Transcatheter Tricuspid and Mitral Valve Edge-to-Edge Repair: The Double Double Orifice

Mary Z. Bechis, MD, FACC, David S. Rubenson, MD, FACC, FASE, and Matthew J. Price, MD,
La Jolla, California

INTRODUCTION

Severe tricuspid regurgitation (TR) is a common comorbid condition in patients with left-sided valve disease and is an independent predictor of mortality.[1] The presence of significant TR portends worse prognosis after successful surgical treatment of mitral regurgitation (MR).[2,3] Therefore, the American Heart Association/American College of Cardiology guidelines recommend concomitant tricuspid annuloplasty repair during left heart surgery for severe TR (Class I) and for any degree of TR with evidence of right ventricular annular dilatation or right heart failure (Class IIa).[4]

As transcatheter therapies for mitral valve disease evolve, so too does the need to address associated TR using percutaneous techniques. The MitraClip system (Abbott Vascular, Santa Clara, CA) was approved in 2013 for transcatheter mitral valve repair for severe symptomatic primary MR in patients at prohibitive surgical risk (Class IIb).[4] Observational studies of patients undergoing transcatheter mitral valve repair demonstrate worse clinical outcomes and higher mortality among patients with baseline grade III or IV TR.[5-7] More recently, case series have demonstrated the potential feasibility and safety of transcatheter tricuspid valve repair using the MitraClip system for severe symptomatic TR in inoperable patients on a compassionate use basis.[8-10] We present a case of double-valve mitral and tricuspid repair using the transcatheter edge-to-edge technique with emphasis on intraprocedural transesophageal echocardiographic guidance relevant to tricuspid valve intervention.

CASE PRESENTATION

An 83-year-old woman with biventricular dysfunction presented with dyspnea, orthopnea, and generalized anasarca in the setting of severe MR and TR. She had a history of coronary artery bypass surgery, transcatheter aortic valve replacement with a self-expanding prosthesis and subsequent pacemaker implantation, pulmonary hypertension, chronic atrial fibrillation on oral anticoagulation, type 2 diabetes, and stage 3 chronic kidney disease. She endorsed progressive New York Heart Association class IV symptoms requiring admission for acute decompensated heart failure. Her comorbidities, frailty, need for redo sternotomy, and calculated Society of Thoracic Surgeons mortality risk of 20% for mitral valve repair placed her at prohibitive surgical risk. Therefore, a decision was made by the heart team for percutaneous dual edge-to-edge valve repair.

Transthoracic echocardiography demonstrated moderate to severe (3+) MR due to mixed myxomatous thickening and functional tethering with effective regurgitant orifice area (EROA) of 0.33 cm^2, regurgitant volume of 62 mL/beat, and pulmonary vein systolic flow reversal (Figure 1, Video 1). There also was severe (4+) TR with vena contracta width of 0.68 cm, aliasing radius of 0.91 cm, and resultant EROA of 0.40 cm^2, hepatic vein systolic flow reversal, and plethoric inferior vena cava (Figure 2, Video 2). Her transcatheter bioprosthetic aortic valve was functioning normally with peak and mean gradients of 13 and 6 mm Hg, respectively. Both ventricles were dilated with reduced systolic function, with left ventricular ejection fraction of 36% and tricuspid annular plane systolic excursion of 1.3 cm. Right ventricular end-diastolic basal dimension measured 4.8 cm. Preprocedural transesophageal echocardiography confirmed these findings (Figure 3, Videos 3 and 4). The right ventricular pacemaker wire was situated between the posterior and septal leaflets, remote from the central TR jet, and therefore excluded leaflet impingement by the pacemaker wire as the predominant mechanism of TR.

Intraprocedural Imaging by Transesophageal Echocardiography

The transcatheter edge-to-edge technique for mitral valve repair has been discussed previously.[11] Transseptal access was obtained under transesophageal echocardiographic guidance, and one MitraClip was successfully placed, bringing together the A2-P2 scallops of the mitral valve, resulting in mild (1+) residual MR with resolution of pulmonary vein systolic flow reversal (Figure 4, Video 5). Attention was then turned to the tricuspid valve.

As with the mitral valve, preprocedural analysis of the tricuspid valve and localization of the regurgitant jet were performed using biplane imaging. A modified basal short-axis tricuspid inflow-outflow view (approximately midesophageal [ME] 60°–90°) visualizes the posterior and anterior leaflets, with the anterior leaflet adjacent to the aortic root and interatrial septum (Figure 5, Video 6). With the transducer aligned precisely along the commissures between the anterior-septal leaflets and the posterior-septal leaflets by adjusting the omniplane angle, a small central segment of the septal leaflet may be visible such that all three leaflets are visualized along the plane of the transducer, posterior-septal-anterior from left to right of the image. This is the tricuspid valve equivalent of the bicommissural view of the mitral valve, allowing the imager to precisely localize the regurgitant jet. Color Doppler identifies the region of regurgitant flow convergence by visualizing the proximal isovelocity surface area. The flow

From the Division of Cardiovascular Disease, Scripps Clinic, La Jolla, California.

Keywords: Transcatheter tricuspid valve repair, Tricuspid regurgitation, Mitral regurgitation, MitraClip, Interventional echocardiography

Conflict of interest: Dr. Bechis has received consulting fees from GE Healthcare. Dr. Rubenson has received consulting fees from GE Healthcare. Dr. Price has received honoraria from Abbott Vascular and Medtronic and speaking fees from Abbott Vascular.

2468-6441
https://doi.org/10.1016/j.case.2018.03.003

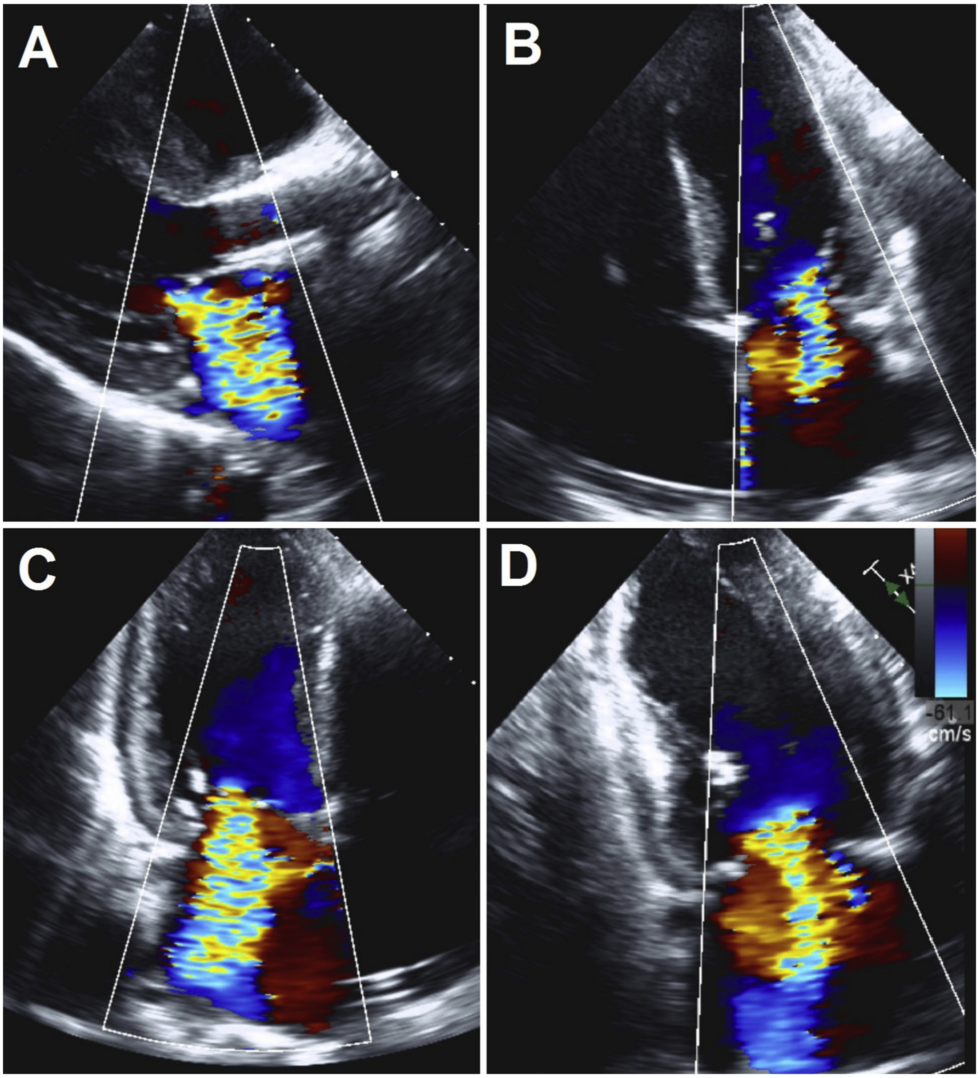

Figure 1 Moderate to severe (3+) MR as seen in **(A)** parasternal long-axis, **(B)** four-chamber, **(C)** three-chamber, and **(D)** two-chamber windows. Except where otherwise specified, the Nyquist range used for all color flow Doppler was ±55–66 cm/sec.

direction is also parallel to the transducer in this window such that the right ventricular systolic pressure and the gradient across the tricuspid valve can be measured using continuous-wave Doppler with reasonable confidence.

Biplane imaging of the tricuspid inflow, resulting in an inverted four-chamber view at approximately ME 150°–180°, visualizes the leaflets coapt in profile in a "grasping" view (Figure 5C, Video 6). With color Doppler on, the biplane cursor is swept from left to right of the inflow image, from posterior-septal to anterior-septal coaptation regions (Figure 6). Visualizing the proximal isovelocity surface area corresponds to the region of regurgitation flow convergence by which to target the intended grasp. Color Doppler is then removed to visualize the underlying leaflet anatomy to determine its suitability for clip grasp (i.e., adequate coaptation depth, lack of calcium on leaflet tips, location of pacemaker or defibrillator wire if present) before proceeding to edge-to-edge intervention.

Following clip deployment on the mitral valve, the guide catheter was withdrawn into the right atrium and steered toward the tricuspid valve in a modified bicaval view (approximately ME 80°–100°) transitioning to the tricuspid inflow view (ME 60°–90° as described above) for clip positioning. The clip is visualized above the leaflets and aligned over the regurgitant jet (Figure 7). Functional TR usually manifests as a large central jet, as was the case here. The clip is preferentially placed between the septal-anterior leaflets or, less commonly, the septal-posterior leaflets for the reason that tricuspid annular dilatation occurs outward in the direction of the lateral right ventricular free wall. In this case, the clip is aligned over the anterior-septal leaflets in the region of the regurgitant jet. The clip arms are visualized open in the biplane "grasping" view (four-chamber ME 0° or its right invert 160°–180°). The proper orientation of the clip perpendicular to the line of coaptation is confirmed in transgastric short-axis (approximately 30°) or by real-time three-dimensional imaging. When properly positioned and oriented, the clip is then lowered just below the leaflets into the right ventricle, taking care to avoid the chordal apparatus, and pulled up for leaflet grasp. As with the mitral valve, the presence of a tissue bridge, adequate leaflet insertion, and clip stability are

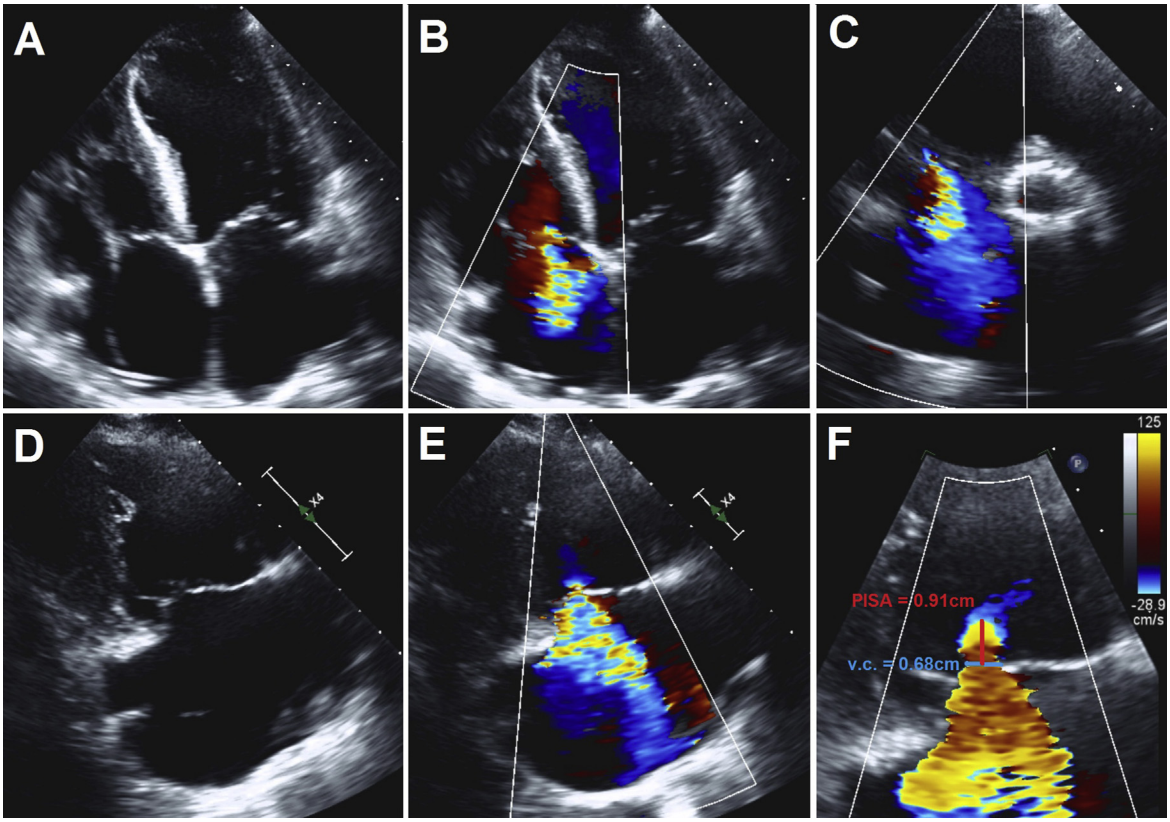

Figure 2 Severe (4+) TR as seen in **(A,B)** four-chamber, **(C)** basal short-axis, and **(D,E)** right ventricular inflow views. **(F)** The vena contracta (v.c.) and aliasing radius of flow convergence measured 0.68 and 0.91 cm, respectively, with calculated EROA of 0.40 cm^2, using an aliasing velocity of −28.9 cm/sec. *PISA*, Proximal isovelocity surface area.

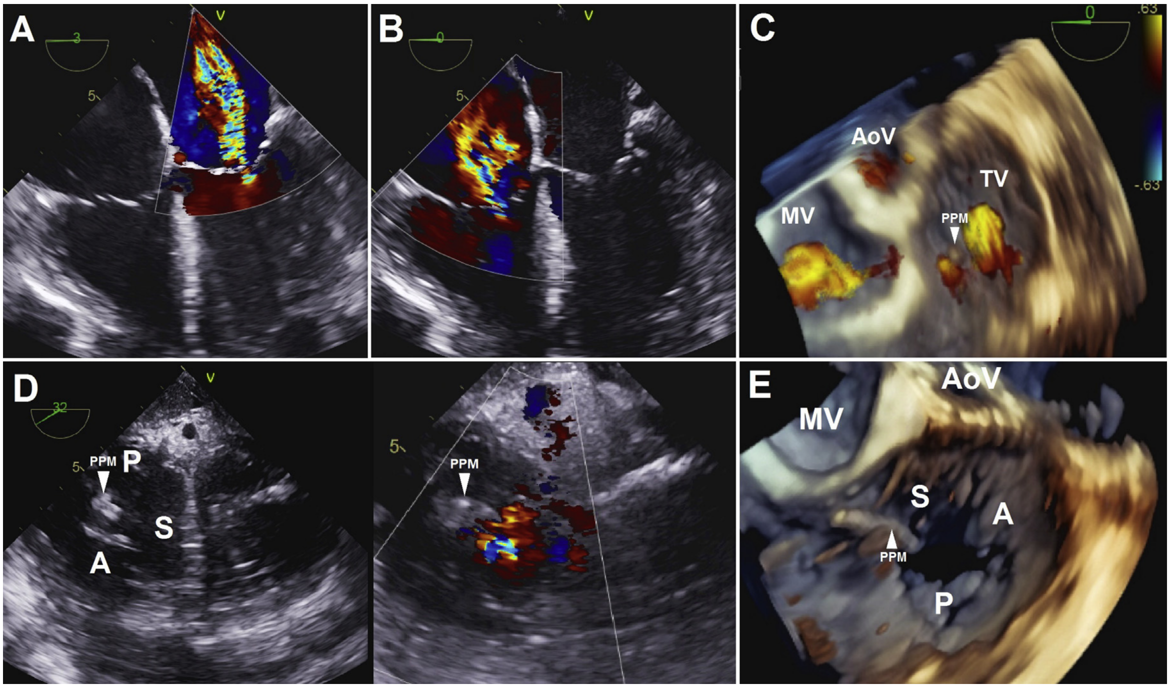

Figure 3 Baseline MR and TR as seen in **(A,B)** four-chamber and **(C)** three-dimensional views on transesophageal echocardiography. The leaflets of the tricuspid valve can be visualized en face **(D)** in transgastric short-axis window or **(E)** by three-dimensional imaging. The pacemaker wire (PPM; *white arrowhead*) can be seen between the posterior and septal leaflets **(D,E)** and appears to be discrete from the central TR jet **(C,D)**. *A*, Anterior; *AoV*, aortic valve; *MV*, mitral valve; *P*, posterior; *TV*, tricuspid valve; *S*, septal.

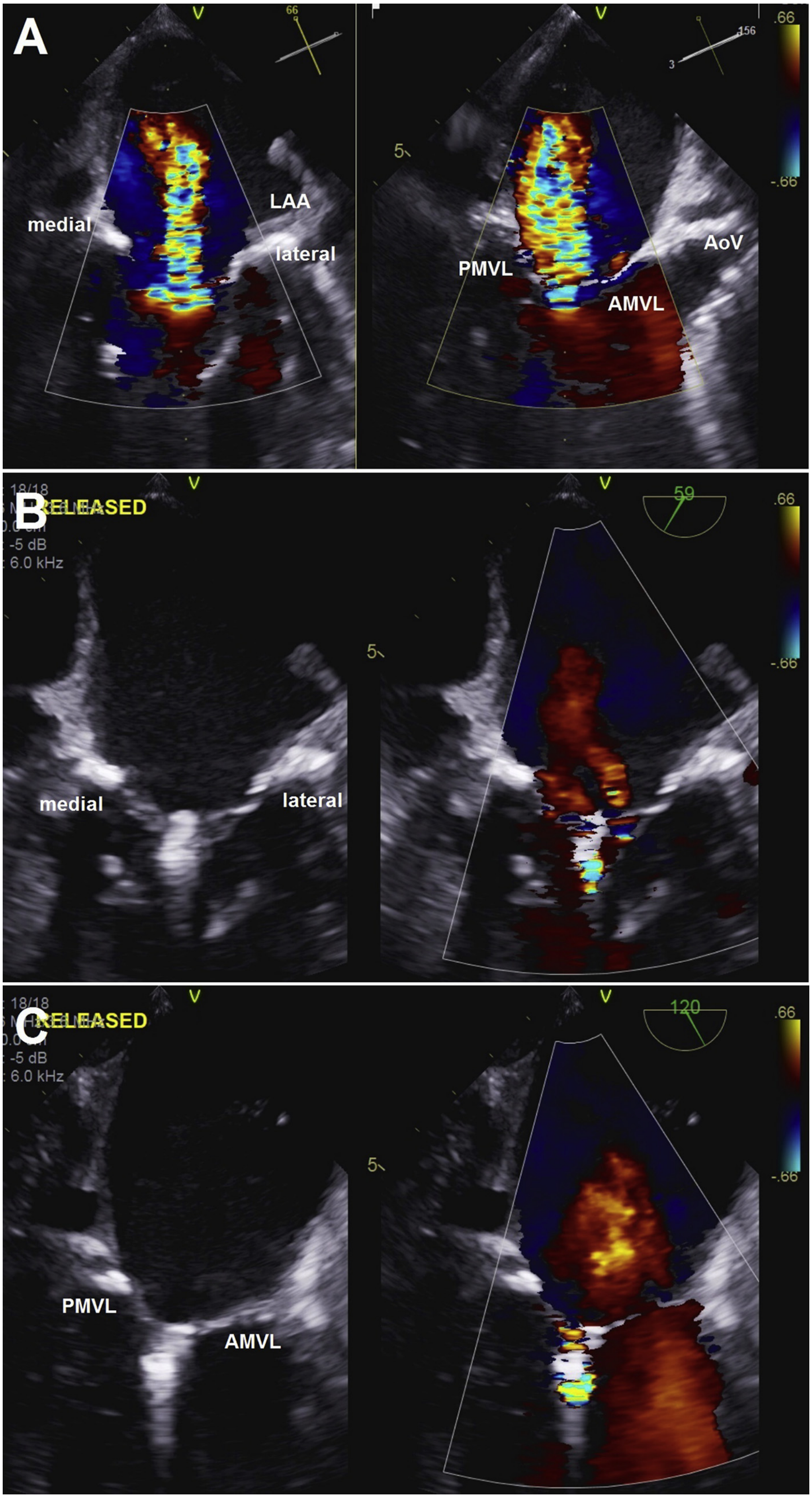

Figure 4 MR **(A)** before and **(B,C)** after successful MitraClip implantation on A2-P2 scallops. **(A)** Biplane imaging of the ME **(B)** bicommissural (approximately 60°) and **(C)** long-axis views (approximately 150°) are commonly used to visualize the mitral valve leaflet anatomy and successful edge-to-edge grasp of the leaflets. *AMVL*, Anterior mitral valve leaflet; *AoV*, aortic valve; *LAA*, left atrial appendage; *PMVL*, posterior mitral valve leaflet.

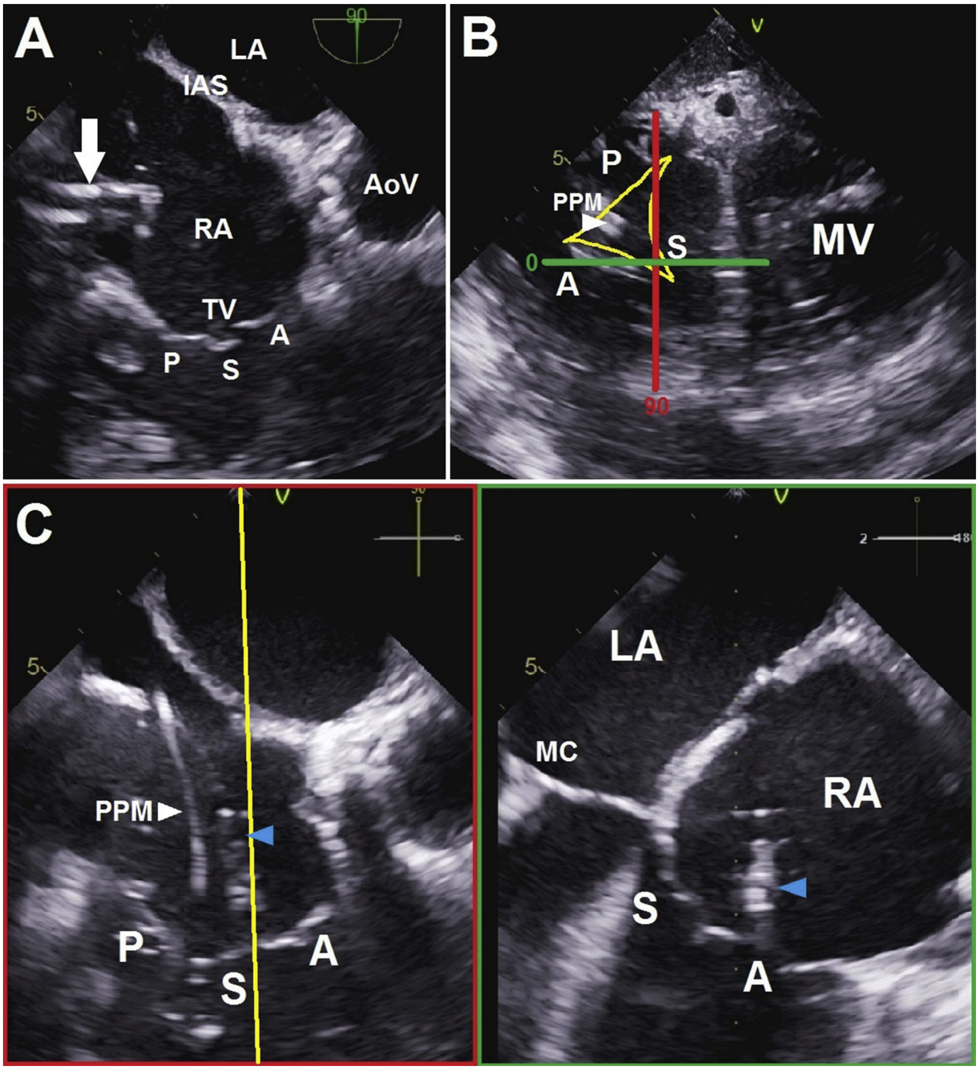

Figure 5 **(A)** The delivery catheter (*arrow*) in the right atrium is directed toward the tricuspid valve in a modified basal short-axis tricuspid inflow-outflow window (ME 90°, plane represented by the red line in panel **B**) that visualizes all three leaflets of the tricuspid valve, posterior-septal-anterior from left to right of the image. **(B,C)** Biplane imaging (*yellow line*) of the inflow view can visualize two of the leaflets in profile in an inverted four-chamber "grasping" view (ME 180°, plane represented by the green line in panel **B**). **(C)** The septal and anterior leaflets are seen here in profile with the clip apparatus (*blue arrowhead*) being maneuvered out of the delivery catheter toward its intended leaflets. The pacemaker wire (PPM; *white arrowhead*) can be seen between the posterior and septal leaflets on the inflow view. *A*, Anterior; *AoV*, aortic valve; *IAS*, interatrial septum; *LA*, left atrium; *MC*, MitraClip; *MV*, mitral valve; *P*, posterior; *RA*, right atrium; *TV*, tricuspid valve; *S*, septal.

confirmed in multiple views and with real-time three-dimensional imaging (Figure 7, Videos 7 and 8). Transtricuspid gradient is obtained using continuous-wave Doppler to avoid significant tricuspid stenosis, defined as <5 mm Hg for native valves.[12]

In this patient, one clip was successfully placed in the tricuspid position between the anterior and septal leaflets to avoid impingement of the pacemaker wire that remained within the posteroseptal commissure (Figure 8, Video 9). A two-grade reduction in TR grade from severe (4+) to moderate (2+) was achieved (Video 10), with resolution of hepatic vein systolic flow reversal. The mean transtricuspid gradient after edge-to-edge repair was 2.0 mm Hg at a heart rate of 70 beats/min. Successful edge-to-edge repair of both valves was confirmed by three-dimensional visualization of double double-orifice valves (Figure 9, Video 11).

Bidirectional flow at the interatrial transseptal puncture site was noted at the time of retracting the catheter into the right atrium. However, the iatrogenic atrial septal defect was not closed at that point in the procedure in order to minimize the risk for the septal closure device to interact with the delivery catheter and clip apparatus during the maneuvers. Furthermore, in some cases, alleviation of TR may adequately improve the right atrial pressures to resolve the bidirectional shunt. Conversely, earlier closure of the shunt may be necessitated by intraprocedural desaturation due to right-to-left shunting. For this patient with long-standing pulmonary hypertension and right ventricular dysfunction, bidirectional shunting persisted despite the reduction in TR (Figure 10, Video 12). Her iatrogenic atrial septal defect was successfully closed using a 20-mm Cardioform Septal Occluder

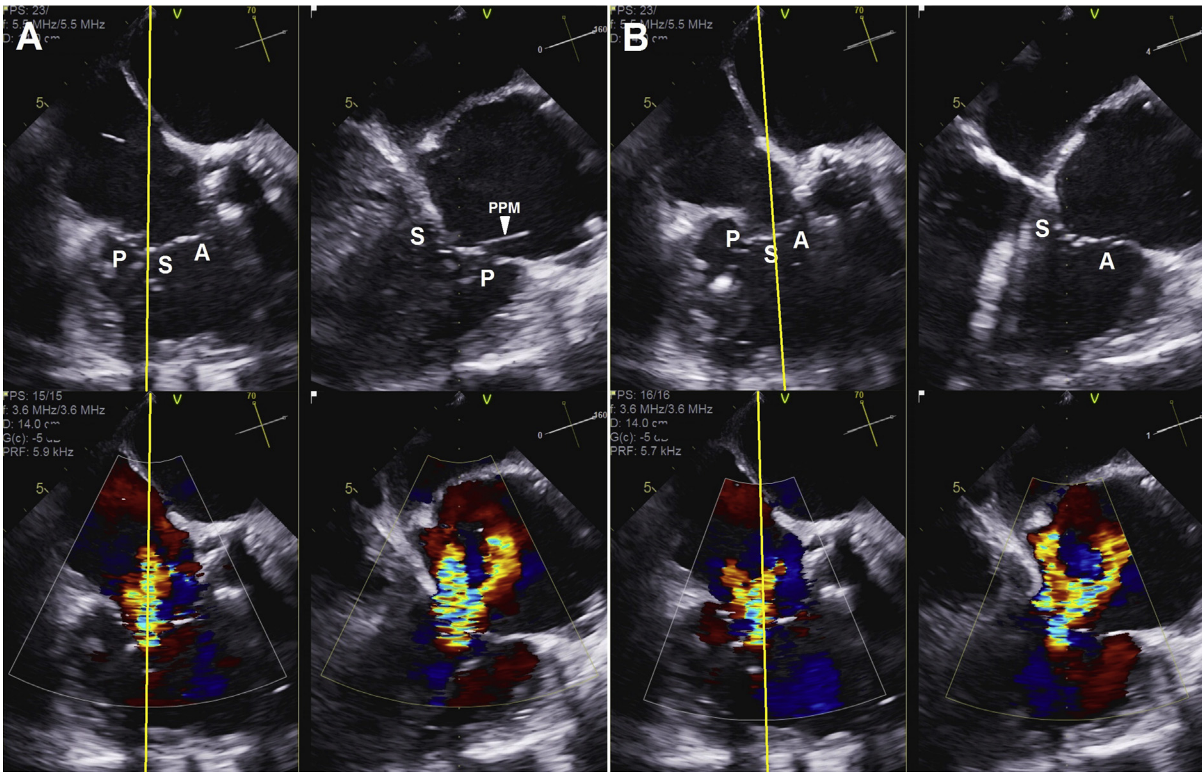

Figure 6 Biplane imaging of the inflow view identifies the predominant regurgitant jet by color Doppler and visualizes the underlying leaflet anatomy in the perpendicular "grasping" view. The **(A)** posterior-septal leaflet and **(B)** septal-anterior leaflet coaptation planes demonstrate the central TR jet seen at both commissures and the pacemaker wire (PPM; *white arrowhead*) between the posterior-septal commissure. *A*, Anterior; *P*, posterior; *PPM*, pacemaker; *S*, septal.

(W.L. Gore & Associates, Flagstaff, AZ) with no residual shunt seen on color Doppler (Figure 10).

DISCUSSION

TR is an independent predictor of morbidity and mortality after successful surgical or percutaneous repair of concomitant mitral valve disease.[1-3,5-7] The majority of TR is functional in etiology and secondary to annular dilatation and malcoaptation. Therefore, tricuspid annuloplasty ring is the most common surgical repair for TR at the time of left-sided surgery. Isolated tricuspid valve surgery for recurrent or persistent TR carries high operative risk with uncertain benefit.[13]

A number of transcatheter techniques for treatment of functional TR are under development, most by correcting malcoaptation or annular dilatation.[14] Several challenges are unique to the tricuspid valve and require particular consideration in the design of transcatheter systems, among them the large size of the tricuspid annulus, the angulation of the valve from the inferior and superior vena cava access points, the thin right ventricular free wall, the abundant trabeculation and subchordal apparatus, and the presence of any right-sided leads or catheters. The right atrium needs to be of adequate size to accommodate the transcatheter devices and maneuvers. Annuloplasty devices must take caution to avoid the adjacent right coronary artery. Adequate leaflet coaptation for edge-to-edge techniques may require a combination of preprocedural diuresis and intraprocedural maneuvers, such as a gentle constant precordial pressure to maximize leaflet contact.

The tricuspid valve also poses new imaging challenges in its large nonplanar annulus, thin leaflets, and the anatomic variability of its leaflets for intervention. Nonstandard echocardiographic windows may be necessary to adequately visualize the valve structure. Sweeps across the valve while adjusting the probe depth or rotation can help demonstrate leaflet relationships, with the coronary sinus as a commonly used marker for the posterior leaflet. For the edge-to-edge technique described above, the regurgitant jet location and subsequent leaflet grasp were viewed from multiple imaging planes, most important the modified basal short-axis tricuspid inflow view (ME 60°–90°), the four-chamber "grasping" view of the leaflets in profile (ME 0°–20° or 160°–180°), and the short-axis (transgastric 30°) and three-dimensional en face views.

Quantification of right ventricular size and function and the presence and severity of pulmonary hypertension is critical for patient selection, as is standardized quantitative grading of TR to assess and compare postprocedural results.[15,16] As demonstrated in this case and in prior case series,[8] the quantitative reduction in TR may be relatively modest (one- to two-grade reduction, often with residual moderate TR) but can nevertheless result in significant clinical improvement. The durability of these recent results is unknown and warrants further investigation.

CONCLUSION

We report a case of successful dual-valve transcatheter repair using the edge-to-edge technique in a patient with symptomatic biventricular heart failure with mixed mitral and tricuspid valve regurgitation.

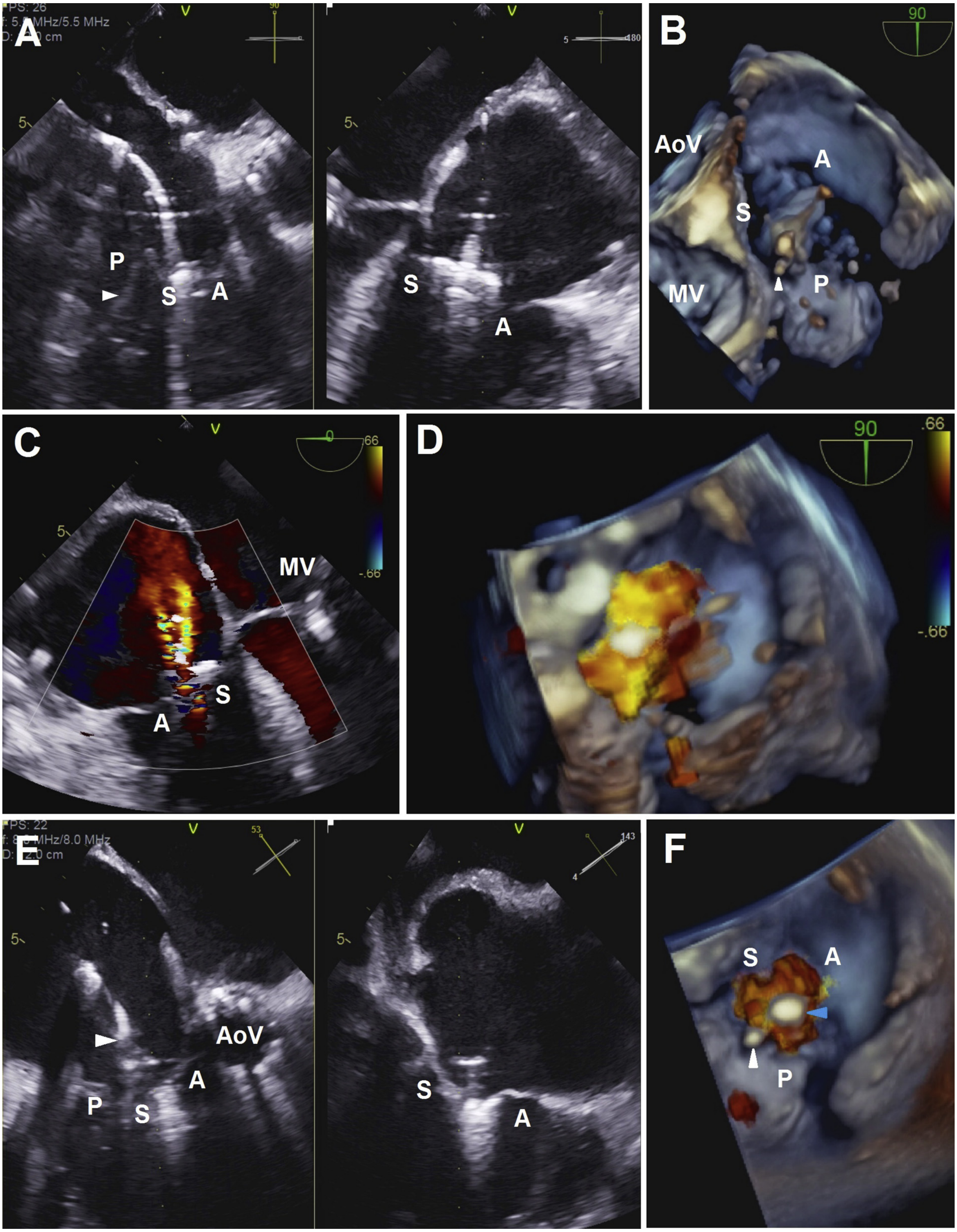

Figure 7 The clip is opened above the anterior and septal leaflets and oriented perpendicular to the coaptation line as seen in **(A)** biplane and **(B)** three-dimensional (3D) images. The pacemaker wire (*white arrowhead*) can be seen in 3D images moving to one side of the clip and does not appear to be entangled in the clip apparatus. The clip is positioned over the regurgitant jet, seen here in **(C)** four-chamber and **(D)** 3D views. **(E)** Successful grasp of the anterior and septal leaflets is confirmed in the inverted four-chamber view. **(F)** The presence of a tissue bridge can be visualized in 3D view. The pacemaker wire (*white arrowhead*) can be seen moving freely adjacent to the clip (*blue arrowhead*). *A*, Anterior; *AoV*, aortic valve; *MV*, mitral valve; *P*, posterior; *S*, septal.

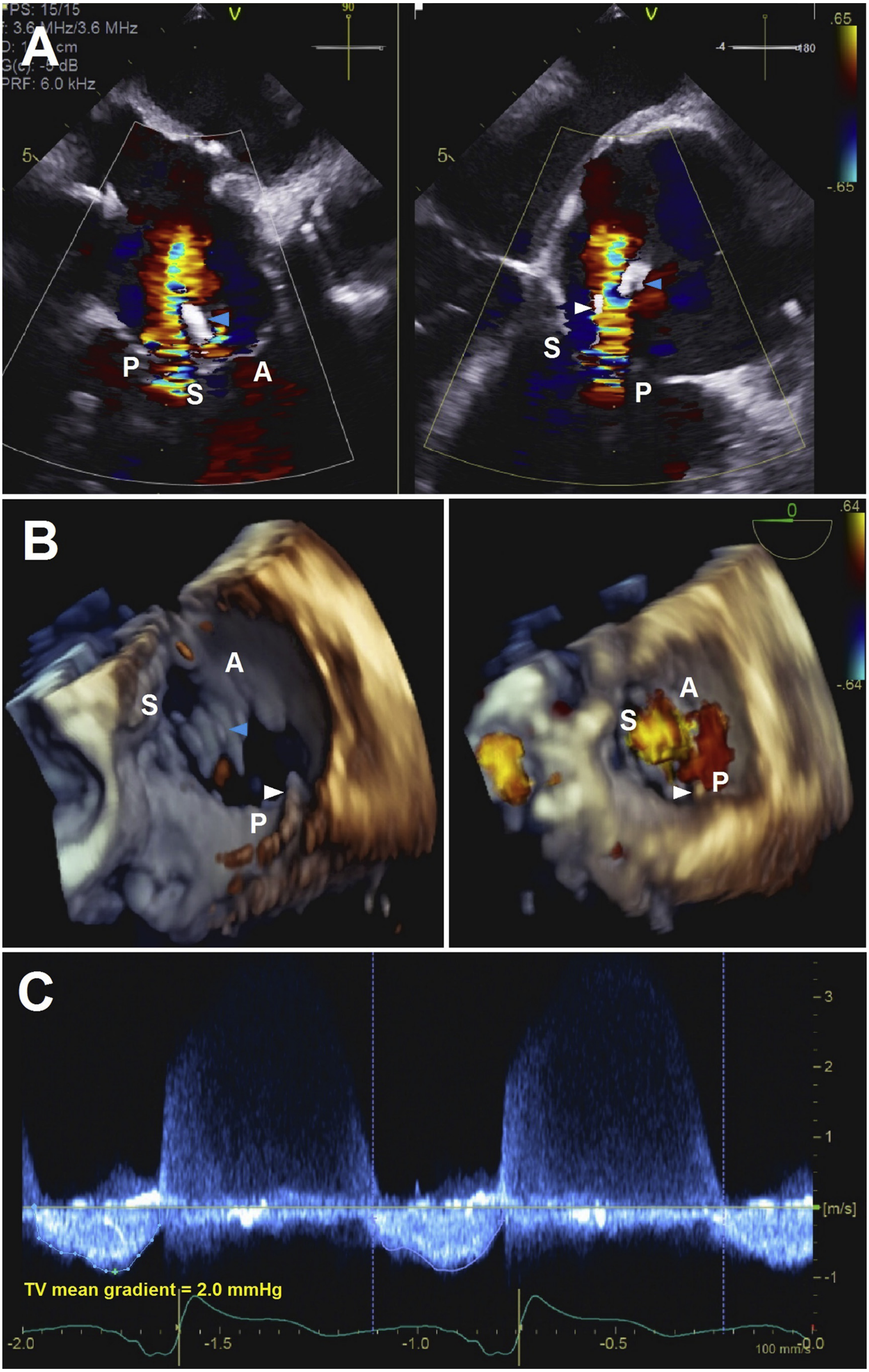

Figure 8 **(A)** One MitraClip was successfully implanted in the tricuspid position between the anterior and septal leaflets with moderate (2+) residual TR. **(B)** The double-orifice valve with tissue bridge is visualized in three-dimensional images with and without color Doppler flow in systole and diastole, respectively. The pacemaker wire (*white arrowhead*) is seen in the posterior orifice, unrestricted by the clip (*blue arrowhead*). **(C)** Mean transtricuspid gradient of 2.0 mm Hg is acceptable. *A*, Anterior; *P*, posterior; *S*, septal; *TV*, tricuspid valve.

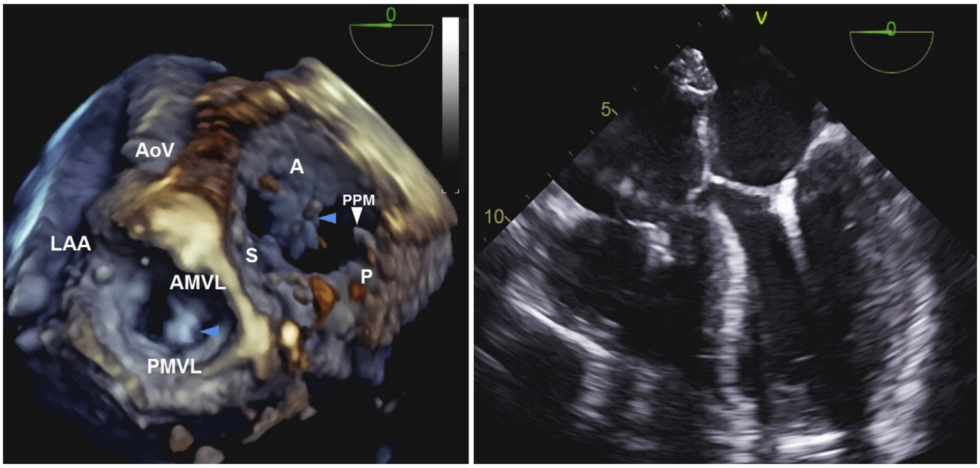

Figure 9 Two double-orifice valves are visualized in three-dimensional images, and clip stability is confirmed in the four-chamber view. The clips (*blue arrowheads*) can be seen separate from the pacemaker wire (PPM; *white arrowhead*), which remains within the posterior-septal commissure. *A*, Anterior; *AMVL*, anterior mitral valve leaflet; *AoV*, aortic valve; *LAA*, left atrial appendage; *P*, posterior; *PMVL*, posterior mitral valve leaflet; *S*, septal.

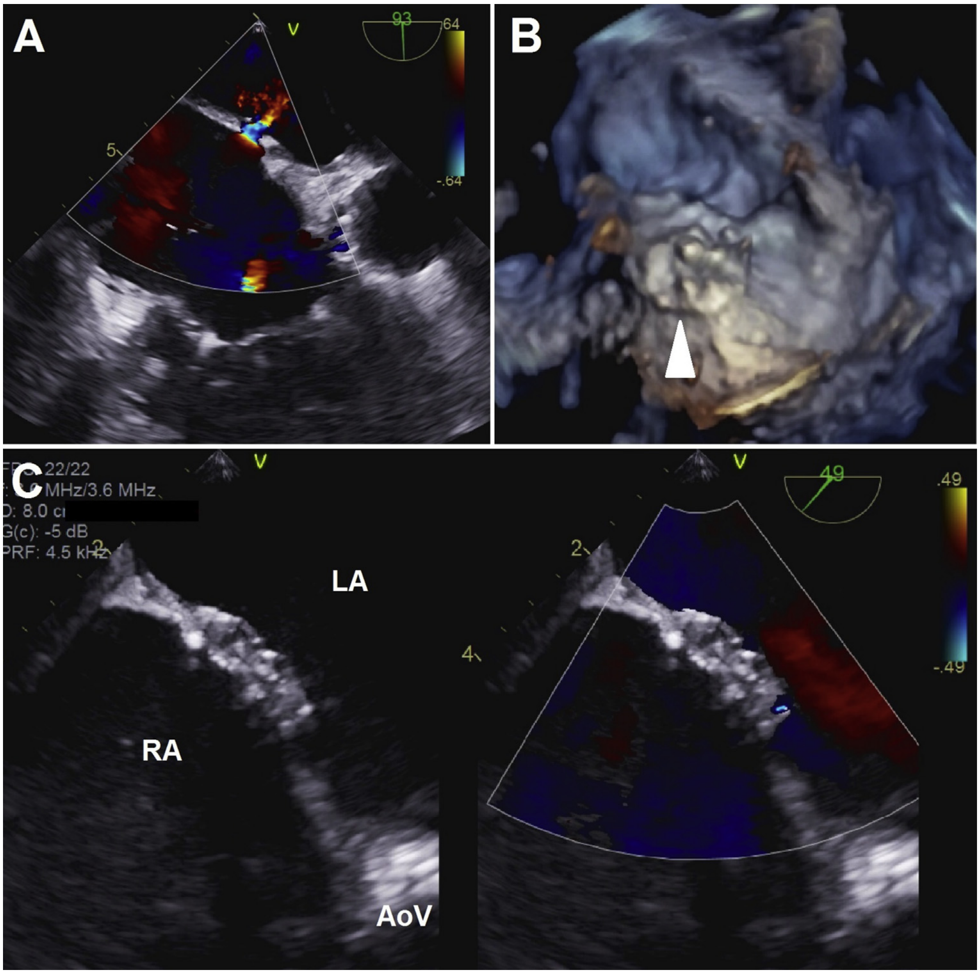

Figure 10 **(A)** Bidirectional shunting is noted at the interatrial site of transseptal puncture in this patient with long-standing pulmonary hypertension and known right ventricular dysfunction. A Cardioform Septal Occluder successfully closed the iatrogenic atrial septal defect, seen here in **(B)** three-dimensional view from the left atrial aspect (*white arrowhead*) and **(C)** in basal short-axis view with and without color Doppler. *AoV*, Aortic valve; *LA*, left atrium; *RA*, right atrium.

A two-grade reduction was achieved in both MR and TR, with evidence of immediate hemodynamic and symptomatic improvement. This case demonstrates the safe and successful application of the edge-to-edge technique in transcatheter repair of the tricuspid valve. Further study is needed to inform patient selection, optimize technique, and assess long-term outcomes.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at https://doi.org/10.1016/j.case.2018.03.003.

REFERENCES

1. Nath J, Foster E, Heidenreich PA. Impact of tricuspid regurgitation on long-term survival. J Am Coll Cardiol 2004;43:405-9.
2. Matsunaga A, Duran CM. Progression of tricuspid regurgitation after repaired functional ischemic mitral regurgitation. Circulation 2005;112:I453-7.
3. Shiran A, Sagie A. Tricuspid regurgitation in mitral valve disease incidence, prognostic implications, mechanism, and management. J Am Coll Cardiol 2009;53:401-8.
4. Nishimura RA, Otto CM, Bonow RO, Carabello BA, Erwin JP III, Guyton RA, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association task force on practice guidelines. J Am Coll Cardiol 2014;63:e57-185.
5. Ohno Y, Attizzani GF, Capodanno D, Cannata S, Dipasqua F, Immé S, et al. Association of tricuspid regurgitation with clinical and echocardiographic outcomes after percutaneous mitral valve repair with the MitraClip system: 30-day and 12-month follow-up from the GRASP registry. Eur Heart J Cardiovasc Imaging 2014;15:1246-55.
6. Schueler R, Öztürk C, Sinning JM, Werner N, Welz A, Hammerstingl C, et al. Impact of baseline tricuspid regurgitation on long-term clinical outcomes and survival after interventional edge-to-edge repair for mitral regurgitation. Clin Res Cardiol 2017;106:350-8.
7. Kalbacher D, Schäfer U, von Bardeleben RS, Zuern CS, Bekeredjian R, Ouarrak T, et al. Impact of tricuspid valve regurgitation in surgical high-risk patients undergoing MitraClip implantation: results from the TRAMI registry. EuroIntervention 2017;12:e1809-16.
8. Nickenig G, Kowalski M, Hausleiter J, Braun D, Schofer J, Yzeiraj E, et al. Transcatheter treatment of severe tricuspid regurgitation with the edge-to-edge MitraClip technique. Circulation 2017;135:1802-14.
9. Hammerstingl C, Schueler R, Malasa M, Werner N, Nickenig G. Transcatheter treatment of severe tricuspid regurgitation with the MitraClip system. Eur Heart J 2016;37:849-53.
10. Schofer J, Tiburtius C, Hammerstingl C, Dickhaut PO, Witt J, Hansen L, et al. Transfemoral tricuspid valve repair using a percutaneous mitral valve repair system. J Am Coll Cardiol 2016;67:889-90.
11. Feldman T, Foster E, Glower DD, Kar S, Rinaldi MJ, Fail PS, et al. Percutaneous repair or surgery for mitral regurgitation. N Engl J Med 2011;364:1395-406.
12. Baumgartner H, Hung J, Bermejo J, Chambers JB, Evangelista A, Griffin BP, et al. Echocardiographic assessment of valve stenosis: EAE/ASE recommendations for clinical practice. J Am Soc Echocardiogr 2009;22:1-23.
13. Rogers JH, Bolling SF. The tricuspid valve: current perspective and evolving management of tricuspid regurgitation. Circulation 2009;119:2718-25.
14. Rodés-Cabau J, Hahn RT, Latib A, Laule M, Lauten A, Maisano F, et al. Transcatheter therapies for treating tricuspid regurgitation. J Am Coll Cardiol 2016;67:1829-45.
15. Rudski LG, Lai WW, Afilalo J, Hua L, Handschumacher MD, Chandrasekaran K, et al. Guidelines for the echocardiographic assessment of the right heart in adults: a report from the American Society of Echocardiography endorsed by the European Association of Echocardiography, a registered branch of the European Society of Cardiology, and the Canadian Society of Echocardiography. J Am Soc Echocardiogr 2010;23:685-713.
16. Zoghbi WA, Adams D, Bonow RO, Enriquez-Sarano M, Foster E, Grayburn PA, et al. Recommendations for noninvasive evaluation of native valvular regurgitation: a report from the American Society of Echocardiography developed in collaboration with the Society for Cardiovascular Magnetic Resonance. J Am Soc Echocardiogr 2017;30:303-71.