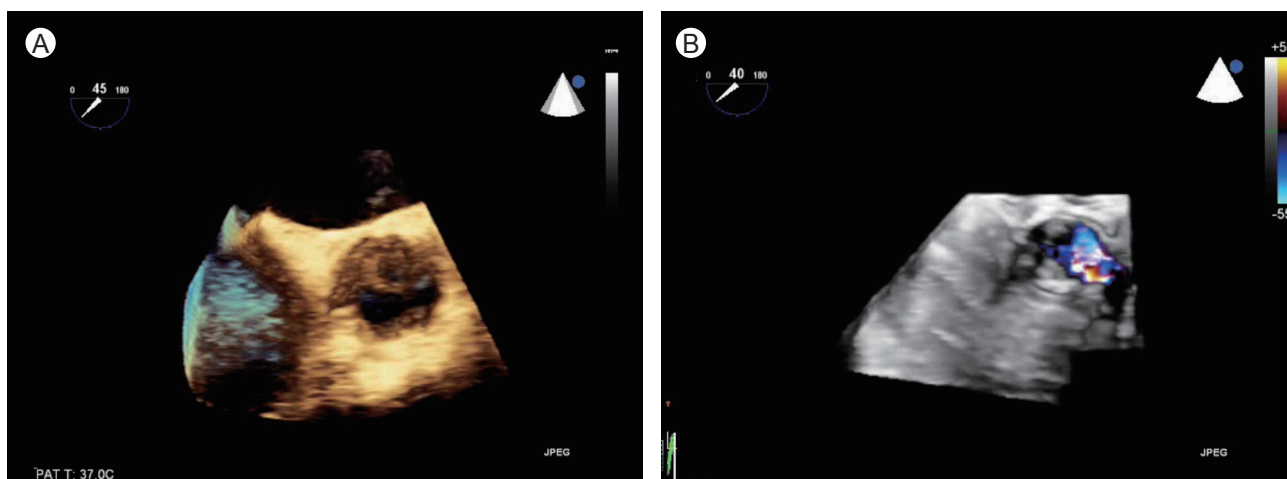

Figure 10. Three-dimensional short axis view. (A) Bioprosthetic aortic valve, postdeployment. (B) Full-volume color flow demonstrates site and severity of aortic regurgitation. Adapt from Fig. 8, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].

Table 1. Transesophageal echocardiography for guidance of transcatheter aortic valve replacement

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1	Assess aortic annular diameter with two-dimensional and three-dimensional
2	Determine left ventricular and right ventricular systolic function; identify other associated valve diseases or cardiac abnormalities
3	Guide and confirm coaxial alignment of the delivery catheter within the left ventricular outflow tract and aortic root
4	Identify the ventricular and aortic ends of the prosthesis prior to deployment of the valve to align with the aortic valve cusps
5	Optimize bioprosthetic valve position before deployment
6	Assess severity of aortic regurgitation after valve deployment
7	Assess for complications including left ventricular dysfunction, coronary obstruction, valve embolization, pericardial tamponade, and aortic annular rupture
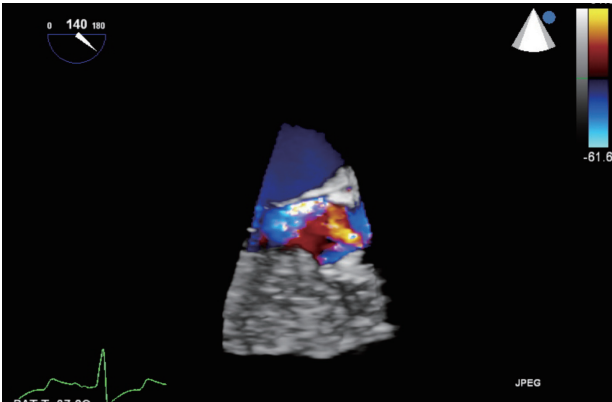
Figure 11. Three-dimensional transesophageal echocardiography color long-axis view of the aortic valve demonstrating moderate paravalvular and transvalvular aortic regurgitation. Adapt from Fig. 13, Siegel et al. Curr Cardiovasc Imaging Rep 2011;4:335-348, with permission from Current Medicine Group LLC [15].

percutaneous approach with the MitraClip resulted in fewer adverse events at 30 days than did surgery. At 1 year, patients in both groups showed a reduced LV end-diastolic volume. Of note, the MitraClip patients exhibited greater improvements in New York Heart Association class and quality-of-life score.

For assessment of MV anatomy, we used the classification of Carpentier et al. [23] to optimize communication regarding MV morphology among echocardiologists and interventional cardiologists. As shown in Fig. 13A, we used the Carpentier nomenclature to describe the MV in the surgical view when using 3D TEE imaging. Two-dimensional TEE assists assessment of MV morphology, but we have found that 3D provides important additional information and more detailed MV morphology. For successful MV clip repair, the structural
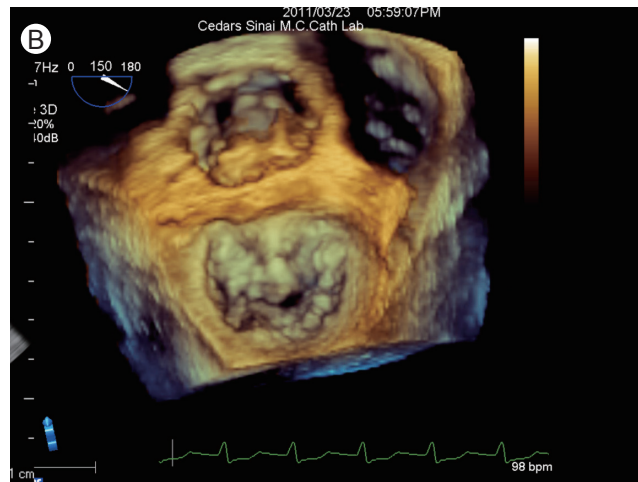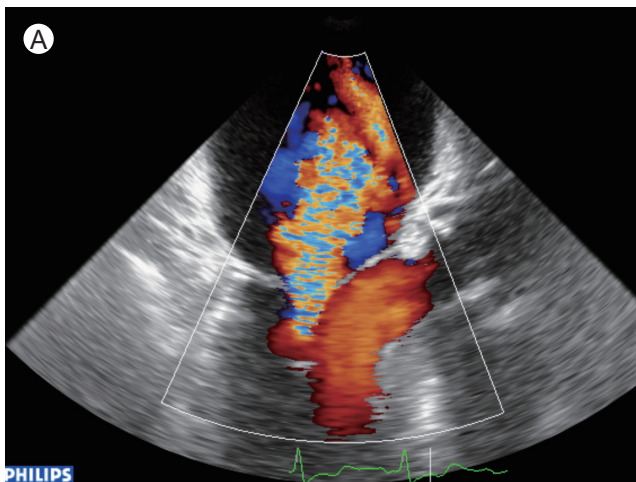

Figure 12. Severe mitral regurgitation following transcatheter aortic valve implantation secondary to transient left ventricular dysfunction with malcoaptation of the anterior and posterior mitral leaflets. Adapt from Fig. 15, Siegel et al. Curr Cardiovasc Imaging Rep 2011;4:335-348, with permission from Current Medicine Group LLC [15].

Table 2. Echo Doppler criteria for MitraClip mitral regurgitation (MR) repair

Inclusion
Grade 3 to 4+ (moderately severe or severe) MR
MR originating from the central two-thirds of the valve (A2, P2)
Degenerative functional etiology
Sufficient tissue for mechanical caption of the valve
Exclusion
Rheumatic MR
Mitral valve area of < 4 cm^2
Flail gap of > 10 mm
Flail width of > 15 mm
Left ventricular systolic internal dimension of > 55 mm
Left ventricular ejection fraction of < 25%
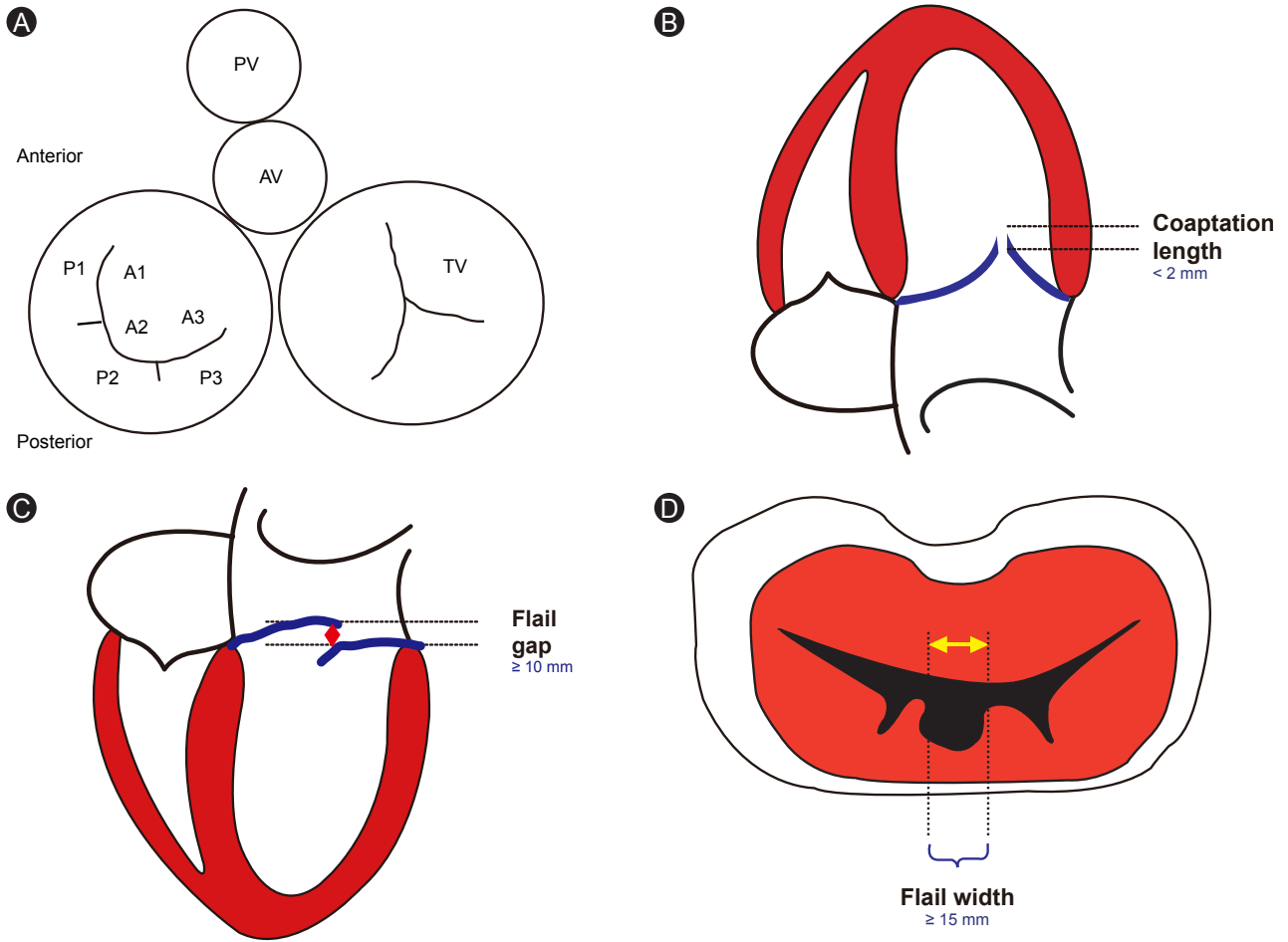
Figure 13. (A) The schematic shows the Carpentier classification of the mitral valve scallops. (B) Measurement of coaptation length. (C) Measurement of flail gap. (D) Measurement of flail width. These measurements are important for the inclusion and exclusion criteria that must be fulfilled prior to MitraClip placement (from Dr. Siegel's slide). PV, pulmonic valve; AV, aortic valve; TV, tricuspid valve; P, posterior leaflet; A, anterior leaflet; 1, lateral scallop; 2, middle scallop; 3, medial scallop.
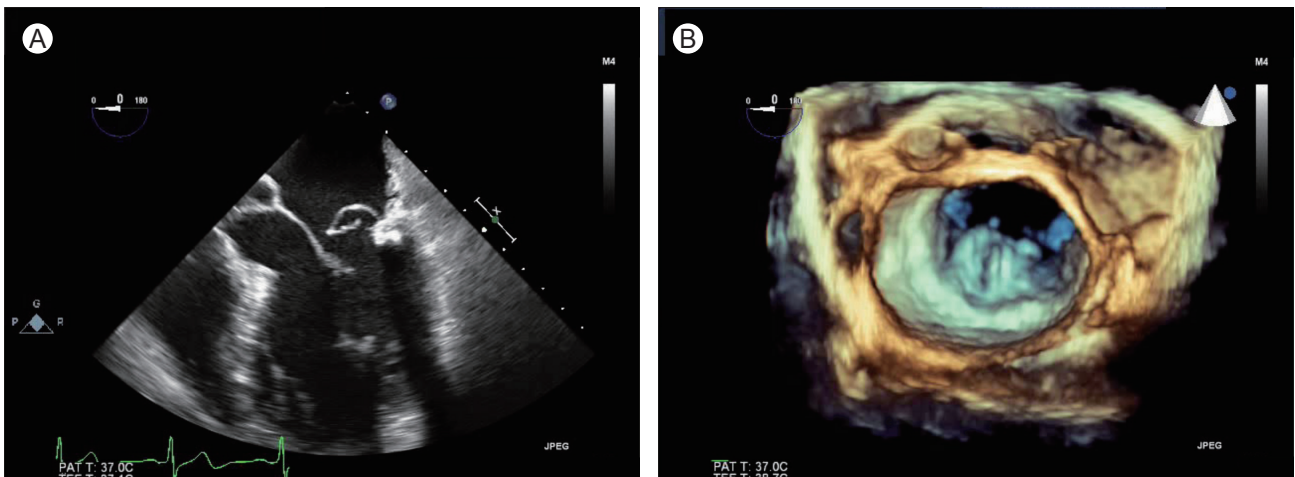
Figure 14. (A) Five-chamber two-dimensional transesophageal echocardiography (TEE) view suggests that the lateral scallop of the posterior leaflet is flail. (B) Three-dimensional TEE reveals that the middle scallop of the posterior leaflet is flail and the presence of two ruptured chordae tendinae. Adapt from Fig. 10, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].
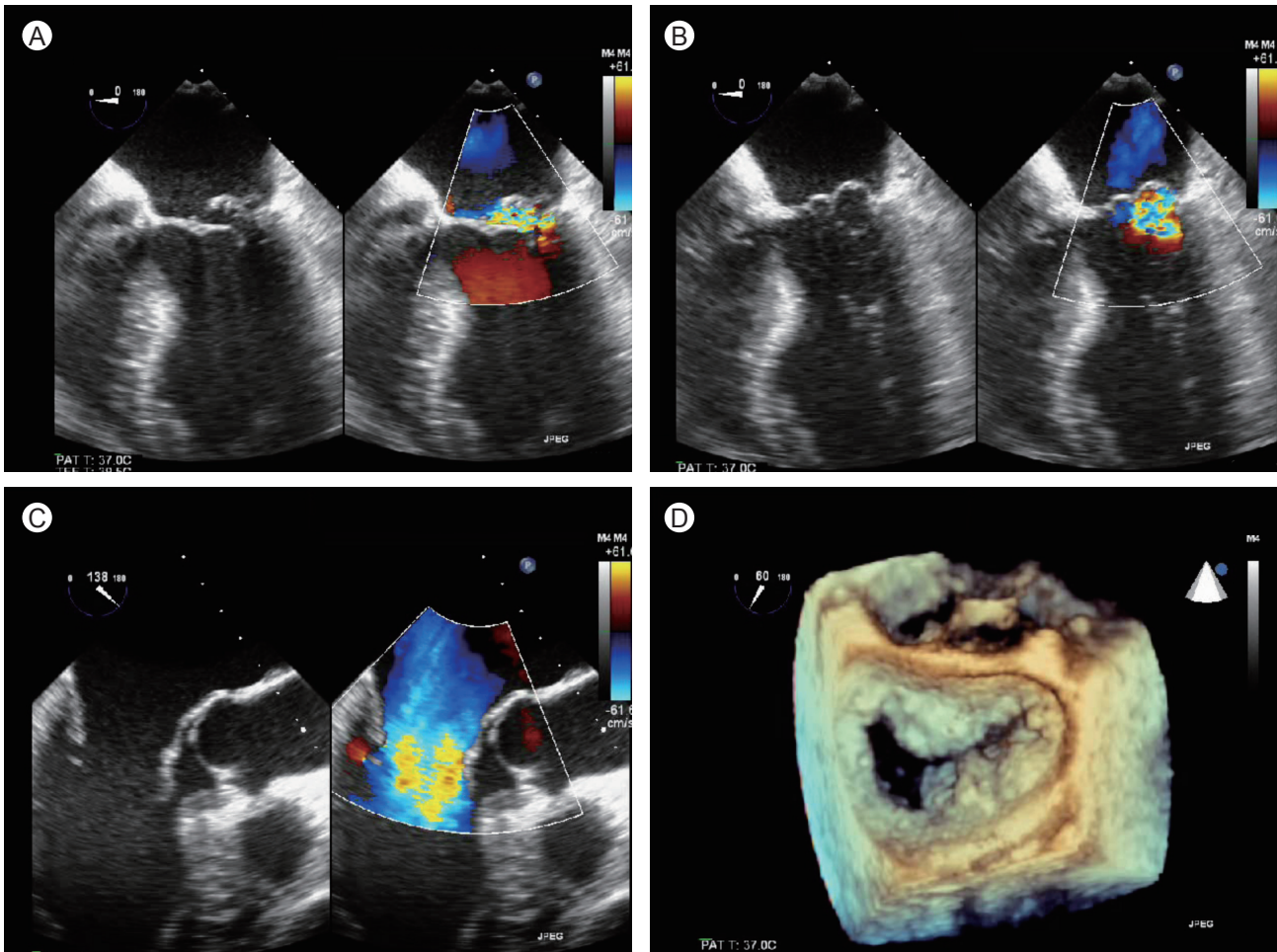
Figure 15. (A, B) Two-dimensional transesophageal echocardiography (TEE) four-chamber views show prolapse and flail of the middle scallop (P2) with associated mitral regurgitation. (C) Two-dimensional three-chamber long-axis view also shows middle scallop (P2) prolapse and flail. (D) Three-dimensional real-time TEE shows flail medial and middle scallops (P2 and P3). Adapt from Fig. 11, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].

abnormalities and the MR must be central. With MV prolapse or a flail MV, the site of the prolapse/flail must be limited to the central portion of the valve for the anterior leaflet (A2) and posterior leaflet (P2). Three-dimensional TEE, which can be done in live 3D TEE, zoom, or full volume imaging modes, generally results in accurate *en face* anatomic definition of the MV (iE33 ultrasound machine, Philips, Andover, MA, USA). The anterior and posterior leaflet scallops can be identified, as can flail segments and associated ruptured chordae tendinae. As shown in Fig. 14A [14], 2D TEE can be misleading in terms of which scallop is prolapsed. In this five-chamber view, 2D TEE appears to show prolapse of the posterior MV lateral scallop (P1) prolapse, whereas on 3D TEE, the prolapse is clearly central (P2) (Fig. 14B) [14]. In our laboratory, we have found that 3D TEE

clarifies the site of MV prolapse in cases that are ambiguous or not identified by 2D TEE. We have screened more than 1,000 patients for the MitraClip, and at the time of writing, 140 patients have had MV clip repair at our institution (Cedars-Sinai Medical Center, Los Angeles, CA, USA). Insufficient MR severity is the most frequent cause of exclusion from the trial. However, on 3D TEE screening, a lateral (A1 and P1) or medial (A3 or P3) prolapse that was not clearly seen on 2D TEE is sometimes found. As shown in Fig. 15 [14], on 2D TEE, the flail scallop appears to be the middle scallop (P2), but on 3D TEE, flail of both the middle and medial scallops was observed (P2 and P3). Thus, this patient, who was referred for the MitraClip, did not meet the criteria because the MR was due to a non-central MV leaflet prolapse and flail. As discussed in Table 3, for this pro-

cedure, the 24 French MitraClip system is advanced from the femoral vein to the right atrium. A transseptal puncture was performed to enable insertion of the catheter into the left atrium (LA). As demonstrated in Fig. 16 [14], for transseptal punctures, the X-plane view is used to simultaneously identify the site of transseptal puncture from a bicaval and aortic short-axis view. This allows confirmation of the puncture site relative to the fossa ovalis as well as its relationship to the aorta (an anterior structure). Prior to transseptal puncture, a four-chamber view is used to assess the distance of the transseptal needle in relation to the plane of the MV. In cases of MV prolapse (especially bi-leaflet prolapse), the puncture site should be more superior along the intra-atrial septum so that there is a greater distance between the transseptal catheter and the plane of the MV annulus. After the transseptal puncture, the MitraClip-guided catheter is advanced into the LA. As shown in Fig. 17 [14], the guide catheter should be oriented toward the MV apparatus. Real-time 3D TEE imaging helps with catheter orientation in a way not possible with 2D TEE. The 3D catheter alignment and directionality can be assessed in the three dimensions of the heart. A 3D TEE view can identify the locations of the guiding catheter, the device, MV, and LA appendage. Next, the MitraClip is advanced toward and opened above the MV in the LA. This can be visualized by 2D TEE, but clip orientation within the LA can be problematic. Prior to the passage of the MitraClip into the LV, it should be located at the midportion of the MV (A2 P2 segments) and oriented perpendicular to the line of MV coaptation. Accurate MitraClip orientation within the LA is often difficult by 2D TEE alone. However, as shown in Fig. 18 [14], with 3D guidance, the clip can be directed to the midportion of the MV and adjusted perpendicular to the line of MV coaptation. The MitraClip is subsequently advanced into the LV. With 2D TEE imaging, a long-axis view (110° to 140°) is generally used to advance the MitraClip

Table 3. Transesophageal echo-guided MitraClip placement (12 steps)

1	Perform transseptal puncture
2	Introduce guide catheter sheath into left atrium (LA)
3	Insert clip delivery system into LA
4	Open clip in LA just above mitral valve (MV)
5	Orient MV clip perpendicular to line of MV coaption at midportion of valve
6	Advance clip into left ventricle
7	Confirm that clip orientation remains at line of MV coaption at midportion of MV
8	Grasp leaflets
9	Confirm leaflet insertion
10	Assess adequacy of mitral regurgitation reduction; if not adequate, consider moving clip or placing second clip
11	Confirm MV gradient of < 5 mmHg
12	Deploy clip
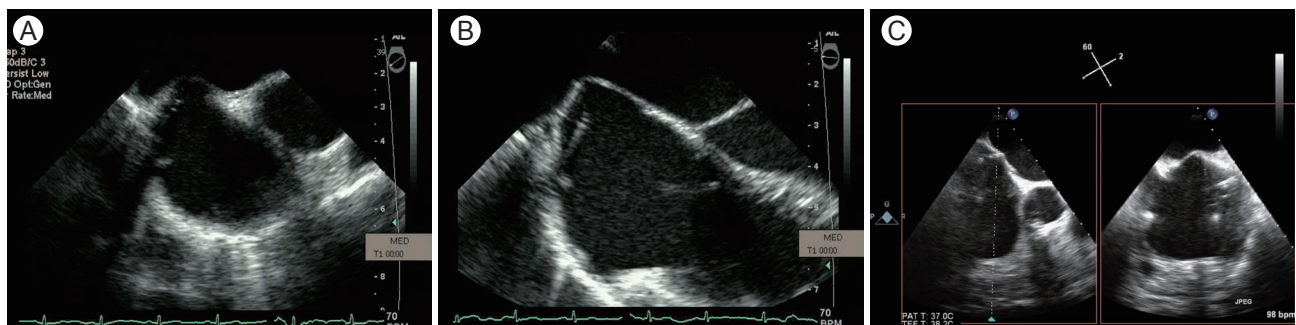
Figure 16. Transeptal puncture using transesophageal echocardiography guidance. (A) Short-axis view at level of the aortic valve shows transseptal catheter indenting the intra-atrial septum. (B) Four-chamber view shows transseptal catheter indenting the intra-atrial septum. (C) X-plane imaging shows simultaneous views of the intra-atrial septum during the transseptal puncture from the aortic short-axis (left panel) and the bi-caval view (right panel). Adapt from Fig. 12, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].
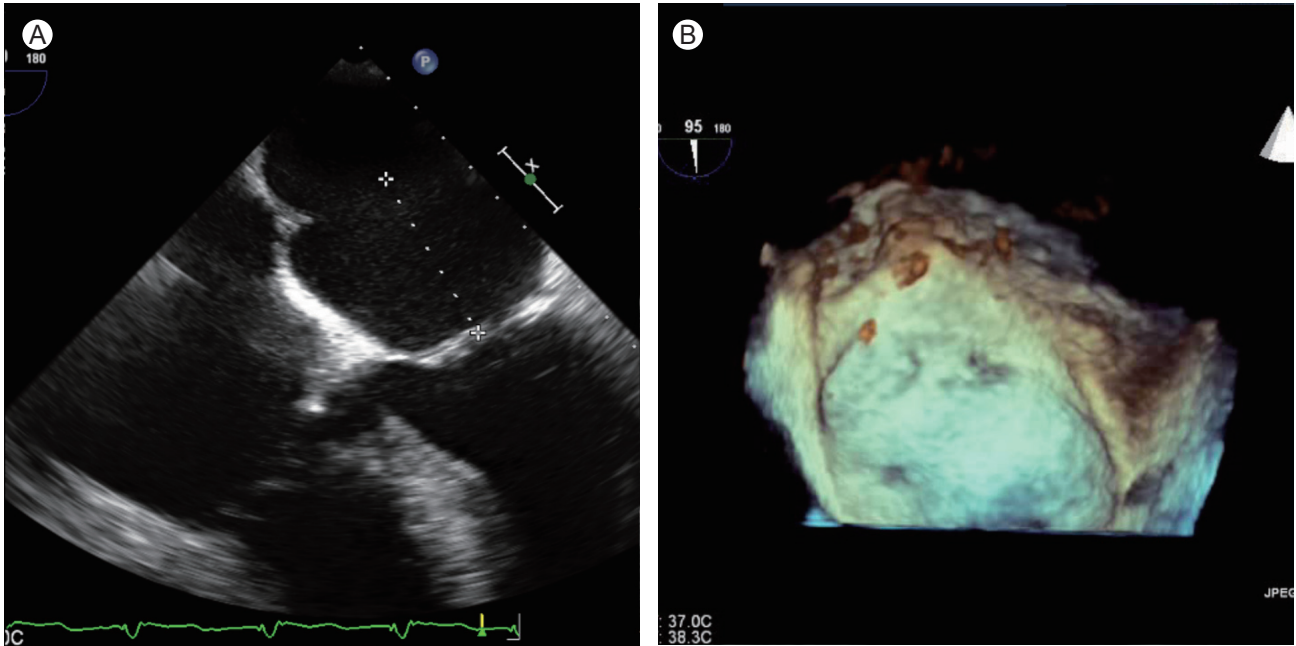
Figure 17. (A) Two-dimensional transesophageal echocardiography (TEE) four-chamber view shows transseptal catheter indenting the intra-atrial septum. (B) Three-dimensional TEE transseptal catheter indenting the intra-atrial septum from the left side of the septum. Adapt from Fig. 13, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].

into the LV. Clip orientation perpendicular to the line of MV coaptation within the LV is feasible with a 2D TEE transgastric view, but is sometimes difficult (Fig. 19). Conversely, as shown in Fig. 16B [14], 3D Mitra-Clip orientation in the LV can often be obtained. If the MitraClip is at the midportion of the valve and perpendicular to the line of MV coaptation within the LV, the interventionalist is set to capture the MV in the midportion of the MV leaflets. This is most often done by 2D TEE from the long-axis view, which shows the A2 P2 segments (angle, 110° to 140°) or in combination with a 3D system X-plane view so that the operator has both long-axis and 2D bi-commissural views (60° to 90°) that allows imaging of the P1 to P3, as well as the A2, segments (Fig. 20) [14]. After MV leaflet capture, standard 2D TEE is used to assess leaflet insertion (multiple views including four-chamber, bi-commissural [two-chamber], and long-axis [three-chamber] views). Three-dimensional TEE color can help with identification if more than one MR jet is present, which can occasionally be missed by 2D imaging alone. If a second or third jet is found, more interrogation of the jet is performed by 2D color as well as spectral Doppler evaluation. In cases with satisfactory leaflet capture and MR reduction, Doppler is used to assess the degree of residual gradient across the MV between the LA and LV to ensure that

there is no mitral stenosis. A gradient of 5 mmHg would be considered unacceptable. A gradient of 3 or 4 mmHg might preclude the use of a second MitraClip. As Fig. 21 shows, after MitraClip deployment, 3D TEE is useful for evaluation of the size and shape of the dual mitral orifices and to assess whether they are symmetrical. If moderate-to-severe MR remains after the first MitraClip, a second MitraClip is generally implanted. 3D TEE color Doppler is often adjunctive to 2D to assist identification of the site of the largest jet as well as its origin. The site of the maximal jet is used to identify where to place the second clip. If a second clip is placed, the valve is reevaluated as was described for the initial clip. Real-time 3D TEE is useful for optimal guidance of the MitraClip procedure [22]. In addition, 3D TEE to 2D TEE improves the confidence of the echo interpretation ($p < 0.001$). In our experience, 3D enhances the confidence of assessment of MV morphology, localization of guiding catheters, and MitraClip placement. Real-time 3D TEE is also associated with a reduction in MitraClip procedure time ($p = 0.35$) by 40 minutes [24].

Complications of the MitraClip procedure

More than 5,000 MitraClip procedures have been performed worldwide, and no intraprocedural mortality has been reported. Of 140 cases in our laboratory,
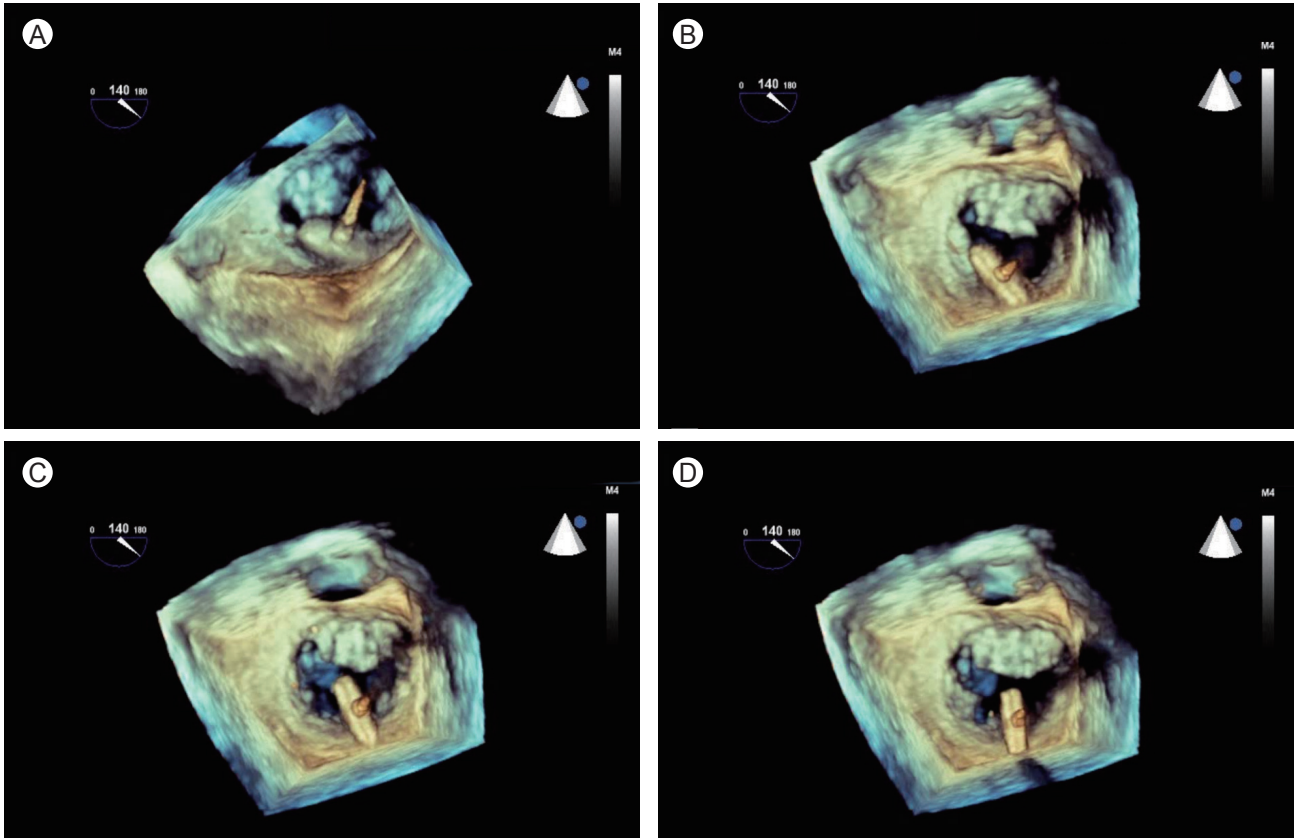
Figure 18. (A-D) Serial three-dimensional images show how the open MitraClip is progressively reoriented so that the clip is at the midportion of the mitral valve (MV) (above A2-P2) and perpendicular to the line of MV coaptation. Adapt from Fig. 15, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].
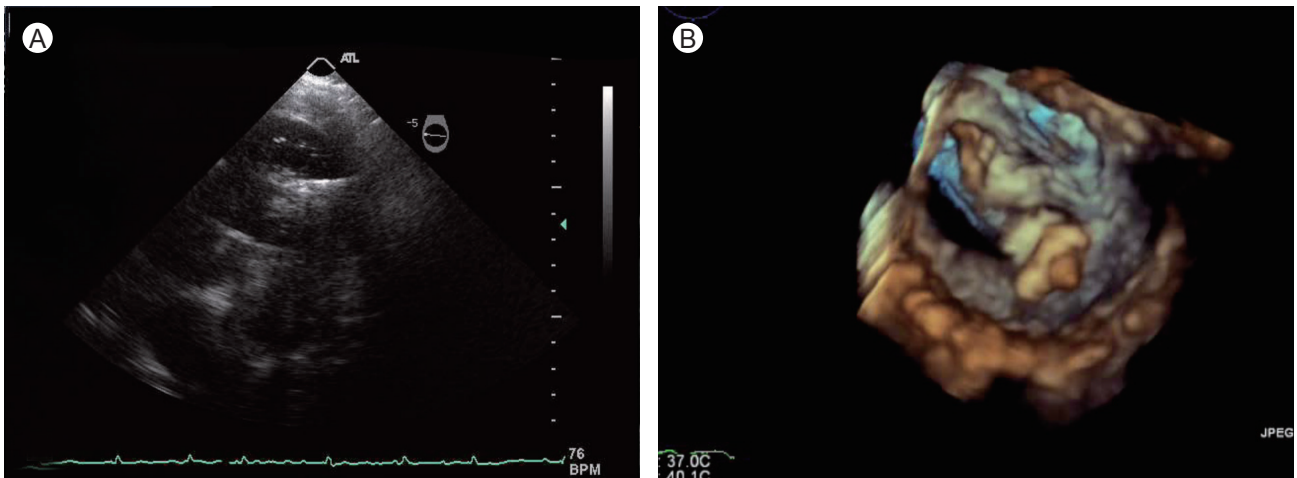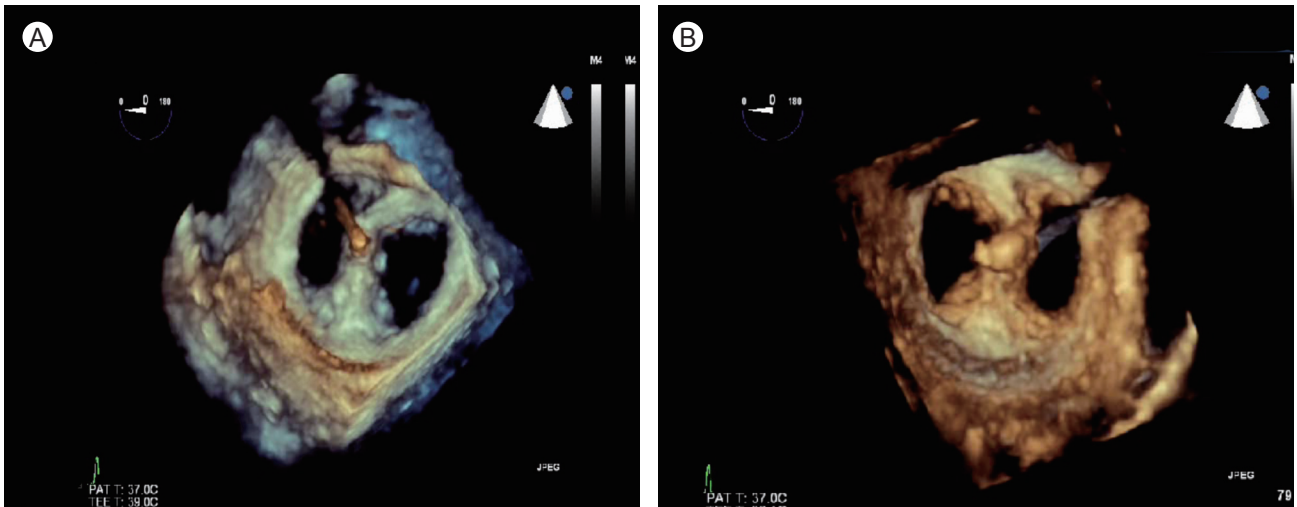

Figure 19. (A) Two-dimensional transesophageal echocardiography transgastric view shows from the left ventricular (LV) that the clip is perpendicular to the mitral valve (MV) line of coaptation and near the central portion of the valve. (B) Three-dimensional view from the LV shows that the clip is at the midportion of the MV (below A2-P2) and perpendicular to the line of MV coaptation (from Dr. Siegel's slide).

1 was cardiac tamponade, 1 hemothorax, and 1 large right-to-left shunt postprocedure. Both the pericardial tamponade and hemothorax cases were drained with-

out complications, and each had successful MitraClip placement. The case with severe right-to-left shunting across the atrial septum after the transseptal puncture
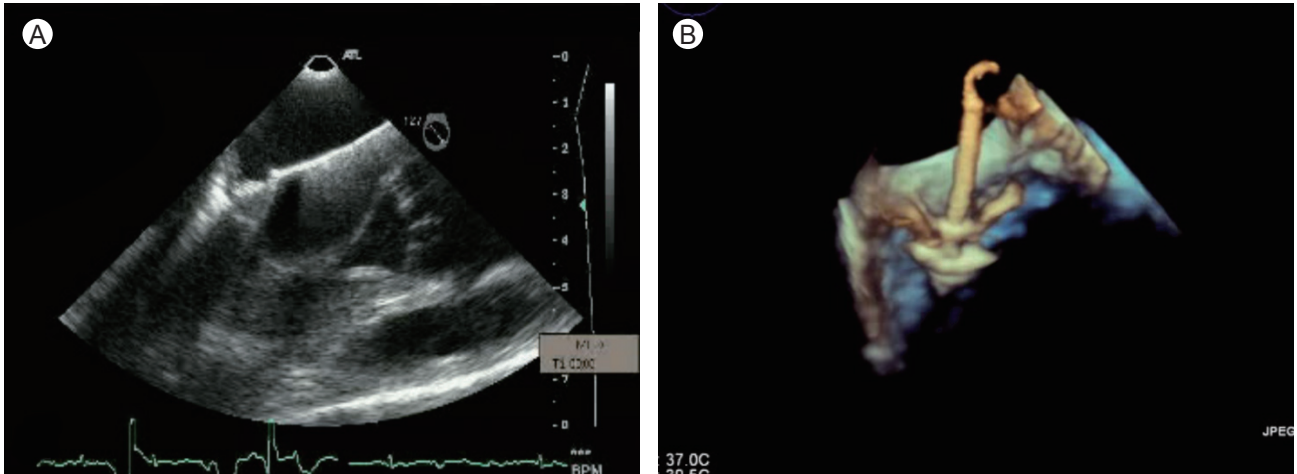
Figure 20. (A) Two-dimensional transesophageal echocardiography (TEE) long-axis view shows the MitraClip grasping the anterior and posterior leaflets. (B) Three-dimensional TEE shows the MitraClip grasping the anterior and posterior leaflets. Adapt from Fig. 17, Siegel et al. Int J Cardiovasc Imaging 2011;27:1165-1177, with permission Springer-Verlag Dordrecht [14].

Figure 21. Three-dimensional echo of transcatheter mitral valve repair. (A) Atrial. (B) Left ventricular (LV) view. Three-dimensional transesophageal echocardiography evaluation of the size and shape of the dual mitral orifices after MitraClip deployment (from Dr. Siegel's slide).

was associated with severe tricuspid regurgitation. After the MitraClip procedure, this shunt had to be closed by an atrial septal defect closure device (Amplatzer, AGA Medical Corporation, Plymouth, MN, USA). Thus, the role of TEE during the procedure should include careful monitoring for the development of cardiac tamponade, which can be a complication of transseptal procedures. In addition, if the patient has severe tricuspid regurgitation (especially in the setting of pulmonary hypertension), we believe that there is a higher risk of developing a substantial right-to-left shunt across the atrial septal puncture site that could require closure by

a percutaneous device. Further, because the MitraClip catheter system is large (22 F), the potential for trauma to intracardiac structures must be monitored. In addition, because the MitraClip reduces the MV orifice size, Doppler and anatomic assessment of the MV is required prior to release of the MitraClip to ensure that there is a minimal postprocedural mitral gradient and no significant mitral stenosis.

The MitraClip procedure has been shown to be safe. Compared with surgery, the MitraClip is associated with less major adverse events. However, surgery (either valve repair or replacement) was more effective in re-

ducing the severity of MR. Both were effective in reducing MR and LV volumes. In a recent study, the MitraClip was associated with significant hemodynamic improvement within 24 hours of placement. Specifically, cardiac output was reduced after clip placement. Moreover, elevated filling pressures (pulmonary capillary wedge pressure and LV end-diastolic pressure) and increased pulmonary artery systolic pressure were reduced by MitraClip placement [25]. In addition, in a recent study of the MitraClip in patients with MR deemed to be at high risk for cardiac surgery (estimated mortality rate, 14.2% to 18.2%), the 30-day procedure-related mortality rate was 7.7%. In the MitraClip group, MR was reduced from III to IV at baseline to I/II in 74% of cases (p = 0.0001). Quality-of-life scores improved and the hospitalization rate decreased in the MitraClip group. The 1-year mortality rate in the MitraClip group was 24% compared with 48% in the control group who received medical therapy (p = 0.047).

In summary, newly evolving transcatheter therapies for valvular heart disease show great promise for AVR in patients with aortic stenosis and for MV repair in patients with MR. At present, echo guidance is used for optimal deployment of these devices, and 3D echo has proven to be a useful adjunct. Transcatheter valve intervention is evolving rapidly. These devices will further evolve, becoming easier, safer, and even more effective.

Conflict of interest

No potential conflict of interest relevant to this article is reported.

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