

Chapter 26: Step-by-step guide: Percutaneous Mitral Valve Edge-to-edge Repair (MitraClip, Abbott Vascular, Santa Clara, CA)

Amy Gin, MD, Ramon Partida, MD, Sammy Elmariah, MD, MPH, Rahul Sakhuja, MD, MPP, MSc
Cardiovascular Division, Massachusetts General Hospital, Boston, MA

Essential or Key Steps

- Transthoracic (TTE) and transesophageal echocardiography (TEE) to determine severity and mechanism of mitral regurgitation, respectively
- Multidisciplinary Heart Team evaluation to confirm patient candidacy for percutaneous mitral valve edge to edge repair and anatomic feasibility of clip placement
- Vascular Access
- Transseptal puncture
- Sheath and clip preparation
- Sheath and clip delivery
- Clip alignment and placement
- Leaflet capture
- Assessment of leaflet capture by TEE
- Clip deployment and release
- Post-deployment assessment and consideration of additional clip placement
- Guide removal
- Vascular closure

Pearls and pitfalls

- Use TTE to determine severity of mitral regurgitation (MR) and TEE to determine mechanism of MR and feasibility for use of MitraClip.
- Consider using ultrasound guidance and micropuncture for initial venous access
- Optimal transseptal puncture is mid-fossa, posterior, and 4.0-4.5 cm height above MR *pathology* moreso than annulus facilitates clip delivery; therefore, height would be higher for patients with prolapse/flail where MR originates above annulus.
- Use of a radiofrequency needle may be useful in cases with difficult transseptal access, such as thickened, aneurysmal, or fibrotic septa. When using the radiofrequency transseptal needle along with TEE guidance, we routinely administer low dose anticoagulation (2500-3000 IU IV heparin) prior to septal puncture, given reports of thrombus formation at the needle tip with radiofrequency energy delivery and low risk of transseptal puncture under TEE visualization
- Once left atrial access is obtained, intravenous unfractionated heparin is administered for a goal activated clotting time of greater than 250 seconds for the duration of the procedure.
- Intraoperative TEE imaging is essential for multiple procedural steps, including transseptal puncture, clip placement and alignment, assessment of leaflet capture, and determining need for additional clips. Clear and frequent communication between the operator and the echocardiographer is crucial.
- Dilating venotomy with 20/22F dilators can facilitate insertion of 24F sheath

- Consider using with Bayliss (or Inoue) nitinol wire in the left atrium or 0.035” stiff wire into the left upper pulmonary vein to deliver 24F sheath
- Always visualize the tip of all devices in left atrium – e.g. sheath, MitraClip – to avoid complications
- Bring MitraClip close to mitral valve prior to opening clip arms and adjusting orientation.
- Orient MitraClip by 3D en-face view on TEE. When oriented properly, clip arms should be fully visualized in 2D LVOT view and no clip arms should be visualized in the TEE intercommissural view
- If placing MitraClip close to commissures, slowly advance the MitraClip across the valve very shallow in the left ventricle and avoid rotating MitraClip to minimize risk for chordal entanglement
- If MitraClip gets entangled in the subchordal apparatus, reverse most recent adjustments to the MitraClip (e.g. if clocked the MitraClip, then counterclock to try to free)
- Visualize leaflet capture when dropping grippers. Take time to confirm leaflet capture in multiple views, including LVOT, 3D, and/or transgastric
- For patients with prominent flail or prolapse, leaflet capture may be facilitated by holding ventilation and rapid pacing to minimize movement
- If leaflets get caught on grippers, cycle the grippers multiple times to try to free leaflet
- When deploying additional MitraClips, it is always a tradeoff between reduction of mitral regurgitation and increase in mitral valve gradient. Sometimes moving a 2nd MitraClip slightly can change both MR and/or gradient
- Goal should be maximal reduction in mitral regurgitation that mitral valve gradient can tolerate; use as many MitraClips as needed to achieve this
- Closing atrial septal defect may be useful in patients with concomitant severe RV dysfunction
- Vascular closure can be accomplished with use of Perclose percutaneous suture closure devices in “preclose” technique or “Figure-of-8” suture in addition to manual compression and protamine administration. For the Perclose sutures, be sure to dissect through the soft tissue to the top avoid deploying sutures in the soft tissue with inadequate closure of the venotomy.

Indications and Patient Selection

Some of the earliest experience in the percutaneous treatment of mitral valvular disease includes the treatment of mitral regurgitation (MR) with the use of the MitraClip system (Abbott Vascular, Santa Clara, CA). The MitraClip (clip) aims to reproduce the edge-to-edge leaflet repair used in the Alfieri surgical technique. The device consists of a 4 mm wide cobalt-chromium implant with two arms that are opened and closed with a delivery system to grasp and approximate the mitral leaflets. It is implanted percutaneously via a transseptal approach under general anesthesia with guidance by both transesophageal echocardiography (TEE) and fluoroscopy.

While less effective at reducing MR severity than traditional surgical approaches, percutaneous intervention with the MitraClip was found to be associated with a more favorable safety profile, as well as similar improvements in functional status, quality of life, and left ventricular size at 12 months in the randomized Endovascular Valve Edge-to-Edge Repair Study (EVEREST II)¹. The results of this study

and subsequent follow up led to FDA approval for MitraClip in 2013 for use in patients with primary mitral regurgitation that are at prohibitive surgical risk. The 5-year results from the EVEREST II trial, in addition to data from multiple post-approval registries, confirmed the findings of EVEREST II and demonstrated the long-term durability of mitral valve repair with the MitraClip²⁻⁵. Long-term results of the EVEREST II trial showed sustained left ventricular remodeling (decrease in left ventricular end-diastolic dimensions) up to 5 years post-MitraClip placement despite more residual mitral regurgitation than with mitral valve surgery; additionally, after 6 months there was no significant difference between the rates of death or re-operation for mitral valve pathology between patients randomized to MitraClip versus mitral valve surgery². Moreover, even in patients with reduction to 2+ MR or less with MitraClip, there is similar improvement in symptoms when compared with greater reduction in MR from surgical intervention. Based on these data, more than 30,000 patients have been treated in the United States and Europe to date.

The MitraClip device is currently indicated for the treatment of significant ($\geq 3+$) symptomatic MR due to primary (degenerative) mitral valvular pathology in patients who are deemed prohibitive risk for mitral valve surgery by a multidisciplinary Heart Team. Transthoracic echo (TTE) is used to grade the severity of MR. TEE has become standard in the pre-procedure assessment of the mitral valve pathology and mechanism of mitral regurgitation. Key anatomic considerations that have been correlated with optimal post-procedure results include: pre-procedure mitral valve area ≥ 4.0 cm²; a non-commissural regurgitant jet; absence of calcification or leaflet cleft in the grasping area; and a flail gap of <10 mm or flail width of <15 mm. The MitraClip is being studied for use in secondary (functional) mitral valve regurgitation through the currently enrolling Cardiovascular Outcomes Assessment of the MitraClip Percutaneous Therapy for Heart Failure Patients with Functional Mitral Regurgitation (COAPT Trial).

Heart Team Evaluation

When evaluating a patient for potential percutaneous mitral valve repair, evaluation by a multidisciplinary Heart Team should be performed (AHA/ACC 2014 guidelines class I recommendation)⁶. The Heart Team should consist of a cardiac surgeon with significant experience in mitral valve surgery, a cardiologist experienced in mitral valvular disease, and other health professionals who can ensure optimal heart failure treatment and suitability of valve anatomy for this technique. The purpose of the multidisciplinary Heart Team includes confirming surgical risk (e.g. STS risk estimate, measures of frailty), identifying other patient factors that may preclude surgical candidacy that are not captured in conventional risk scores, as well as assessing the likelihood of procedural success and patient benefit.

Procedural Steps

Once a patient has been deemed an appropriate candidate for percutaneous mitral valve edge-to-edge repair based on multidisciplinary Heart Team evaluation, the procedure is divided into 4 main steps: 1) vascular access, 2) transseptal puncture, 3) MitraClip implantation, and 4) vascular access closure.

The procedure is performed under general anesthesia with both fluoroscopic and TEE guidance. TEE is the primary tool used to guide the procedure. The majority of patients are extubated at the conclusion of

the procedure unless extenuating circumstances (e.g. severe lung disease or decompensated heart failure) require prolonged mechanical ventilation at the discretion of the heart team, including the cardiac anesthesiologist.

Access

Vascular access is preferentially obtained in the right common femoral vein per standard practice for transseptal catheterization. We aim to obtain vascular access over the mid femoral head as identified by fluoroscopy. Our default approach is to perform percutaneous femoral venous access under ultrasound guidance using a micro-puncture access needle and 4 French micro-puncture sheath. Ideal venous puncture can be confirmed by visualizing the transition between the micropuncture needle and wire over the femoral head as shown in Figure 1. The 4 French sheath is exchanged for a 6 French introducer, followed by deployment of 2 suture-mediated closure devices (Perclose ProGlide, Abbott Laboratories, Abbott Park, IL) oriented perpendicularly from one another (often deploying the suture at 10 o'clock and 2 o'clock if the patient's head is associated with 12 o'clock) (Figure 2). Given venous access, there is minimal back-bleeding through the device, and sutures have to be deployed largely based on feel. The deployed Perclose sutures are secured without tightening or locking. The vascular access is then upsized as needed to maintain hemostasis (often requiring 8F sheath). On completion of the procedure, the two Perclose sutures can be tightened and locked per protocol to achieve hemostasis. We perform the tightening of the Perclose devices over a wire in order to maintain vascular access if necessary. This method is termed the "Pre-Close technique."

Transseptal Puncture

Following vascular access, left atrial access is obtained via transseptal puncture. Our default approach includes the use of both fluoroscopic and TEE guidance to perform the transseptal puncture. Optimal puncture location along the interatrial septum (IAS) is critical to the probability of technical success. An ideal transseptal puncture is located posteriorly and superiorly across the IAS. Figure 3 shows a representative TEE view of an optimal transseptal puncture location, approximately 4.0-4.5 cm above the mitral annulus. The puncture height can be measured relative to the level of the pathology, which is often more ventricular or "lower" than the annulus in functional patients and more atrial or "higher" than the annulus in patients with mitral valve prolapse.

To perform the transseptal puncture, a transseptal sheath and dilator (e.g. 8F Mullins, SL1, SL2 sheaths) are positioned in the superior vena cava over a 0.035 inch J-tipped guidewire. The guidewire is then removed and exchanged for a transseptal needle. We favor using a radiofrequency NRG® transseptal needle (Baylis Medical, Montreal, Quebec, Canada), which is advanced to the tip of the dilator in preparation for puncture. Alternatively, a Brockenbrough needle is commonly used. The sheath, dilator, and needle are manipulated together to the desired IAS location. Once optimal position is confirmed by TEE, the system is advanced into the left atrium (using a radiofrequency pulse with the Baylis system). Position in the left atrium is confirmed by TEE, fluoroscopy, and left atrial pressure tracing. Following confirmation of position, the needle is fixed and the sheath and dilator are advanced slightly and carefully, avoiding the posterior wall of the left atrium. Finally, the sheath is advanced over the needle and dilator. The dilator and needle are subsequently removed, leaving the sheath in place within the left atrium.

The use of a radiofrequency needle rather than a traditional stainless steel Brockenbrough needle (Medtronic, Minneapolis, MN) allows for more controlled crossing of the IAS and requires less mechanical force. This is particularly useful in difficult transseptal access cases, such as those with thickened, aneurysmal, or fibrotic septa⁷. When using the radiofrequency needle system, our practice is to administer low dose anticoagulation (e.g. 2000-4000 units of unfractionated heparin) prior to IAS puncture, given reports of thrombus formation at the needle tip with radiofrequency energy delivery and puncture, taking into account the additional safety provided when using TEE guidance.

Once acceptable left atrial access is obtained, the patient is fully anticoagulated with additional intravenous unfractionated heparin for a total of at least 100 units per kilogram for a goal activated clotting time of greater than 250 seconds.

Transseptal techniques for structural heart interventions are reviewed elsewhere in more detail⁷.

Sheath and Clip Preparation

Following successful transseptal access, the steerable delivery guide catheter and clip delivery system (CDS) are inspected and prepped (see Figure 4). The outer diameter of the delivery guide catheter is 24 French (8.1mm) with an 800mm working length. The steerable guide catheter is de-aired and knob function is tested outside of the body in a systematic fashion. Similarly, the CDS is de-aired, and knob and MitraClip functionality are tested outside the body. Heparinized saline flush lines are connected to the MitraClip system and kept running throughout the duration of the procedure in order to minimize the risk of air embolism. We assign one person to monitor and maintain the pressure bags and flush lines full of saline so that no air is introduced into the system. When the MitraClip is being introduced into the sheath or deployed, we increase the rate of saline infusion; otherwise, we maintain a slow constant flow of saline to avoid volume overload.

Sheath and Clip Delivery

Delivery of the steerable guide catheter into the left atrium requires the use of a supportive guidewire. One approach is to place a 0.035 inch Amplatz Super Stiff guidewire of 260 cm length (Boston Scientific, Marlborough, MA) in the left upper pulmonary vein using a 5F multipurpose catheter.

Alternatively, when delivery of a multipurpose catheter and heavy wire into the LUPV proves difficult, it is possible to deliver the steerable guide catheter into the left atrium over a ProTrack Pigtail Wire (Baylis, Montreal, Quebec, Canada) with the flexible spiral tip positioned in the body of the left atrium.

It can be helpful to dilate the venotomy with a 20 and/or 22 French dilator (Cook Endovascular Dilator Set, Cook Medical, Bloomington, IN). The steerable guide catheter and dilator are advanced as a unit over the guidewire under fluoroscopic guidance. On initial skin and vessel entry, the +/- knob is turned to straighten the unit, and then returned to the neutral position once positioned in the right atrium.

Under fluoroscopic and TEE guidance, the dilator and guide are then oriented towards the left atrium fluoroscopically, and advanced over the wire approximately 1-2 cm into the left atrium. The dilator is withdrawn into the sheath to assist the echocardiographer in identifying the tip of the delivery guide. Once identified, the wire and dilator are then removed, taking care to aspirate the guide to prevent entrainment of air.

Once the steerable guide catheter is positioned in the left atrium, the MitraClip is introduced through the guide taking care to line up the Alignment Marker on the steerable guide catheter with the Alignment Marker on the CDS. This ensures that the knobs deflect the CDS in the intended direction. The CDS is then advanced under fluoroscopic guidance so that the tip of the clip is in line with the tip of the guide catheter in the left atrium.

Intraprocedural TEE Guidance and Imaging

The importance of TEE imaging during the MitraClip procedure cannot be overemphasized. TEE imaging for the MitraClip procedure is discussed separately in a dedicated chapter. Transseptal puncture, device positioning, and leaflet capture all must be confirmed by TEE as fluoroscopy alone is inadequate. Certain TEE views are especially important, including the 0-degree and left ventricular outflow tract (LVOT) (120-150-degrees) for anterior-posterior positioning and leaflet grasping, intercommissural view (60-90-degrees) for medial-lateral positioning, and the 3-D en-face view to orient the MitraClip and confirm the appearance of a double-orifice with an adequate grasp. Clear and frequent communication between the operator and the echocardiographer to facilitate positioning of the MitraClip is key.

Clip Alignment and Implantation

The clip can then be advanced into the left atrium via the steerable guide catheter. In order to effectively manipulate the CDS, the radiopaque markers on the CDS must “straddle” the radiopaque marker at the tip of the guide catheter fluoroscopically. One must withdraw the guide to within 1cm of the IAS and torque the guide in order to find space in the left atrium to advance the MitraClip to “straddle” (see Figure 5) without injuring adjacent structures. Once the MitraClip is safely outside the guide catheter (in “straddle”), the clip is directed posterior and medially towards the mitral annulus. This maneuver is done with iterative adjustments of the guide and CDS. These adjustments typically consist of posterior torque on the guide in combination with medial deflection of the M/L knob on the steerable sleeve. The CDS delivery catheter advances when medial deflection (M) is applied requiring periodic withdrawal of the delivery catheter. TEE guidance and visualization of the clip within the left atrium is crucial during these movements to avoid clip advancement into the left atrial appendage, trauma to the left atrial wall, or interaction with the warfarin ridge. See Figure 6 for a fluoroscopic image of clip orientation when advanced to the mitral valve.

Within the left atrium, the clip should be positioned 1 cm above the mitral valve and centralized over the regurgitant jet. The sleeve handle should be secured in the stabilizer using the screw-in fastener. With the clip positioned above the mitral annulus, the grippers are raised. Next, the clip is unlocked and the clip arms are opened to 180 degrees. The clip is then re-locked. Using TEE guidance, the clip is directed above the target anterior and posterior leaflet segments to grasp: this may be done with

adjustment of the M/L or A/P knobs, or by advancement or retraction of the guide and CDS together (advancing to move lateral and retracting to move medial). The clip arms are aligned perpendicular to the line of coaptation in a 3D en-face view of the mitral valve (Figure 7) using clock- or counterclockwise manipulation of the delivery catheter handle. In order to translate torque and rotate the clip, the delivery catheter should be advanced and retracted with careful attention not to advance the MitraClip across the valve. The mid esophageal LVOT view on TEE can also help confirm clip position by clearly demonstrating the splayed open clip with clip arms at 180-degrees.

Once alignment has been confirmed by 3-D TEE, the clip is advanced across the mitral valve with careful attention not to advance the MitraClip too deeply into the left ventricle. Watching this movement by TEE in the mid esophageal 120-150 degree view of the LVOT is often the most helpful to visualize trajectory and confirm the clip has passed below the mitral leaflets. Fluoroscopy is often also helpful to identify rotation of the clip as it is advanced. The clip is advanced just across the leaflets. At this time, the clip arms are closed to a grasping angle between 120-160 degrees. Care must be taken to avoid excess manipulation below the mitral annulus – particularly towards the commissures – as this could lead to entanglement of the MitraClip in the subchordal apparatus.

Leaflet Capture

With the clip at grasping angle below the mitral annulus and leaflets, the delivery catheter is withdrawn until both the anterior and posterior leaflet segments are seen to be resting upon the respective clip arms. The grippers are lowered to fasten leaflets to the clip arm. Ideally, the leaflets can be seen to insert between the gripper and the respective clip arm to reduce the risk for single leaflet detachment or clip embolization. If there is difficulty capturing both leaflets simultaneously, the leaflets may have to be engaged sequentially by placing one leaflet atop its respective clip arm, followed by torquing the steerable guide posterior or anterior while retracting the clip delivery handle prior to engaging the other leaflet. With the current generation of MitraClip, both leaflets must be grasped simultaneously, as the grippers do not function independently. Particularly with flail mitral leaflets, rapid right ventricular pacing or administration of an adenosine IV bolus can be used to temporarily stop leaflet movement and facilitate leaflet grasp. When both leaflets have been confirmed to be captured between the grippers and clip arms, the clip arms are closed to 60-degrees. With an effective grasp, mitral regurgitant color flow on TEE should be reduced (often best seen in the intercommissural or short-axis view) as the clip arms are closed.

Post-capture assessment

Taking time to ensure that everyone on the MitraClip team agrees that both leaflets are adequately captured is essential. Leaflet capture should be confirmed in multiple TEE views – oftentimes, best seen in the LVOT view, 0-degree view, 3-D and/or transgastric views. One should be able to clearly visualize the insertion of the leaflet into the clip. After leaflet capture is confirmed, the clip should be fully closed while watching regurgitant color flow resolve with an adequate grasp.

If either leaflet grasp or clip position is unsatisfactory, the grippers are lifted, the clip is unlocked, and the clip is opened. If the issue was inadequate tissue capture, leaflet grasp can be reattempted from this position. If the clip position requires more extensive adjustments or realignment, the clip should be

opened to an inverted position and withdrawn into the left atrium where the system can be prepared for another attempt.

After clip closure, the delivery catheter should be advanced slightly to reduce tension on the system, and further TEE interrogation is performed to evaluate impact on the degree of mitral regurgitation and assess transmitral valve gradient. There should be an adequate systolic blood pressure to fully interrogate the extent of MR. The heart rate should be appropriately controlled to fully assess the transmitral valve gradient. If the transmitral valve gradient has increased, careful consideration must be given to the potential hemodynamic impact if a clip were to be deployed in this position.

Clip Deployment and Release

Once satisfactory clip placement and leaflet grasp have been confirmed, the clip is deployed. The clip lock is tested by turning the arm positioner in the open direction and confirming under fluoroscopy that the arms do not open. The arm positioner is then turned to the closed side of neutral. A final mitral valve gradient assessment is done by TEE to ensure the clip has not caused significant mitral stenosis. The flush rate is increased on the saline drips. First, the gripper lever cap and the “O” ring are removed. Each end of the nitinol gripper line is grasped and the one end of the line is retracted 3-5 cm to confirm that the line can be removed. Next, the clip lock lever cap and “O” ring are removed. Holding each end of the lock line, one end is slowly retracted until the line is withdrawn. It is important to take care to avoid entangling and knotting the lock line. This establishes the final arm angle. At this time, the arm positioner is set in the neutral position and the release pin is removed from the delivery catheter handle. The arm positioner is then turned in the open direction until the release pin groove is exposed. The actuator knob on the back of the delivery catheter is turned approximately 8 times in the counterclockwise direction until the clip is released. The delivery catheter handle is then retracted to allow for at least 1 cm separation between the clip and the delivery catheter tip. If TEE confirms clip position remains stable, the gripper line is then withdrawn completely by retracting one end. The delivery catheter handle is then withdrawn until the radiopaque ring is against the tip of the sleeve. Final clip position and stability are confirmed by both TEE and fluoroscopy. Figure 8 shows a representative fluoroscopic view of a deployed MitraClip after release of the gripper line. Video 1 shows TEE imaging of a released MitraClip in stable position. The CDS is carefully retracted into the sheath under TEE guidance by reversing the movements used to advance the clip initially to the mitral annulus, with attention to avoiding traumatizing the left atrium with the exposed pin.

Multiple Clip Insertion and Considerations

If there is significant residual mitral regurgitation after clip placement without significant transmitral gradients, additional clips may be required. Attention is needed when placing multiple clips to avoid dislodging the previously placed clip(s). Placement of a second clip more lateral to the first clip is often easier than placing a second clip more medial to the first. Steps to prepare, deliver, and align additional clips in the left atrium are the same. When advancing a second clip across the mitral annulus, the clip should be advanced in the closed position to prevent interaction with the first clip. It is critical to observe this motion under fluoroscopy in addition to TEE in order to ensure the second clip remains clear of the first. Once below the mitral annulus, the clip is opened to 180 degrees and clip alignment is

confirmed. Leaflet grasp/capture, clip assessment, and clip deployment are then performed as previously described.

Clip Retrieval/Guide Removal

If the clip has been inserted, but the decision is made to not deploy the clip (e.g. leaflet grasp is unattainable or significant mitral stenosis develops), the clip should be fully inverted (beyond 180-degrees) and withdrawn into the left atrium. Then, the clip should be locked and fully closed, with the grippers lowered. The delivery catheter handle is then retracted while releasing all prior sleeve deflections (M/L and A/P knobs to neutral) until the delivery catheter radiopaque ring is against the tip of the sleeve. By retracting the delivery catheter handle, the clip and CDS should be withdrawn completely into the guide. It is critical to ensure that the clip is parallel to the guide in order to withdraw the clip smoothly into the sheath without catching the edge, injuring adjacent structures, or embolizing the clip. When the CDS is approximately halfway into the guide, begin gentle aspiration on the guide sideport with a 50-60 mL syringe. When the CDS has been withdrawn to the point that proximal sleeve alignment marker is just outside the clip introducer, the CDS and clip introducer are removed simultaneously from the guide and a finger is placed over the guide hemostasis valve. Slow aspiration with the 50-60 mL syringe is continued to remove any air from the guide.

To remove the guide, the guide is first retracted into the right atrium. The guide may be straightened by turning the +/- knob. The guide system is then removed completely from the femoral vein while providing hemostasis.

Vascular Closure

After removal of the MitraClip system, hemostasis of the 24 French venous puncture can be obtained in multiple ways. The “Pre-Close” technique has been described above (see Figure 2). In the appropriate patient, hemostasis can be facilitated with the use of protamine. Manual compression should be applied in all cases as well. Another technique that has been described is the use of a “Figure-of-Eight” subcutaneous suture to achieve hemostasis after removal of large-bore femoral venous sheaths⁸.

Possible complications and procedural strategies

- a. Access complication – Procedural risks include bleeding and vascular damage associated with the access site and large-caliber venotomy. Ultrasound guidance and use of a micropuncture access kit may be considered to assist with access. In appropriate patients, hemostasis can be facilitated with the use of protamine.
- b. Anomalous venous anatomy – Anomalous venous anatomy (e.g. azygous continuation of the inferior vena cava) may preclude cardiac access through the femoral veins. Routine venograms do not appear to facilitate access, although careful attention to the intravenous course of wires with venography as warranted is recommended. Alternative access for these cases includes transhepatic access or direct right atrial access via surgical incision.

- c. Complications of transseptal puncture - Potential complications of transseptal puncture include cardiac tamponade or aortic puncture. TEE guidance should minimize these complications by directing transseptal puncture and directly visualizing its passage. The needle should be visualized prior to advancing the dilator to minimize the risk for complication. Pressure assessment through the transseptal needle can also be helpful. Other products, such as SafeSept wires (Pressure Products, San Pedro, CA) advanced through the transseptal needle to confirm location can also be helpful. If inadvertent aortic perforation occurs, consideration should be given as to whether to withdraw transseptal equipment. If it is only the transseptal needle, one might consider withdrawing the needle, reversing heparin with protamine, and closely observing the patient. Alternatively, percutaneous repair can be attempted with placement of a closure device across the communication between the right atrium and the aorta. Cardiac tamponade may be managed conservatively with reversal of anticoagulation, pericardiocentesis, and close monitoring. However, one should be prepared to address these complications with emergent surgical repair as needed. As described above, use of a radiofrequency transseptal needle may be considered to ensure precise puncture location and prevent sliding of the transseptal needle.
- d. Pulmonary vein injury - Support wires are often placed in the left pulmonary veins as equipment is advanced into the left atrium. The sheath and dilator should be watched carefully as the IAS is crossed both fluoroscopically as well as on TEE short-axis views to assess depth. Trauma to the pulmonary vein may result in life-threatening pulmonary hemorrhage. If blood is noted within the endotracheal tube or ventilation becomes more difficult, the patient must be rapidly assessed and decision made whether to administer protamine and abort the procedure. Selective intubation of the non-bleeding lung may be used in this scenario to maintain ventilation.
- e. Intracardiac thrombus - It is critical to maintain a therapeutic activated clotting time (ACT > 250 sec) with intravenous heparin during this procedure to prevent thrombus formation on the equipment. Pre-existing intracardiac thrombus is a contraindication to the MitraClip procedure. Given the safety of using TEE guidance for transseptal puncture, we often administer some heparin prior to transseptal puncture, particularly when using a radiofrequency needle. Upon crossing, we will maintain and frequently aspirate and flush our transseptal sheath until a therapeutic ACT is achieved before advancing a wire with potential thrombogenicity into the left atrium.
- f. Aorta hugging clip - As the clip is advanced in the left atrium towards the mitral annulus, the clip trajectory may track the course of the aorta (a so-called “aorta hugging” clip). Using the + knob and anterior guide torque can offset this trajectory. However, it is important to bear in mind that anterior guide torque will also bring the system lower in the atrium.
- g. Chordal entanglement - Manipulation of the clip below the mitral annulus carries the risk of clip entanglement in the mitral apparatus. If the clip becomes entangled, reversal of the preceding maneuvers are the first steps to try and extract the clip. The clip should be inverted. Repeatedly raising and lowering the grippers (“cycling the grippers”) to release any tethered tissue, torquing the delivery system, and/or slightly advancing the clip into the left ventricle to relieve tension may be helpful to extricate the clip. If the clip cannot be removed despite exhaustive attempts, an

option is to deploy the clip onto the entangled subchordal mitral apparatus rather than tearing chords by trying to force the clip back into the left atrium

- h. Single leaflet attachment - If there is not substantial tissue grasp, it is possible for one of the leaflets to become dislodged from the closed clip, creating a single leaflet attachment. If the clip has been released, there is no way to extract the clip other than surgically. However, if the clip has stable grasp on the single leaflet, consideration may be given to leaving the device in place. Placement of an additional clip adjacent to the clip with single leaflet attachment may both provide stability and reduce the degree of mitral regurgitation; however, there may not always be appropriate anatomy or adequate mitral leaflet tissue for an additional clip to be placed.

References:

1. Feldman T, Foster E, Glower DD et al. Percutaneous repair or surgery for mitral regurgitation. *The New England journal of medicine* 2011;364:1395-406.
2. Feldman T, Kar S, Elmariah S et al. Randomized Comparison of Percutaneous Repair and Surgery for Mitral Regurgitation: 5-Year Results of EVEREST II. *Journal of the American College of Cardiology* 2015;66:2844-54.
3. Puls M, Lubos E, Boekstegers P et al. One-year outcomes and predictors of mortality after MitraClip therapy in contemporary clinical practice: results from the German transcatheter mitral valve interventions registry. *European heart journal* 2016;37:703-12.
4. Philip F, Athappan G, Tuzcu EM, Svensson LG, Kapadia SR. MitraClip for severe symptomatic mitral regurgitation in patients at high surgical risk: a comprehensive systematic review. *Catheterization and cardiovascular interventions: official journal of the Society for Cardiac Angiography & Interventions* 2014;84:581-90.
5. Maisano F, Franzen O, Baldus S et al. Percutaneous mitral valve interventions in the real world: early and 1-year results from the ACCESS-EU, a prospective, multicenter, nonrandomized post-approval study of the MitraClip therapy in Europe. *Journal of the American College of Cardiology* 2013;62:1052-61.
6. Nishimura RA, Otto CM, Bonow RO, et al. 2014 AHA/ACC guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Journal of the American College of Cardiology* 2014;63:e57-185.
7. Alhkouli M, Rihal CS, Holmes DR Jr. Transseptal Techniques for Emerging Structural Heart Interventions. *JACC Cardiovasc Interv* 2016;9:2465-2480.
8. Cilingiroglu M, Salinger M, Zhao D, Feldman T. Technique of temporary subcutaneous “Figure-of-Eight” sutures to achieve hemostasis after removal of large-caliber femoral venous sheaths. *Catheter Cardiovasc Interv* 2011;78:155-60.

Figure 1: Optimal location for venous access puncture with micropuncture access needle.



Figure 2: Perclose positioning in “Pre-Close” technique for large bore access venotomy.



Figure 3: TEE-guided transseptal puncture location showing tenting of the interatrial septum 4.0-4.5 cm above mitral annulus prior to puncture.

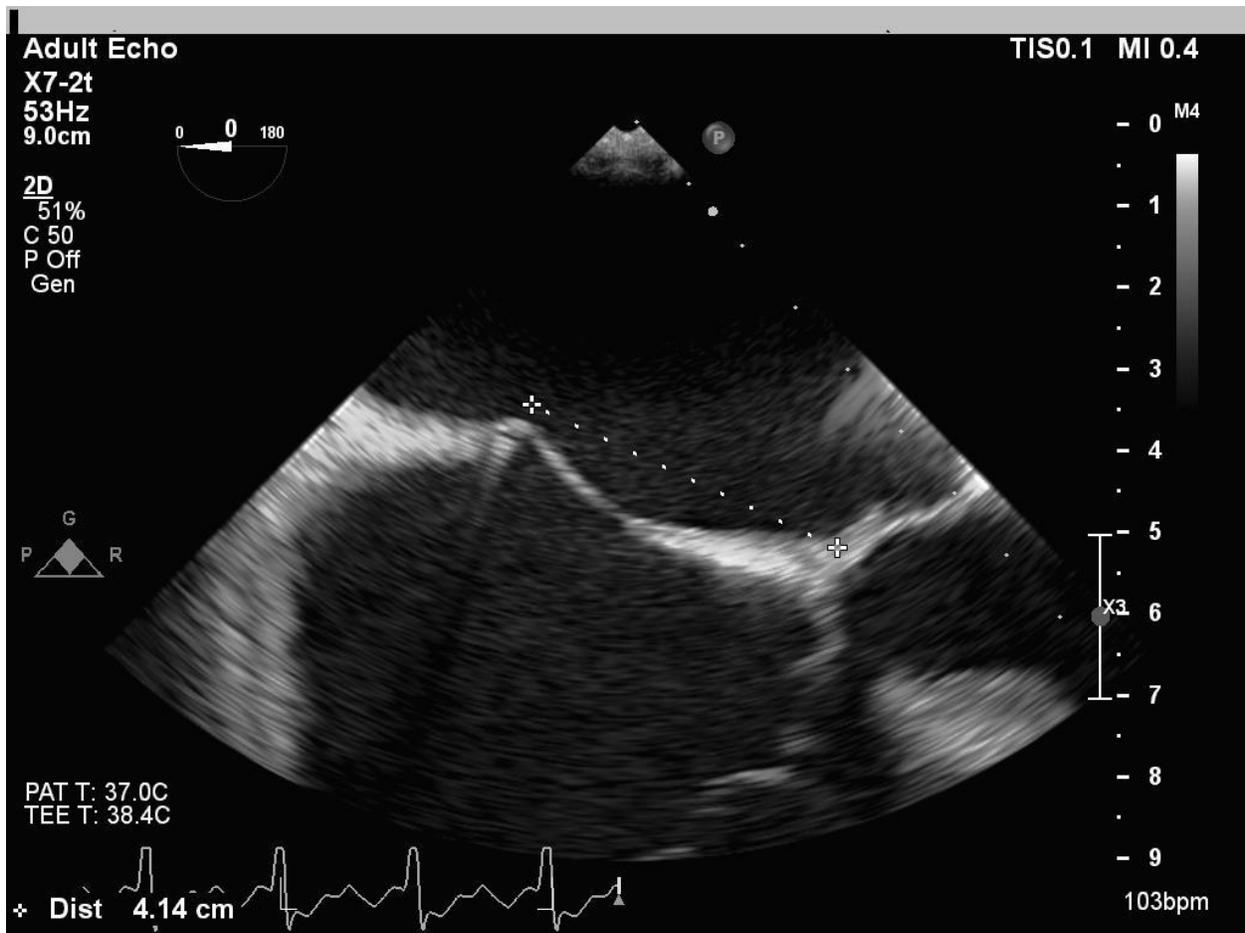


Figure 4: The MitraClip device (A). Appearance of the steerable guide catheter with the clip delivery system (CDS) inserted (B). Components of the steerable guide catheter include 1. Radiopaque Tip Ring, 2. +/- Knob. Components of the CDS include 3. Radiopaque Alignment Markers, 4. M/L Knob, 5. A/P Knob, 6. Gripper Lever, 7. Lock Lever, 8. Arm Positioner. Images reproduced with permission from Abbott Vascular, Santa Clara, CA.

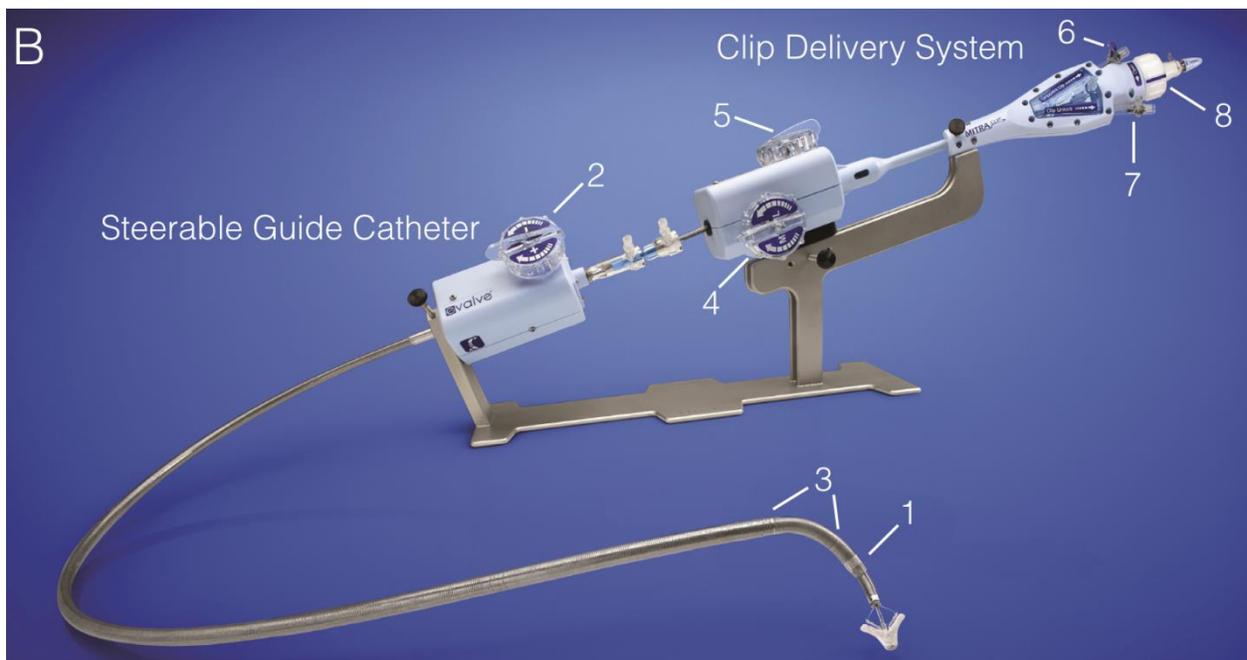
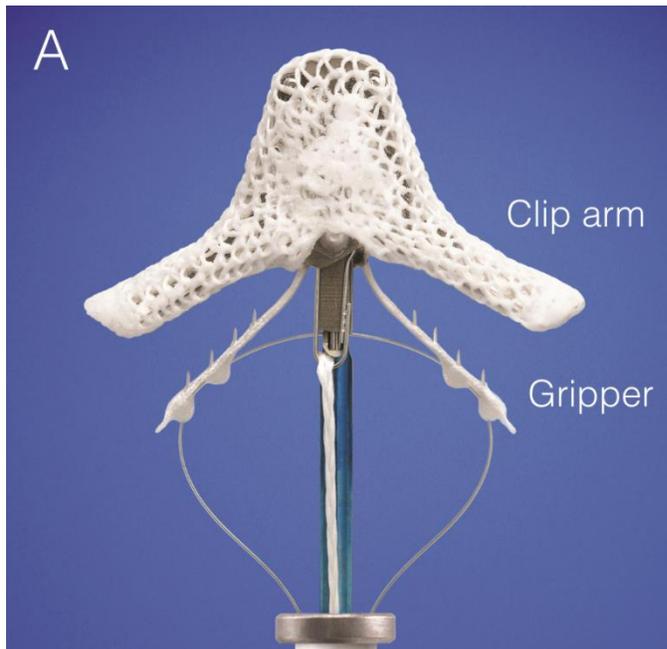


Figure 5: Fluoroscopic appearance of the clip delivery system (CDS) and steerable guide catheter in “straddle”: the radiopaque markers on the CDS (arrows) are on either side of the radiopaque marker at the tip of the guide catheter (arrowhead).

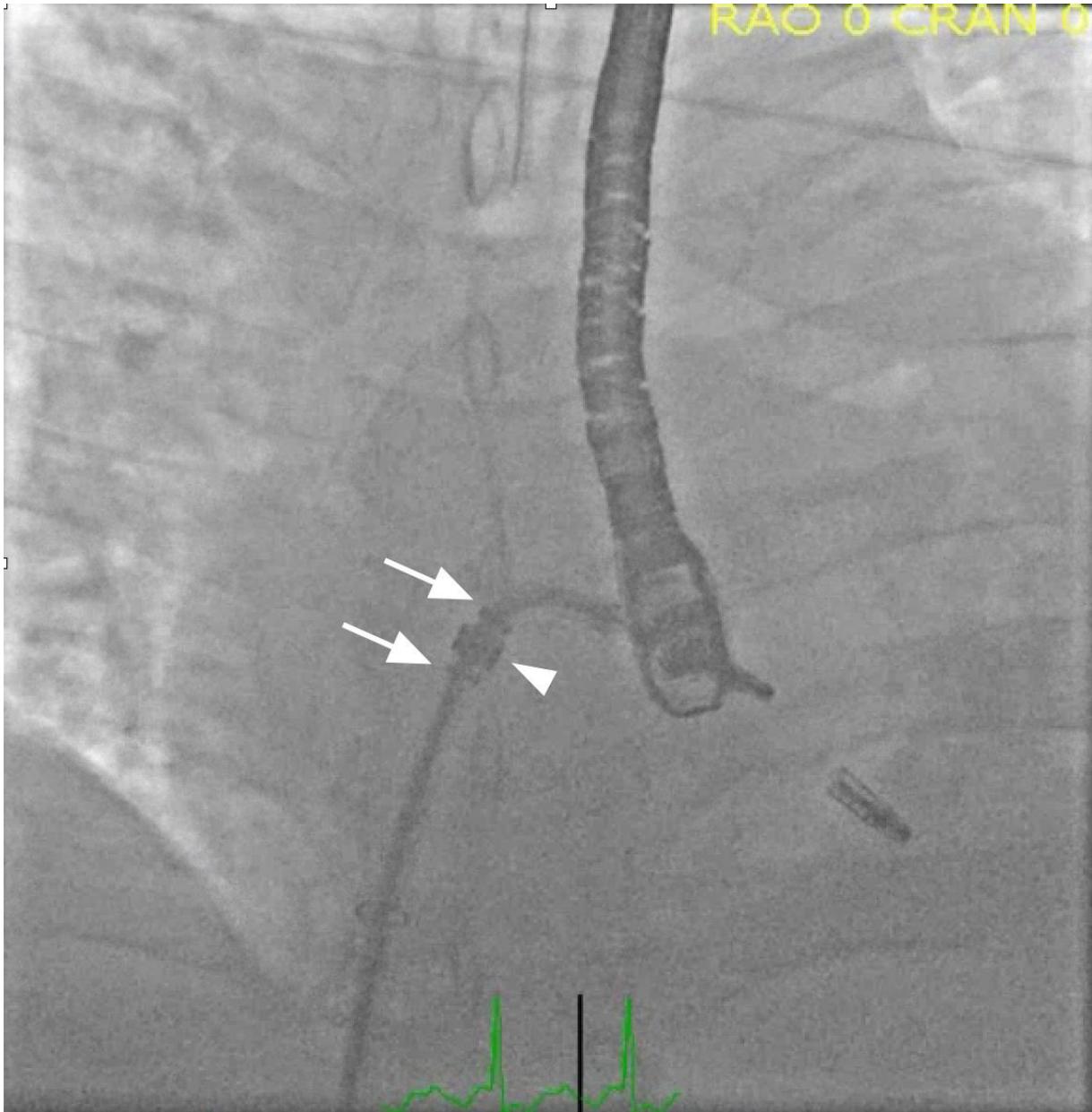


Figure 6: Fluoroscopic view in anterior-posterior (AP) projection of typical clip orientation when advanced to the mitral valve.



Figure 7: 3-D TEE image of clip alignment perpendicular to the line of leaflet coaptation prior to mitral valve crossing.

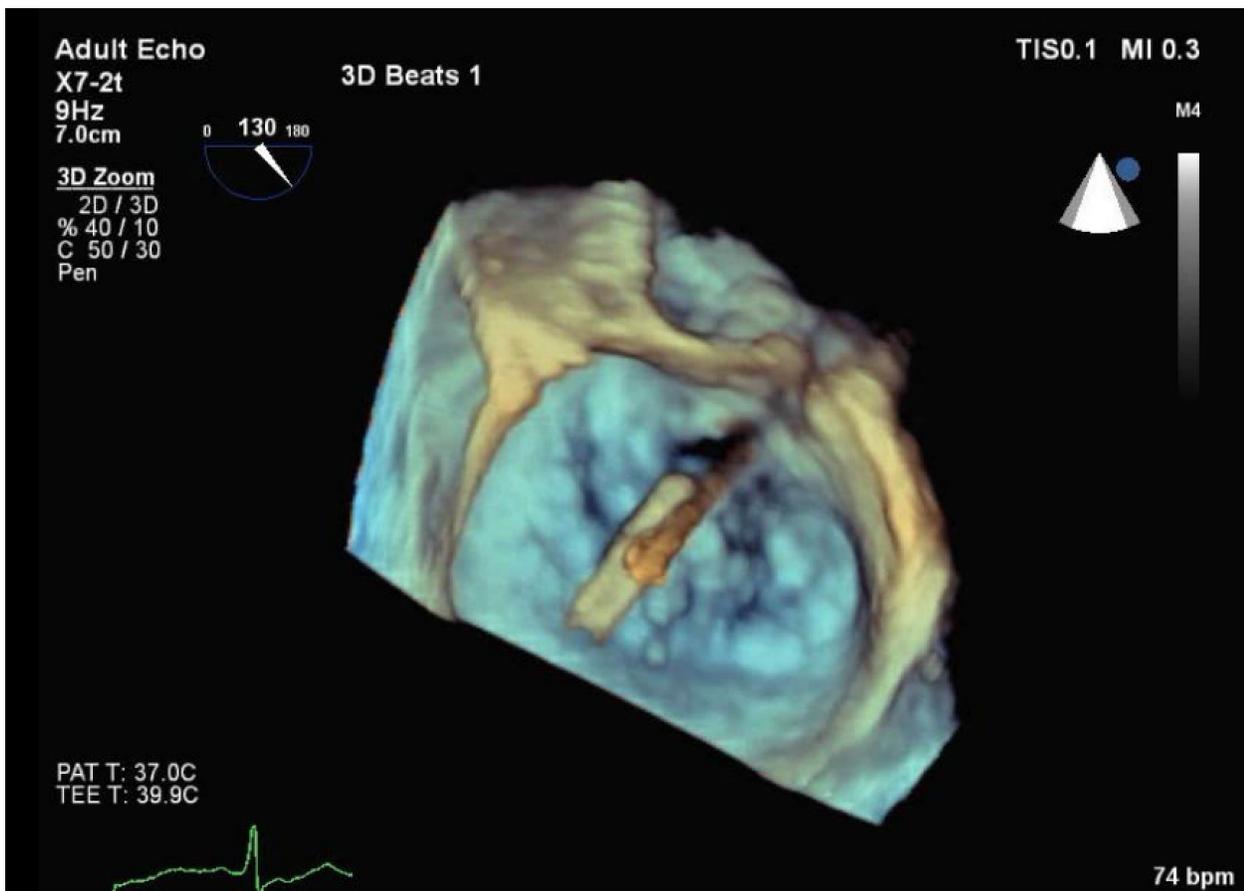
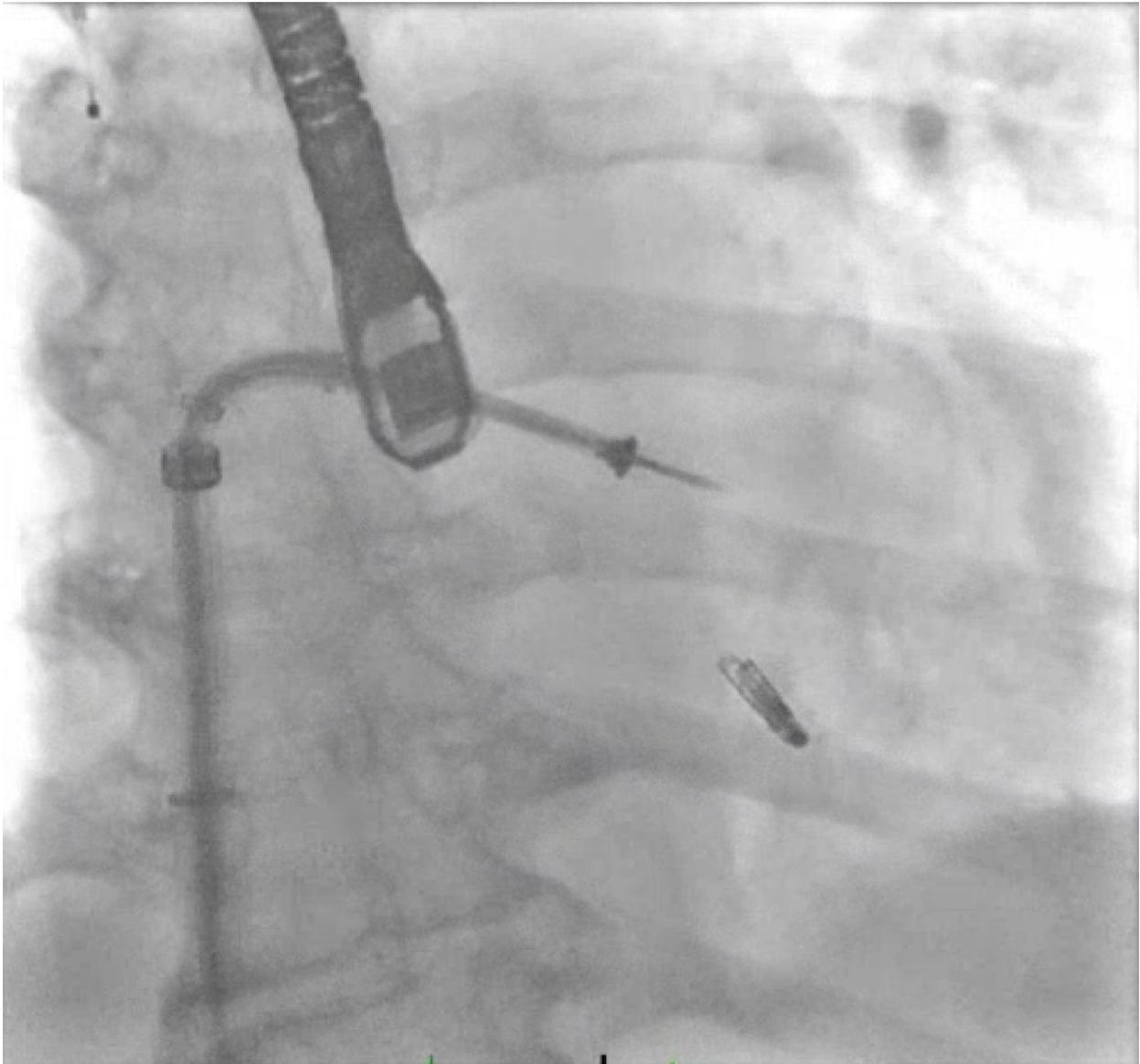


Figure 8: Representative fluoroscopic view in anterior-posterior (AP) projection of a deployed MitraClip after release of the gripper line.



Video 1: TEE mid esophageal LVOT view showing a released MitraClip device in 2-D (A) and with color Doppler (B).