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Mitral Transcatheter Edge-to-Edge Repair With the PASCAL Precision System: Device Knobology and Review of Advanced Steering Maneuvers

Santiago Garcia, MD [a,*], Sammy Elmariah, MD [b], Robert J. Cubeddu, MD [c], Firas Zahr, MD [d], Mackram F. Eleid, MD [e], Susheel K. Kodali, MD [f], Puvi Seshiah, MD [a], Rahul Sharma, MD [g], D. Scott Lim, MD [h]

[a] The Christ Hospital Health Network, Cincinnati, Ohio, USA
[b] University of California, San Francisco, California, USA
[c] Naples Heart Institute, Naples, Florida, USA
[d] Oregon Health Sciences University, Portland, Oregon, USA
[e] Mayo Clinic, Rochester, Minnesota, USA
[f] Columbia University, New York, New York, USA
[g] Stanford University, Palo Alto, California, USA
[h] University of Virginia, Charlottesville, Virginia, USA

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ABSTRACT

In 2022, the Food and Drug Administration approved a second mitral transcatheter edge-to-edge repair device for the treatment of primary mitral regurgitation (PASCAL Precision Transcatheter Valve Repair System, Edwards Lifesciences, Irvine, CA). The PASCAL Precision system consists of a guide sheath, implant system, and accessories. The implant system consists of a steerable catheter, an implant catheter, and the implant (PASCAL or PASCAL Ace). The guide sheath and steerable catheter move and flex independently from each other and are not keyed, allowing for freedom of rotation in three dimensions. This manuscript provides an overview of the PASCAL Precision system and describes the basic and advanced steering maneuvers to facilitate effective and safe mitral transcatheter edge-to-edge repair.

ABBREVIATIONS

LA, left atrium; LAA, left atrial appendage; LVOT, left ventricular outflow tract; MR, mitral regurgitation; M-TEER, mitral-transcatheter edge to edge repair; TEE, transesophageal echocardiography.

Mitral valve regurgitation is the second most common valvular heart disease with an estimated prevalence of ≥10% among those aged 75 or older.[1] Transcatheter edge-to-edge repair of the mitral valve (M-TEER) is one of the most common structural heart interventions with more than 100,000 implants worldwide. Current American College of Cardiology/American Heart Association guidelines list M-TEER as a class II-A recommendation for patients with primary/degenerative mitral regurgitation (MR) at high or prohibitive surgical risk, and secondary/functional MR with persistent symptoms despite optimal medical therapy in patients with anatomies suitable for device implantation and without futility markers.[2] Both indications are predicated on rigorous clinical trial and registry data accumulated over the last 15 years.[3–6]

In 2022, the Food and Drug Administration approved a second M-TEER device for the treatment of primary MR (PASCAL Precision Transcatheter Valve Repair System, Edwards Lifesciences, Irvine, CA).[7] This approval was predicated on the results of a randomized clinical trial (CLASP IID, NCT03706833) comparing PASCAL with the Mitra Clip system (Abbott Structural Heart, Santa Clara, CA) in patients with symptomatic degenerative MR and prohibitive surgical risk. The PASCAL

* Address correspondence to: Santiago Garcia, MD, Structural Heart Program and Harold C. Schott Foundation Endowed Chair for Structural and Valvular Heart Disease, The Carl and Edyth Lindner Center for Research and Education at The Christ Hospital, 2139 Auburn Ave, Cincinnati, OH 45219.
E-mail address: santiagogarcia@me.com (S. Garcia).

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Precision system demonstrated noninferiority based on 30-day safety and 6-month efficacy endpoints.[8] A second trial (CLASP IIF, NCT03706833) in patients with secondary MR is ongoing.

This manuscript provides an overview of the PASCAL Precision system and describes the basic and advanced steering maneuvers to facilitate effective and safe M-TEER.

PASCAL Precision System

The PASCAL Precision system consists of a guide sheath, implant system, and accessories including a stabilizer rail system and table (Figure 1). The implant system consists of a steerable catheter, an implant catheter, and the implant (PASCAL or PASCAL Ace).

Guide Sheath

The guide sheath provides access to the left atrium (LA) by passing over a 0.035" guidewire through a femoral vein access site and a transseptal puncture. The guide sheath has a 22 Fr outer diameter, a 79 cm working length, and a hydrophilic coating. The rotational control knob (flex knob) positions the guide sheath by actuating the flexion mechanism at the distal end. As the flex knob is rotated clockwise, the distal end of the guide sheath will flex in the direction of the flush port on its handle. A peel-away loader is used to introduce the implant system through the guide sheath seals.

Steerable Catheter

The outermost catheter of the PASCAL Precision system is the steerable catheter, which has a flex knob that actuates the flexion mechanism to navigate and position the implant to the desired location. The steerable catheter has flex indicators on either side of the handle and a flush port for continuousLA pressure monitoring. The implant catheter runs through the steerable catheter and is attached to the implant by sutures, nitinol fingers, and a threaded shaft.

Implant Catheter

The implant catheter handle (Figure 2) contains color-coded clasp sliders with a clasp lock that enables simultaneous or independent clasp movement and a paddle knob that opens and closes the implant. Rotation of the implant catheter handle rotates the implant in the direction of the rotation (i.e., clockwise or counterclockwise) to align with the desired target implant location. Finally, removing the implant release cover exposes the suture locks and implant release knob controls necessary to release the implant from the catheter.

PASCAL and PASCAL Ace Implants

The implant is available in two configurations: the PASCAL implant and the lower-profile PASCAL Ace implant (Figure 3a). The primary components of the implant are the spacer, paddles, and clasps, which are constructed from nitinol and covered by polyethylene terephthalate cloth (Figure 3b). The spacer fills the regurgitant orifice area and reduces the distance to approximate the leaflets. The clasps contain a single row of 4 retention elements on each side that allow for atraumatic, staged leaflet capture and leaflet optimization. The retention elements are in close proximity to the tips of the clasps. The paddles have a curved design that may help reduce stress on the leaflets. The PASCAL Ace implant contains narrower paddles and spacer designed to allow for improved navigation through dense chordal regions.

Accessories

The PASCAL Precision system is used in conjunction with the PASCAL stabilizer rail system and the PASCAL table during a procedure. The stabilizer rail system aids with the positioning and stabilization of the device PASCAL Precision system during implantation procedures. The table is used outside of the sterile field (beneath the sterile drape) to provide a stable platform for the guide sheath, implant system, and stabilizer rail system.

Implant Navigation

The guide sheath and steerable catheter move and flex independently from each other and are not keyed, allowing for freedom of rotation in 3 dimensions (Supplemental Video 1). The *guide sheath* helps position the implant over the desired treatment location, which is the mitral valve line of coaptation. For example, when the flex knob of the guide sheath is actuated, the implant will move posteriorly, which can help correct an aorta hugger. Conversely, if the implant is posterior to the line of coaptation, unflexing the guide sheath will move the implant anterior (Supplemental Video 1).

The *steerable catheter* rotates independently of the guide sheath. Once the implant is over the mitral valve line of coaptation, actuation of the flex knob of the steerable catheter will move the implant in the medial to lateral plane. Adding flex to the knob moves the implant in a lateral-to-medial trajectory. Conversely, unflexing the knob moves the implant in a medial-to-lateral trajectory.

Advancing or retracting the steerable catheter will move the implant's position in the lateral (advancing) or medial (retracting) direction. In contrast, clockwise or counterclockwise rotation of the steerable

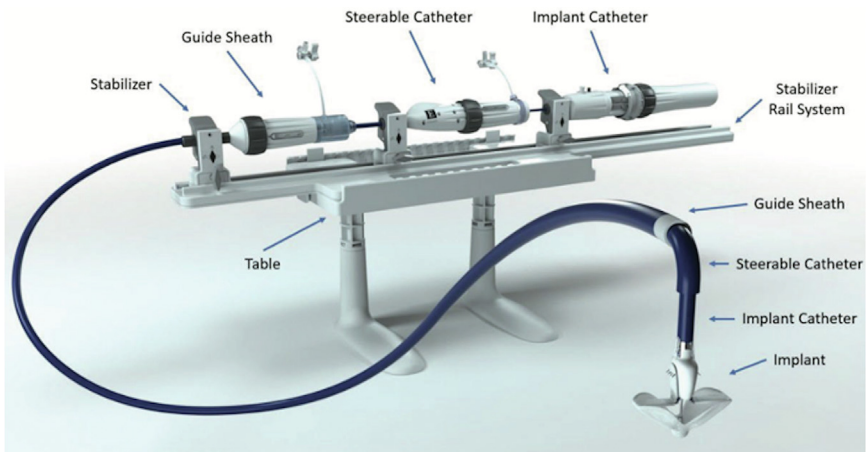


Figure 1. Components of the PASCAL Precision Delivery System. The 3 key components of the Pascal system include the guide sheath, steerable catheter, and implant handle.

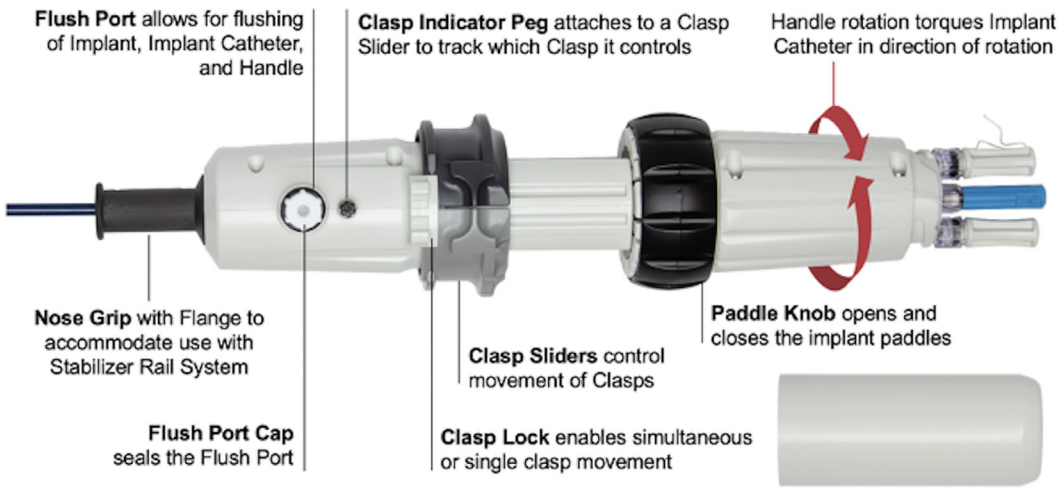


Figure 2. Implant catheter handle contains the color-coded clasp sliders, the paddle knob that opens and closes the implant, the suture locks, and implant release knob controls.

catheter will move the implant's position and trajectory in the posterior and anterior direction, respectively.

Procedural Steps

Venous access is obtained using fluoroscopic landmarks and ultrasound guidance. Preclosing the access site with a single device (Perclose, Abbott Vascular, Santa Clara, CA) can facilitate hemostasis. The desired location of the transseptal puncture is mid-fossa and posterior with a desired transseptal height of ≥45 mm above the level of mitral leaflet coaptation. This is guided by transesophageal echocardiography (TEE) using orthogonal views (bi-caval and short-axis) with height measurements performed in a 4-chamber view, from the point of maximal tenting to the mitral valve plane. Once access to the LA is obtained, the guide sheath and introducer are inserted over a guidewire. A minimum of 2 cm of guide sheath insertion is recommended to minimize the risk of losing transseptal access. The guide sheath is secured in the stabilizer, and the guidewire/introducer are removed. Aspiration of blood is not required during removal of the introducer/guidewire. The implant/loader are inserted in the guide sheath, the steerable catheter is advanced until the implant exits the guide sheath seals (approximately 10 cm), at which point the loader is pulled back and peeled away. At this point, aspiration of 45 cc of blood and flushing of the guide sheath is required to prevent air embolism. The guide sheath flush port should be positioned between 4 o'clock and 6 o'clock.

Implant System Insertion

The implant enters the LA in an elongated position (42-43 mm long) and must be closed prior to steering toward the mitral valve. It is important to ensure the implant is fully exposed in the LA (i.e., out of the guide sheath) prior to closing to minimize contact with the guide sheath upon closing. This is accomplished by direct fluoroscopic visualization of the spacer and proximal plate outside the guide sheath prior to closing (Figure 4a). The implant is closed by rotating the paddle knob clockwise and retracting the clasps by pulling back on the clasp sliders.

However, if space in the LA is limited and does not allow for full implant exposure, the implant may still be closed after limited exposure, but the clasps should not be retracted until out of the guide sheath. The minimum acceptable implant exposure is at least to the paddle spacer junction, which is approximately 27 mm from the tip of the implant (Figure 4b). After closing the implant, the steerable catheter is advanced until the spacer is completely out of the guide sheath, at which point the clasp sliders are retracted. At this point, the steerable catheter is rotated so that the fin is positioned at approximately 2 o'clock while the implant

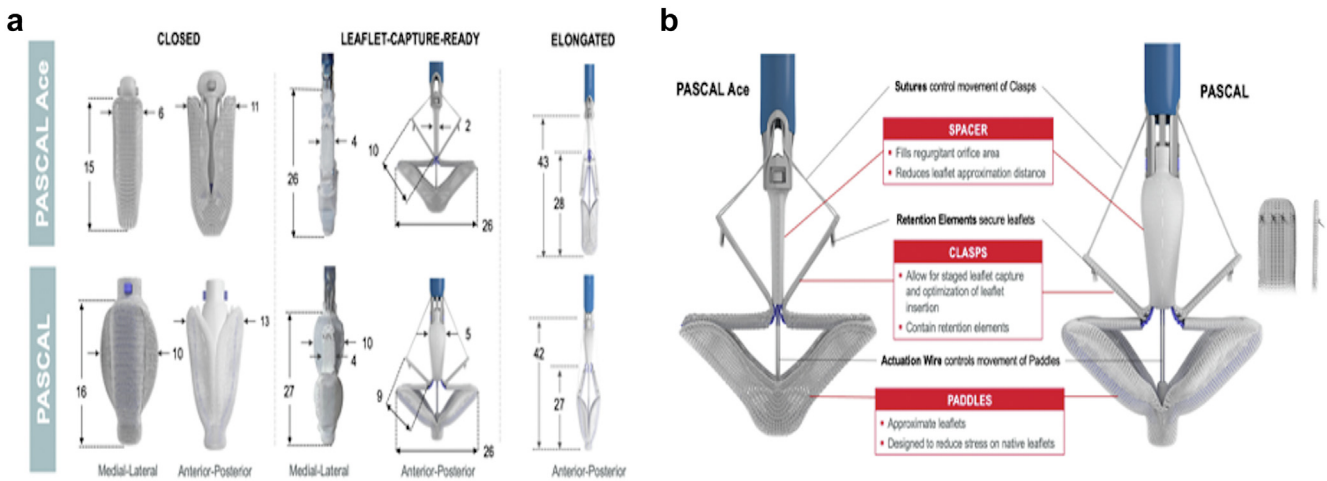


Figure 3. (a) Dimensions in mm of the PASCAL implant in various configurations: closed (left), leaflet capture-ready (center), and elongated (right). (b) Device components (spacer, clasps, and paddles).

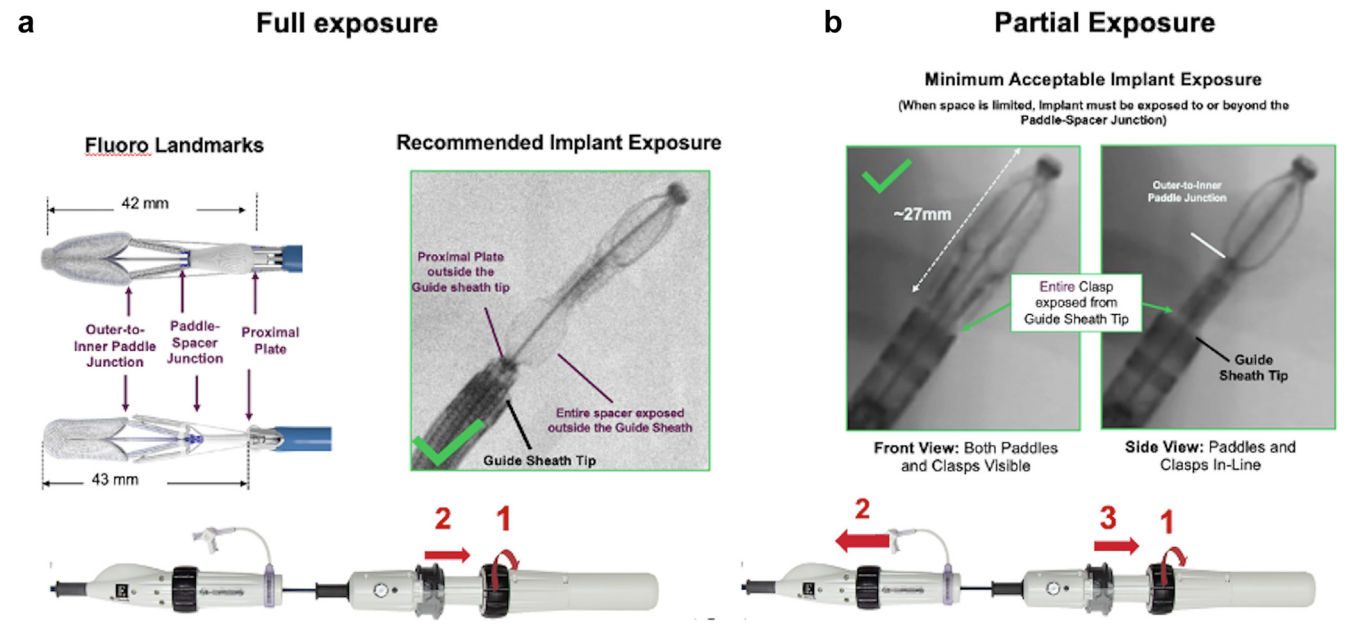


Figure 4. Implant system insertion in the left atrium with the implant fully exposed (a) and partially exposed (b). If space in the left atrium is limited, the implant can be closed after the paddle-spacer junction is outside the guide sheath.

catheter is positioned with the flush port facing up at 12 o'clock positioning.

Implant Trajectory and Position

Steering in the LA requires that the steerable catheter flex outside of the guide sheath. The radiopaque marker on the steerable catheter indicates the end of the flex section, and if space in the LA permits, it should be visualized on fluoroscopy outside the guide sheath prior to flexing toward the mitral valve. If space in the left atrium is limited, a stepwise approach of flexing/advancing is preferred to ensure the steerable catheter is not overflexed inside the guide sheath.

Once the implant clears the left atrial appendage (LAA) and is positioned over the mitral valve it is important to check and adjust, if necessary, the trajectory of the catheter and the position of the implant over the mitral valve plane. This is informed by TEE either using 2D orthogonal views (intercommissural and left ventricular outflow tract [LVOT]) or preferably with 3D multiplane reconstruction allowing for precise alignment to the mitral annular plane. The authors recommend correcting the trajectory first and then focusing on the position of the implant.

Correcting Trajectory in the Anterior-Posterior Plane

Anterior-Posterior Trajectory ("Aorta Hugger")

This is best appreciated in the LVOT view (Figure 5). The catheter is tilted as it travels from top to bottom of the LA, being closer to the aorta on top and away from the aorta as it gets closer to the mitral valve plane. Corrections of trajectory in the anterior-posterior plane require opposing movements of 2 catheters: the guide sheath and steerable catheter.

Anterior-posterior trajectory is corrected by flexing the guide sheath and rotating the steerable catheter counterclockwise. The first action (flex guide sheath) would move the guide sheath posterior, and the second (rotate the steerable counterclockwise) would move the steerable catheter anterior. These two opposing actions on the system will typically correct a posterior trajectory.

PA Trajectory

This is the mirror image of the aorta hugger and is corrected by opposite maneuvers. Correcting an anterior trajectory requires unflexing the guide sheath to move it anterior or closer to the aorta and rotating the steerable catheter clockwise to move it posterior.

Correcting Trajectory in the Medial-Lateral Plane

This is best appreciated in the intercommissural view (Figure 5). In cases of medial-lateral trajectory, the catheter appears closer to the interatrial septum on top and the LAA in its most caudal position as it gets closer to the mitral valve plane. This is corrected by flexing the steerable catheter. When a latero-medial trajectory is present, the opposite occurs (i.e., the catheter travels from LAA to interatrial septum as it gets closer to the mitral valve plane) and is corrected by unflexing the steerable catheter.

Adjusting Position of the Implant

Once trajectory is confirmed to be perpendicular to the mitral valve plane, the position of the implant can be adjusted. Advancing or retracting the steerable catheter will move the implant laterally or medially, respectively, whereas rotating the steerable clockwise or counterclockwise will move the implant posteriorly or anteriorly, respectively. A summary of steering maneuvers to correct trajectory and position is presented in Figure 6.

Maneuvers to Gain/Lose Height From the Mitral Valve Plane

In situations where the implant is too close to or far from the mitral valve plane after exiting the guide sheath, steering in the LA can be difficult, and advanced maneuvers may be required to gain or lose height as necessary.

To gain height (i.e., low transseptal puncture), the guide sheath is rotated clockwise (posterior rotation) and the steerable catheter is rotated counterclockwise (anterior). To lose height, the guide sheath is rotated counterclockwise (anterior) and the steerable catheter is rotated clockwise (posterior). It is recommended to check for flex on the guide sheath and adjust as needed before and after maneuvers to gain and lose height to ensure the implant is over the mitral valve line of coaptation. The presence of flex is necessary during these maneuvers.

Implant Orientation and Clasp Actuation

The device paddles should be oriented perpendicular to the line of coaptation at the desired treatment location. The implant catheter handle

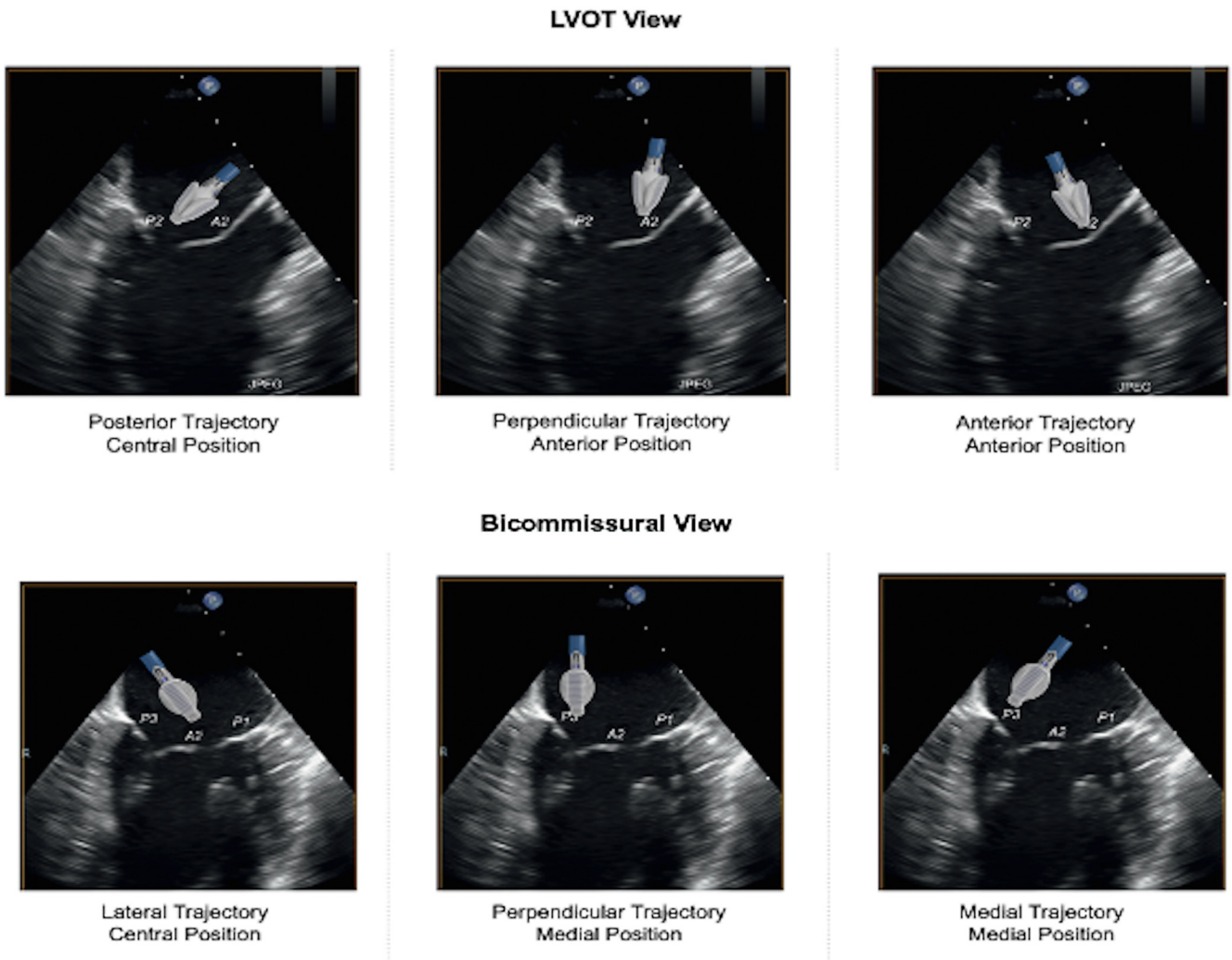
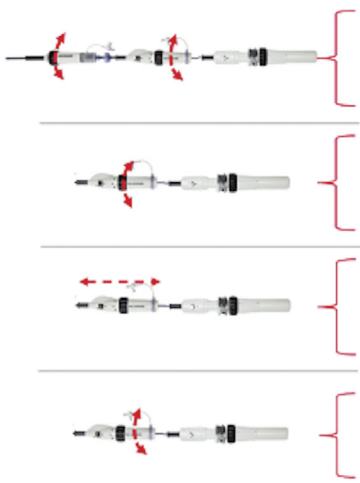


Figure 5. Visualization of trajectory and position of the PASCAL implant on TEE using orthogonal views.
Abbreviations: LVOT, let ventricular outflow tract; TEE, transesophageal echocardiogram.



Example Observation on Echo	System Manipulation
Implant **trajectory** is too **posterior**	**Flex** Guide Sheath and rotate Steerable Catheter **counterclockwise**
Implant **trajectory** is too **anterior**	**Unflex** Guide Sheath and rotate Steerable Catheter **clockwise**
Implant **trajectory** is too **lateral**	**Flex** Steerable Catheter
Implant **trajectory** is too **medial**	**Unflex** Steerable Catheter
Implant **position** is too **medial**	**Advance** Steerable Catheter
Implant **position** is too **lateral**	**Retract** Steerable Catheter
Implant **position** is slightly **anterior**	Slightly rotate Steerable Catheter **clockwise**
Implant **position** is slightly **posterior**	Slightly rotate Steerable Catheter **counterclockwise**

Figure 6. Advanced steering maneuvers of the guide sheath and steerable catheter to correct implant trajectory and position of the PASCAL implant.

can be rotated clockwise or counterclockwise, which will have a similar effect on the paddles. This is best appreciated on a 3D en face view. Subsequently, the anterior and posterior clasps should be identified on TEE and fluoroscopy by advancing and retracting the clasp sliders after sliding the lock to the side.

Leaflet Capture

Prior to crossing the valve, it is important to ensure the clasps are fully retracted against the spacer. The implant catheter is advanced in a capture-ready position (i.e., paddles at 180° angle) into the left ventricle until the paddles are below the free edges of the leaflets. The retention elements remain in the LA to avoid unintended interaction with the subvalvular apparatus. It is important to confirm trajectory and position have not changed after advancing the implant. At this point, the implant catheter is slowly retracted under TEE guidance until the leaflets are visualized moving freely between the clasps and paddles. A minimum of 6 mm of leaflet insertion is recommended. It is important that the leaflets should lay flat, not curled, in the inner paddles and reach the apex of the clasps. At this point, the clasps can be dropped simultaneously or individually depending on the procedural strategy. Leaflet insertion is usually confirmed by multiple methods (i.e., clasps bouncing, recording and reviewing of clasps lowering, echo sweep in intercommissural view and observing LVOT view medial and lateral to the implant, measuring free leaflet length before and after, tissue bridge, and MR reduction). Once a leaflet insertion is deemed adequate, the implant can be closed by rotating the paddle knob clockwise until an audible click is heard. Slight advancement of the implant is employed to release tension on the leaflets. Prior to release, it is recommended to confirm symmetric paddle closure, no tension on the implant catheter on fluoroscopic visualization, and sufficient implant catheter exposure to avoid unexpected device changes after release. A thorough echocardiographic assessment of MR severity (residual MR, pulmonary veins, gradients, etc.) and LA pressure recording is recommended.

Implant Release and System Removal

The implant release cover is removed from the implant catheter handle by rotating it counterclockwise while securing the implant catheter handle to prevent inadvertent rotation. The suture locks (white) are unscrewed and removed from the suture lock bases one at a time while securing the implant catheter handle with the left hand. After pulling and removing both sutures, the next step is to continuously rotate the blue implant release knob counterclockwise while simultaneously applying continuous retraction force to unthread the actuation wire from the distal tip of the implant and fully release the implant from the catheter. Upon release of the implant, the implant catheter is retracted into the steerable catheter, which is gradually unflexed and retracted until it enters the guide sheath, at which point both catheters are removed. The guide sheath is also unflexed and removed unless an additional implant is needed. Repeat echocardiographic assessment is recommended after implant release.

Leaflet Optimization and Device Troubleshooting

Leaflet capture is optimal when the leaflet tips are fully inserted into the apex of the clasps. When leaflet insertion is not ideal, optimization maneuvers can be employed. A step-by-step description of leaflet optimization maneuvers is presented in Figure 7. The clasps are kept down and the clasp sliders advanced while the paddles are opened to a capture-ready position. Using the steerable catheter, the implant is rotated towards the desired leaflet (i.e., the one that needs to be optimized). Subsequently, the implant catheter is retracted to create slack in the leaflet, followed by partial retraction of the clasp, which allows the natural advancement of the leaflet into the apex of the clasp. At this point, the clasp is lowered, and the steerable catheter is rotated back to the center of the valve (Figure 7).

Multiple Implants

Some mitral pathologies require multiple devices for optimal MR reduction.

For a second PASCAL implantation, device insertion, navigation in the LA, adjusting trajectory, position, and orientation are similar to what was described for the first implant. The implant can be configured in either the elongated or closed position prior to crossing the mitral valve. If the implant paddles are elongated before crossing the lower profile of the device would not push the leaflets apart like they would if the implant were in the capture-ready position. The implant is then advanced until the curved portion of the paddles is past the leaflet-free edge. If the implant is closed prior to crossing, it minimizes the chance of the retention elements interacting with the first implant. Either way, after crossing the valve, the implant configuration is changed to capture-ready position. Leaflet capture and assessment are similar to what was described for the first implant. Of note, PASCAL devices in close

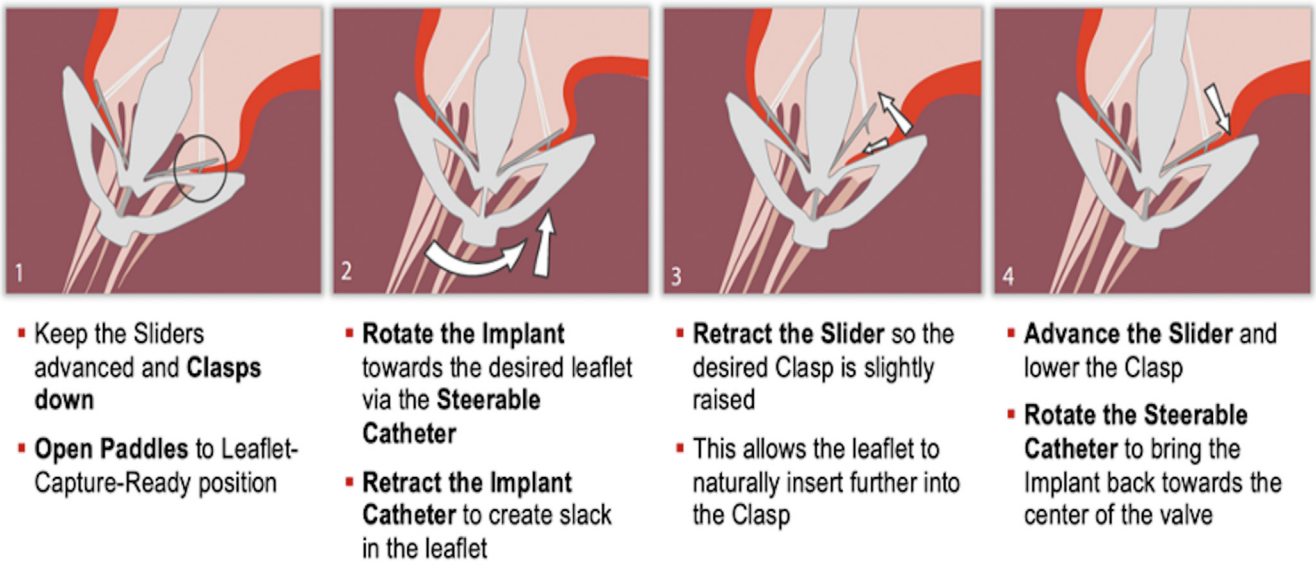


Figure 7. Leaflet optimization maneuvers. The paddles are open to leaflet capture-ready position, and the implant is rotated toward the desired leaflet. The implant is then retracted to create slack on the leaflet. At this point, the clasp is raised to allow the leaflet to naturally insert further into the clasp.

proximity to each other provide more effective MR reduction when they are relatively parallel to each other on fluoroscopy. Visualization of the second implant trajectory in orthogonal angiographic projections can be useful to ensure parallel orientation.

Implant Retrieval

Although rarely needed in clinical practice, complete implant retrieval is possible (Supplemental Video 2). A series of maneuvers are needed to achieve full implant retrieval: 1) retract clasp sliders and elongate the implant in the ventricle; 2) retract implant to the LA, close the implant, and fully retract against the steerable catheter tip; 3) unflex steerable catheter until the implant is distal to the guide sheath tip; 4) advance the clasp sliders; and 5) elongate the implant and raise clasp to approximately 45° before retracting into the guide sheath. For a partial retrieval (i.e., chordal entanglement), steps 1 and 2 are used until the device is back in the LA.

Conclusions

M-TEER is the most common structural procedure performed to address severe MR and is supported by a growing body of evidence accumulated over the last 2 decades. The PASCAL and PASCAL Ace implants have unique design features that may expand the anatomies suitable for M-TEER.[9] Using the key device characteristics and functionality described here facilitates safe and effective M-TEER.

ORCIDs

Santiago Garcia https://orcid.org/0000-0002-1806-6783
Mackram F. Eleid https://orcid.org/0000-0001-6082-5379
Puvi Seshiah https://orcid.org/0009-0007-3192-3878

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Review Statement

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Supplementary Material

Supplemental data for this article can be accessed on the publisher's website.

References

1 Nkomo VT, Gardin JM, Skelton TN, Gottdiener JS, Scott CG, Enriquez-Sarano M. Burden of valvular heart diseases: a population-based study. *Lancet*. 2006;368:1005-1011.
2 Otto CM, Nishimura RA, Bonow RO, et al. 2020 ACC/AHA guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Joint Committee on clinical practice guidelines. *Circulation*. 2021;143:e72-e227.
3 Feldman T, Foster E, Glower DD, et al. Percutaneous repair or surgery for mitral regurgitation. *N Engl J Med*. 2011;364:1395-1406.
4 Feldman T, Kar S, Elmariah S, et al. Randomized Comparison of percutaneous repair and surgery for mitral regurgitation: 5-year results of EVEREST II. *J Am Coll Cardiol*. 2015;66:2844-2854.
5 Stone GW, Lindenfeld J, Abraham WT, et al. Transcatheter mitral-valve repair in patients with heart failure. *N Engl J Med*. 2018;379:2307-2318.
6 Kar S, von Bardeleben R, Rottbauer W, et al. Contemporary outcomes following transcatheter edge-to-edge repair. *JACC Cardiovasc Interv*. 2023;16(5):589-602.
7 Available at:. https://www.fda.gov/medical-devices/recently-approved-devices/pascal-precision-transcatheter-valve-repair-system. Accessed May 5, 2023.
8 Lim DS, Smith RL, Gillam LD, et al. Randomized Comparison of transcatheter edge-to-edge repair for degenerative mitral regurgitation in prohibitive surgical risk patients. *JACC Cardiovasc Interv*. 2022;15:2523-2536.
9 Hausleiter J, Lim D, Gillam L, et al. Transcatheter edge-to-edge repair in patients with Anatomically Complex degenerative mitral regurgitation. *J Am Coll Cardiol*. 2023;81(5):431-442.