Robotic degenerative mitral valve repair: an evolution

Daniel J. Romary, Hallie L. Jefferson, Kevin E. Hodges

Division of Cardiac Surgery and Bluhm Cardiovascular Institute, Northwestern University Feinberg School of Medicine and Northwestern Medicine, Chicago, IL, USA

Correspondence to: Kevin E. Hodges, MD. Division of Cardiac Surgery and Bluhm Cardiovascular Institute, Northwestern University Feinberg School of Medicine and Northwestern Medicine, 676 N St. Clair St., Suite 730, Chicago, IL 60611, USA. Email: Kevin.hodges@nm.org.

Robotic mitral valve repair (RMVr) has advanced considerably since its introduction at the turn of the millennium. Surgical techniques and technological innovations have addressed many of the limitations of early RMVr procedures. Today, RMVr is recognized as a safe, effective, and adaptable approach to degenerative mitral valve disease, with applications extending to commonly associated conditions such as atrial fibrillation and tricuspid valve disease. Patient selection criteria are now more rigorously defined, and robotic surgical teams are expanding the scope of practice to include increasingly complex cases. This review summarizes the evolution of RMVr techniques, current patient selection strategies, modern outcomes, and training considerations for surgeons and teams. We outline our institutional approach to RMVr and highlight key components for surgeons seeking to establish new programs or expand existing ones.

Keywords: Degenerative mitral regurgitation (degenerative MR); mitral valve repair; robotic cardiac surgery; minimally invasive surgery

Submitted Aug 29, 2025. Accepted for publication Jan 10, 2026. Published online Jan 29, 2026.
doi: 10.21037/acs-2025-dmv-0175
View this article at: https://dx.doi.org/10.21037/acs-2025-dmv-0175

Introduction

Since the first open surgical mitral valve repair performed via median sternotomy, cardiac surgeons have been innovating less invasive approaches, including superior hemi-sternotomy and right mini-thoracotomy (1,2). These minimally invasive techniques can be technically demanding due to limited visualization and restricted working space—challenges that robotic assistance is uniquely positioned to overcome. Early pioneers such as Carpentier (3) and Chitwood (4) recognized this potential, such that minimally invasive mitral valve repair was the first cardiac surgery for which robotic technology was successfully applied in 1997.

Early studies of robotic mitral valve repair (RMVr), and more broadly minimally invasive mitral valve surgery (MIMS), demonstrated encouraging results. An international meta-analysis of 35 studies [1997–2010] reported reduced rates of postoperative atrial fibrillation (18% *vs.* 22%), red blood cell transfusions (1.5 *vs.* 3.5 units), sternal infections (0.04% *vs.* 0.27%), and time to return to normal activity (6.3 *vs.* 12 weeks) for patients undergoing thoracotomy (including robot-assisted) compared to sternotomy (5). However, these early studies also found the minimally invasive approach to have a higher rate of groin infection (2% *vs.* 0%), aortic dissection/injury (0.2% *vs.* 0), and phrenic nerve palsy (3% *vs.* 0%), a longer cross-clamp (95 *vs.* 74 min) and total cardiopulmonary bypass (CPB) time (144 *vs.* 111 min), and most notably, nearly double the risk of stroke (2.1% *vs.* 1.2%) (5). Before RMVr could be adopted widely as a safe and effective alternative to standard approaches, challenges of patient selection, device access, and complication rates had to be addressed.

Patient selection

Appropriate patient selection remains one of the most critical factors for safe and successful RMVr. Early relative contraindications were largely based on technical difficulty, including morbid obesity (6) and excessive mitral annulus calcification (7). The elevated stroke rate in early series was

a serious concern (5), perhaps attributable to unrecognized aortoiliac atherosclerotic disease heightening the embolic risk during femoral cannulation and peripheral CPB (8). At Cleveland Clinic in 2013, 29 (21%) of 140 patients evaluated for RMVr were found on preoperative computed tomography angiography (CTA) to have aortic or iliac atherosclerotic disease significant enough to prompt conversion to a conventional approach (8). None of the 111 patients who proceeded with RMVr experienced a permanent stroke, leading to the standardization of preoperative CTA for all RMVr candidates (8).

In 2022, Cleveland Clinic published a formal patient selection algorithm based primarily on echo and computed tomography (CT) exclusion criteria (9). It recommends a robotic approach for patients with isolated degenerative mitral valve disease unless any of the following are present: greater than mild aortic regurgitation, moderate to severe mitral annular calcification, left ventricular ejection fraction <50%, pulmonary artery systolic pressure >60 mmHg, greater than mild aortoiliac atherosclerosis, femoral artery <7 mm in diameter, or severe pectus excavatum (9). While some have criticized the algorithm for being overly conservative or impractical for broad application (10,11), it underscores the importance of a standardized process of evaluation for key safety features.

Modern series have demonstrated that RMVr can be performed safely on patients previously excluded, such as those with obesity (12), mitral annular calcification (13), and advanced age (14). Patient evaluation must also consider the need for concomitant procedures such as tricuspid valve repair or surgical ablation for atrial fibrillation, ensuring that guideline-directed interventions are not compromised for the sake of a robotic approach.

Evolution in technique

Technical refinements have transformed RMVr into the contemporary operation performed today. While femoral cutdown remains common for CPB initiation, percutaneous cannulation offers similar outcomes with potentially fewer groin complications (i.e., seroma, hematoma, pseudoaneurysm or infection) (15,16).

Mini-thoracotomy incisions have progressively decreased in size, with some centers transitioning to totally endoscopic approaches (1,13,17-19). To facilitate cross-clamping without central access, options include variations of Chitwood's original transthoracic clamp (4), including a device with detachable aortic cross-clamp head (DeTACH, Corcym, London, UK), or endoaortic balloon occlusion (EABO). Multiple comparative studies (18,20), including a 2024 analysis of the Society of Thoracic Surgeons' Adult Cardiac Surgery Database (STS-ACSD) (21), have shown similar outcomes between transthoracic clamping and EABO, with some suggesting shorter CPB time (20,21) and patient length of stay (17) with EABO. For selected patients, approaches that avoid aortic cross clamping altogether can be performed, including beating heart (22) and moderate hypothermic ventricular fibrillatory arrest RMVr (23).

Modern outcomes

Long-term data from high-volume centers confirm the durability and safety of RMVr in the modern era. Cedars-Sinai's first 300 cases showed fewer complications, fewer reoperations, and decreased procedure times in the latter half of the cohort (24). At Cleveland Clinic, the first 1,000 RMVr procedures achieved a 99% repair rate and demonstrated a reduced stroke rate from 2% to 0.8% over time (25). Mayo Clinic's 10-year follow-up of 843 patients reported 93% freedom from reoperation (26). The University of Chicago's 550 consecutive, totally endoscopic RMVr cases, in a high-complexity cohort [Society of Thoracic Surgeons (STS) mortality risk 2.1%], demonstrated 1.3% 30-day mortality and 95% freedom from reoperation at 5 years (17).

Meta-analyses comparing MIMS (including RMVr) to conventional sternotomy report a shorter hospital length of stay and a comparable to superior risk of short-term morbidity and mortality (27-29). While RMVr typically requires longer cross-clamp times, evidence from high-volume centers demonstrates that outcomes are comparable to conventional approaches (28).

Comparing non-robotic minimally invasive approaches, RMVr, and conventional sternotomy, one meta-analysis reported that MIMS—but not RMVr—was associated with an increased risk of mitral valve reoperation compared to conventional sternotomy, suggesting that the robotic approach may provide technical advantages for a superior repair (30). Results from the STS-ACSD did not find a difference in repair success rates between these three groups, but they did suggest that RMVr patients had a shorter length of stay and fewer readmissions than non-robotic thoracoscopic or sternotomy repair in the U.S. population (31). In Europe, a recent single-center,

propensity score-matched study not only agreed that RMVr length of stay is shorter than that for non-robotic MIMS, but also found these patients are more likely to be discharged to home, as opposed to a facility (32).

Undoubtedly, RMVr remains more expensive than conventional surgery on average (approximately $10,000 in risk adjusted cost), but with shorter lengths of stay and lower rates of complications requiring readmissions, high-volume centers can arguably achieve cost parity (33). Further, returning to work sooner provides economic benefits to patients and their employers (34,35).

RMVr is also effective for complex and concomitant procedures without compromising outcomes. It has been successfully applied in performing surgical ablation for atrial fibrillation (36), tricuspid valve repair (37), and combined interventions such as septal myectomy, coronary artery bypass grafting, and aortic valve replacement (23). In patients with endocarditis (38), prior open heart surgery (39), or prior transcatheter edge-to-edge repair (40), RMVr has proven safe and effective in experienced hands.

Current data overall supports MIMS as a safe and durable approach in appropriate patients. Specific advantages of RMVr include unparalleled anatomical visibility with increasingly smaller surgical incisions resulting in shorter lengths of stay with similar mortality risks to standard approaches. Applicability of RMVr need not be limited by case complexity or the need for concomitant procedures when performed at high-volume centers.

Trends & training in RMVr

Between 2015 and 2021, RMVr was performed at 103 hospitals across the United States (31). Its application to more complex pathologies, including anterior leaflet disease, has increased from 5% in 2011 to 12% in 2022 (41). As outcome data continue to demonstrate safety and durability, interest in performing RMVr is growing, and more centers are seeking to establish programs.

A key consideration for new RMVr programs is the learning curve. Cross-clamp duration has been correlated with mortality in RMVr, making early efficiency crucial (42). Centers have reported proficiency after approximately 30 live cases (43). In a report of two different European centers initiating RMVr—one having previously performed non-robotic MIMS, and the other only conventional mitral surgery—both centers were able to successfully achieve proficiency as measured by surgical case duration (44). Although prior MIMS experience was helpful, as noted by a shorter time to mastery, it should be noted that it is not required for safe adoption.

Program success depends on coordinated team performance. The robotic setup places the surgeon at the console, making the bedside assistant's role essential for instrument exchange, exposure, and troubleshooting. Structured, team-based simulation training can prepare surgical, perfusion, and anesthesia staff to anticipate and manage potential intraoperative complications (45,46). Maintaining those skills by routinely performing robotic surgery, as few as two cases per month (45), is imperative to success.

Training pathways vary (47-49), but effective training should combine high-fidelity simulation, proctored live cases, and gradual expansion of complexity. With increasing exposure to robotics in general and thoracic surgery training, incoming residents can apply non-cardiac robotic skills to robotic cardiac cases. As experience grows from any training pathway, opportunities exist for ongoing refinement to improve efficiency, incorporate broader concomitant cases, and adopt emerging technology, ensuring the continued advancement of RMVr capabilities.

Tips from our RMVr technique

The contemporary RMVr operation at our center reflects the technical refinements of early pioneers in both mitral and robotic surgery. While multiple approaches have been described in the literature (17,46,47,50), we will outline our preferred method, focusing on practical details that contribute to a reproducible setup and strategy.

Anesthesia setup and positioning

After induction, the patient is intubated with a double-lumen endotracheal tube. A central venous line is established in the distal right internal jugular vein (RIJ). More proximally on the RIJ, micropuncture access is obtained and a catheter left in place for percutaneous cannulation if needed. The patient is positioned supine with a scapular roll on the right side. If bilateral thoracoscopic access is planned, a deflated pressure bag is placed under each shoulder. Arms are tucked bilaterally. A transesophageal echo (TEE) probe is inserted, and the patient is sterilely prepped and draped, taking care to include the proximal RIJ catheter in the sterile field.

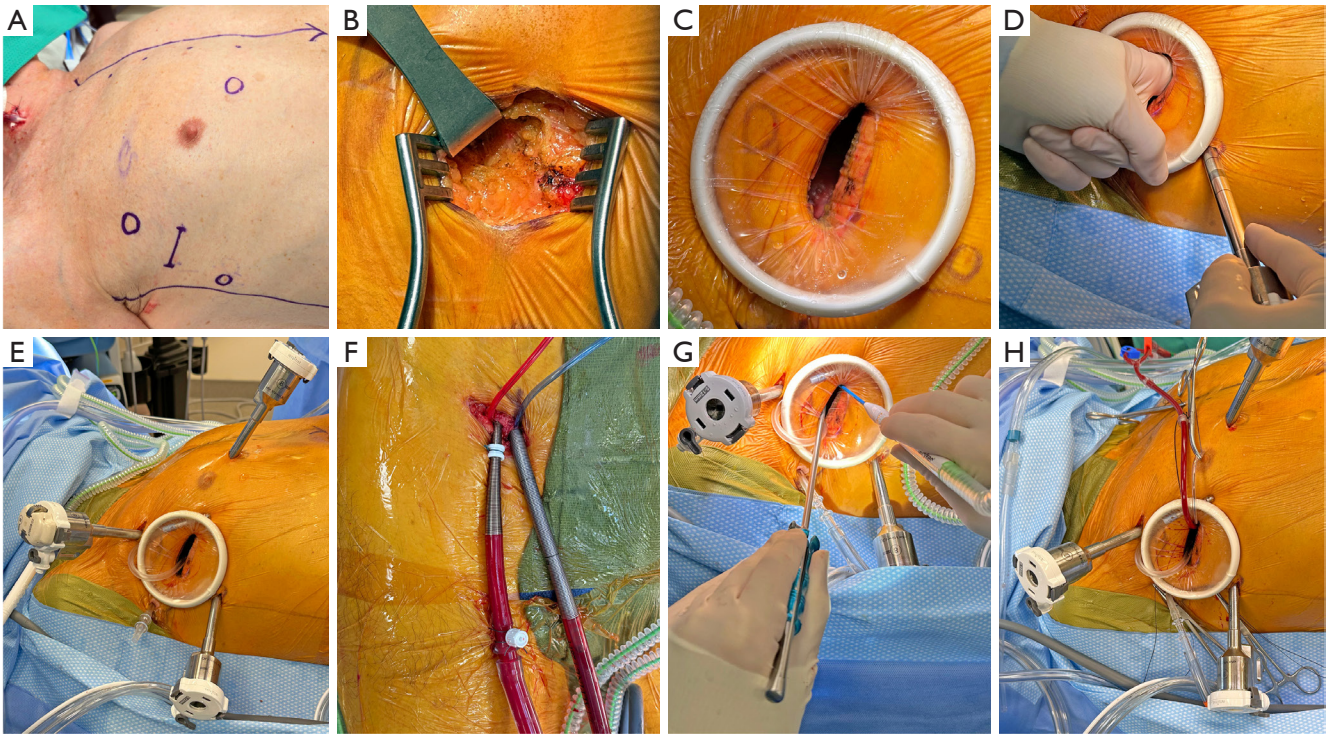

Figure 1 Steps prior to docking robot. (A) Pre-operative markings for thoracotomy and three robotic ports; (B) superior retraction of pectoralis muscle during thoracotomy dissection; (C) thoracotomy with wound protector; (D) trocar placement involving manually retracting internal wound protector; (E) pre-bypass set up after basket has been pulled through posterior incision; (F) femoral cannulation via 2 cm cut down; (G) opening pericardium without rib spreading; (H) antegrade/root vent canula placed prior to docking robot.

Left atrial appendage ligation and ligament of Marshall division (if indicated)

For patients with significant atrial fibrillation burden (i.e., persistent atrial fibrillation or history of multiple cardioversions) we begin with a left thoracoscopic approach for guideline-directed left atrial appendage occlusion (51). A pressure bag under the left scapula is inflated to facilitate optimal positioning. We perform a standard three-port approach and open the pericardium posterior to the phrenic nerve using a Maryland tip tissue sealer-divider (LigaSure, Medtronic, Minneapolis, MN, USA). We identify and divide the ligament of Marshall and occlude the left atrial appendage with an epicardial clip (AtriClip Pro-2 or Pro-V, Atricure, Mason, OH, USA) under TEE guidance. Intercostal nerve blocks are performed with 0.25% bupivacaine, a chest tube is placed through the most inferior port, and the incisions are closed.

While the left atrial appendage can be accessed from the right side via the transverse sinus in most patients, we find that a left sided approach has two key advantages: (I) ability to access and divide the ligament of Marshall, which has intrinsic arrhythmogenicity and (II) the ability to confirm adequate occlusion of the left atrial appendage with real-time TEE assessment. We prefer the transverse sinus approach for patients with low-burden paroxysmal atrial fibrillation to avoid the need for left-sided port access and an additional chest tube.

We feel strongly that patients with atrial fibrillation should undergo epicardial clip application (52) rather than internal suture closure, as internal closure has been associated with failure rates as high as 60% (53,54).

Right mini-thoracotomy and port sites

We begin the formal RMVr operation by making a 2–3 cm incision at the right 4th interspace just anterior to the anterior axillary line (*Figure 1A*). This incision is carried down to the pleura in a muscle-sparing fashion, having an assistant retract the lateral border of pectoralis major

superiorly (*Figure 1B*). The right lung is deflated prior to entering the pleura. For women, the skin incision is made in the inferior breast crease and tunneled to the fourth interspace for thoracic access as described above. After ensuring hemostasis, a small rigid Alexis wound protector (Applied Medical, Rancho Santa Margarita, CA, USA) is inserted (*Figure 1C*). Compared to more flexible alternatives, we have found that a rigid wound protector enhances exposure and often obviates the need for additional rib spreading. This is especially true in women, where the breast tissue tends to collapse the soft tissue around the access incision.

Three, 8-mm robotic trocars are inserted into the 3rd, 4th, and 6th interspaces, respectively. We use blunt-tipped obturators to avoid port site bleeding. When inserting the trocars, the internal portion of the wound protector must be retracted to avoid resistance (*Figure 1D*). A basket suction device is inserted by pulling the proximal end through a 3-mm incision posterior to the thoracotomy in the 4th intercostal space using laparoscopic forceps (*Figure 1E*).

Femoral cannulation

Simultaneously to the previous step, the femoral artery and vein are exposed in standard fashion through a 2-cm cutdown approach. The venous canula is inserted first using Seldinger technique with intraoperative TEE visualization of the wire as it traverses the right atrium into the superior vena cava (SVC). A multi-stage venous canula is inserted with the tip of the canula well into the SVC, as it will pull back with retraction of the heart intraoperatively. For patients with body surface area greater than 2.0, or those requiring bicaval cannulation for right atrial procedures, the RIJ catheter from step 1 is exchanged for an SVC canula. A femoral arterial cannula is inserted after visualization of a guidewire in the descending aorta. CPB can then be initiated (*Figure 1F*).

For patients with borderline femoral artery size (<7 mm) it may be prudent to perform femoral artery exposure before making any chest incisions, as femoral artery spasm can occasionally compromise the safety of femoral artery cannulation. For patients with small femoral arteries, options include sewing a "chimney" graft to the femoral artery or insertion of a distal antegrade perfusion catheter.

Pericardial incision and antegrade/root vent placement

The thoracic anatomy is assessed visually through the mini thoracotomy. If the diaphragm is likely to interfere with insertion of instruments through the right-sided port, a retraction suture is placed, and the diaphragm is retracted inferiorly. Correct position of the mini thoracotomy is confirmed by visualization of the right superior pulmonary vein.

The pericardium is incised 3-cm anterior to the phrenic nerve (*Figure 1G*). Whenever possible, we avoid excessive resection of thymic fat, which can be a problematic source of post-operative bleeding. One posterior retraction suture is placed at the level of the SVC-right atrium junction and a second at the level of the right atrium-inferior vena cava (IVC) junction. These are anchored percutaneously taking care to avoid excessive traction on the phrenic nerve. An anterior pericardial retraction stitch is placed at the level of the aortic fat stripe and brought out through the thoracotomy. A purse-string suture is placed in the aorta proximal to the fat stripe and the antegrade/root vent canula is placed (*Figure 1H*). We make every effort throughout this process to avoid use of a rib-spreading retractor to minimize post-operative pain. If patient body habitus prevents visualization without retraction, this section may be completed robotically.

Robot docking & cross clamping

The robot (DaVinci Xi, Intuitive, Sunnyvale, CA, USA) is then docked with the camera in arm 2 through a trocar floating in the thoracotomy. We begin with Resano forceps in arm 1, a dual blade retractor in arm 3, and monopolar curved scissors in arm 4. The large DaVinci SutureCut Needle Driver and DeBakey forceps are also open and available for exchange when needed (*Figure 2A*,*2B*).

The bedside assistant applies the aortic cross-clamp (DeTACH, Corcym, London, UK) under surgeon visualization at the console (*Figure 2C*) (55). We favor this detachable aortic cross-clamp over EABO or the standard Chitwood clamp, finding it more reliable and technically straightforward without any chance of robot arm interference. A dose of Del Nido cardioplegia is then delivered and the heart is arrested. The patient is cooled to 32 degrees Celsius.

Left atrial Cox-maze procedure (if indicated)

If performing surgical ablation, the left-sided lesions (56) are performed first with cryoablation (cryoICE, Atricure, Mason, OH, USA). These include an epicardial coronary

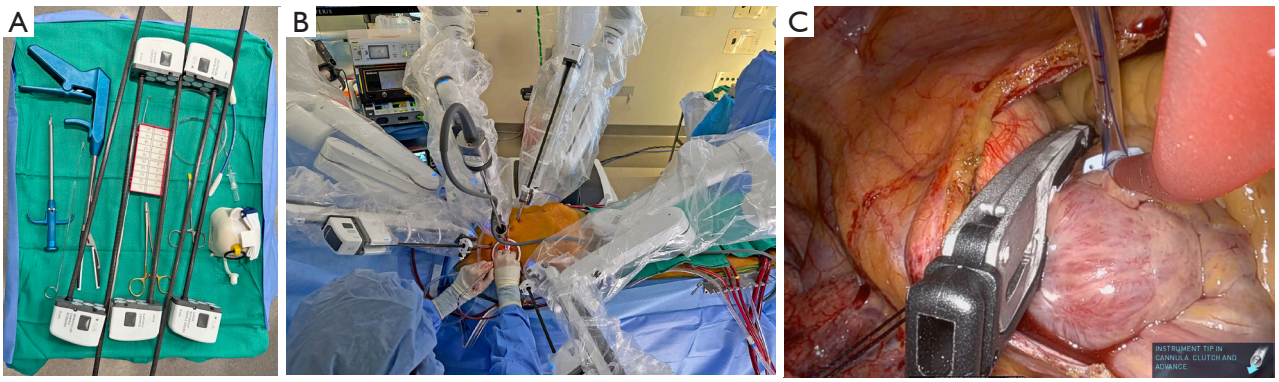

Figure 2 Robot setup. (A) Organized tray including robotic instruments used for robotic mitral valve repair and DeTACH clamp; (B) robot docked with bedside assistant; (C) application of aortic cross clamp.

sinus lesion, intracardiac mitral anulus lesion, and a box around all four pulmonary veins. The posterior box lesion is extended somewhat laterally from the left pulmonary vein orifices, across the Coumadin ridge, to overlap the base of the previously clipped left atrial appendage.

Mitral valve exposure and repair

The left atrium is opened through Sondergaard's groove, and the dual blade retractor is inserted to expose the mitral valve. Repair techniques are individualized according to pathology. Posterior leaflet resection can be performed with curved bipolar scissors. Resection and cleft closures (50) are performed using interrupted sutures with 4-0 Prolene (Ethicon, Raritan, NJ, USA) on an RB-1 needle, cut to 10 cm. If neo-chords are required, they can be created using CV-4 GORE-TEX suture (Gore Medical, Flagstaff, AZ) (*Figure 3A-3C*).

Annuloplasty

We then perform a partial band annuloplasty using a flexible annuloplasty device (Duran AnCore, Medtronic, Minneapolis, MN, USA) that has been removed from the template and holder. Three, 2-0 Ethibond (Ethicon, Raritan, NJ, USA) sutures on an RB-1 needle cut to 11, 10, and 8 cm, respectively, each pre-tied at one end, are used consecutively to run the length of the band on the annulus (*Figure 3D*). We have found that using three separate sutures at these precise lengths, rather than one long suture, prevents the need to have an assistant follow and promotes reproducible spacing. We find this approach to be more expedient than interrupted sutures and extracorporeal fasteners (i.e., COR-KNOT, LSI Solutions, Victor, NY, USA). The perfusionist can begin warming the patient to a goal of 37 ℃ while the annuloplasty is being performed if no other procedures are planned.

Testing the repair and left atrial closure

Using a suction-irrigator device, the assistant fills the left ventricle with saline to evaluate for valve competency and additional repair stitches are placed as needed (*Figure 3E*). A flexible suction catheter is placed across the mitral valve for deairing, and the left atriotomy is closed in a running fashion with CV-4 GORE-TEX suture with the bedside assistant following.

Right atrial Cox-maze and/or tricuspid repair (if indicated)

If bi-atrial surgical ablation is planned, the right-sided Cox-maze cryo lesions are then created. These consist of: vertical right atrial incision, lesion to the tricuspid anulus, lesion to the right atrial appendage, and lesions to the SVC and IVC. It is essential to avoid the sinus node complex, especially near the SVC-right atrium junction, to minimize the risk for postoperative pacemaker requirement.

If concomitant tricuspid valve repair is indicated (57,58), we perform tricuspid valve annuloplasty with a flexible annuloplasty band and running suture technique, similar to that described for the mitral valve in step 9.

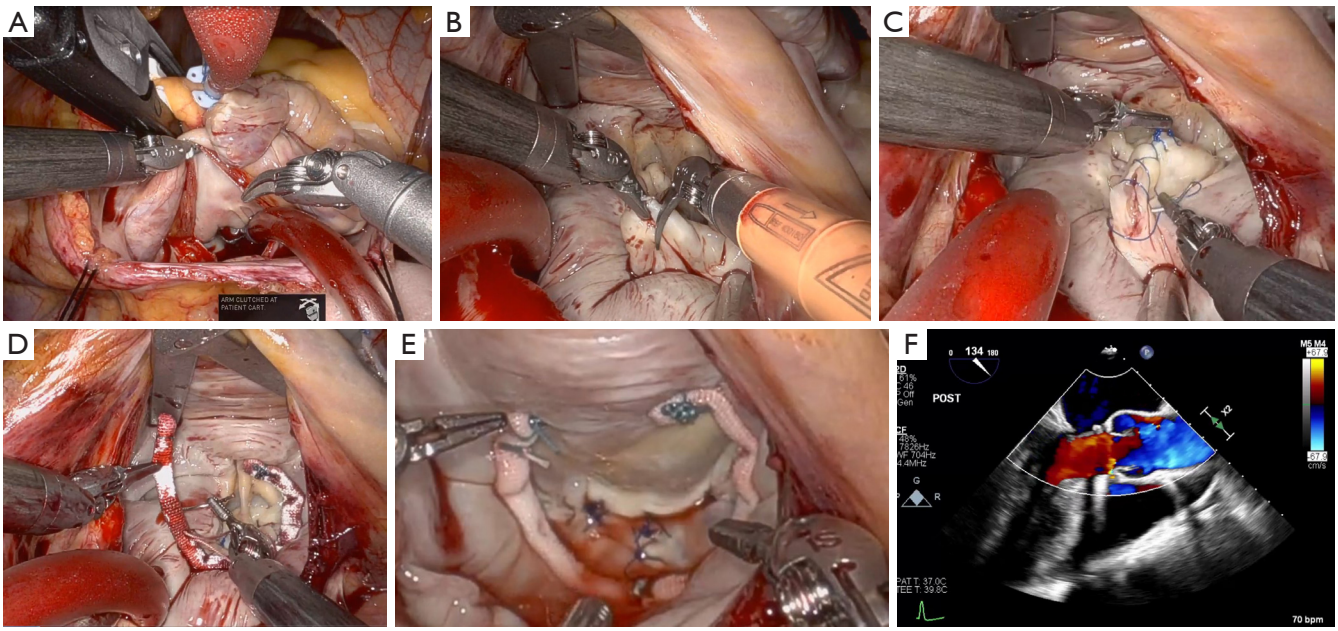

Figure 3 Intraoperative robotic mitral repair. (A) Left atriotomy; (B) triangular resection; (C) suture repair of valve; (D) running-suture partial band annuloplasty; (E) saline valve test; (F) post-repair transesophageal echo showing no mitral regurgitation.

Echocardiographic assessment

The cross-clamp is removed, the left lung is ventilated, and CPB is weaned briefly to evaluate the valve on TEE (*Figure 3F*). The suction catheter is briefly turned off and removed from the heart. A complete echocardiographic assessment is performed. Ideally there is trace-no residual mitral regurgitation (MR); however, if significant MR is present, the atriotomy should be reopened and additional repair or replacement pursued (59). If there is only mild residual MR, reapplication of the cross clamp and further repair of the valve can be pursued if there is a clearly identified, repairable etiology.

De-cannulation and closing

Once the valve is deemed competent and any concomitant procedures are completed, we reinforce suture lines and place an additional purse string suture around the aortic root vent, before undocking the robot. The root vent is removed, lungs are recruited, and CPB is formally weaned. After cannulas and ports are removed and hemostasis is achieved, all incisions are closed, including a peri-costal stitch around the thoracotomy site. A single chest tube is inserted though the most inferior port site. If possible, the patient is extubated in the operating room and taken to the Intensive Care Unit (ICU) (*Figure 4*).

Conclusions

RMVr has progressed from a novel technology to an established, durable option for appropriately selected patients with degenerative mitral valve disease and associated conditions. Advances in patient selection, operative technique, and team-based training have allowed RMVr to match or exceed the safety and efficacy of conventional approaches while offering the benefits of less invasive surgery. The wider success of RMVr depends on expert surgeons, cohesive team performance, and further establishment of high-volume centers with standardized protocols and robot-specific training. As experience grows and technology advances, the scope of RMVr will continue to expand. The cardiac surgery community should continue to invest in training, data transparency, and referral networks to ensure more patients can benefit from this approach, thereby acknowledging that RMVr has evolved from novel to standard of care.

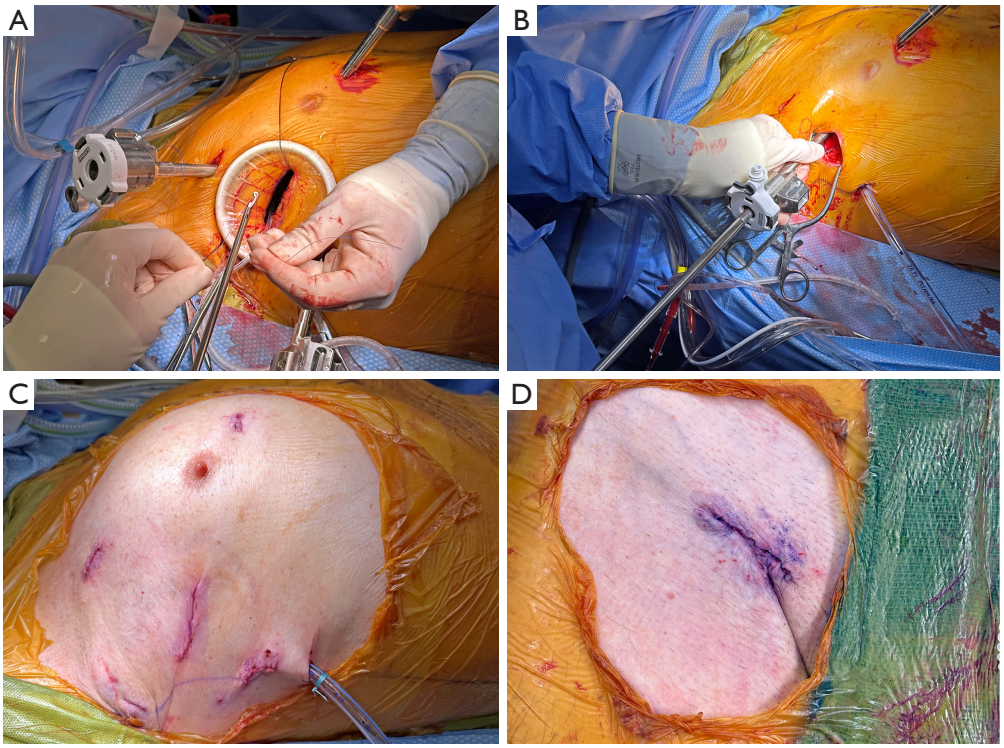

Figure 4 Steps after un-docking. (A) Closing antegrade cannula site with knot-pusher; (B) using camera to check for port-site bleeding; (C,D) final closed incisions on thorax and groin with single chest tube in place.

Acknowledgments

None.

Footnote

Funding: None.

Conflicts of Interest: K.E.H. is a consultant and proctor for Intuitive Surgical and a consultant for Atricure. The other authors have no conflicts of interest to declare.

References

1. Bonatti J, Crailsheim I, Grabenwöger M, et al. Minimally Invasive and Robotic Mitral Valve Surgery: Methods and Outcomes in a 20-Year Review. Innovations (Phila) 2021;16:317-26.
2. Wolfe JA, Malaisrie SC, Farivar RS, et al. Minimally Invasive Mitral Valve Surgery II: Surgical Technique and Postoperative Management. Innovations (Phila) 2016;11:251-9.
3. Carpentier A, Loulmet D, Aupècle B, et al. Computer assisted open heart surgery. First case operated on with success. C R Acad Sci III 1998;321:437-42.
4. Chitwood WR Jr, Nifong LW, Elbeery JE, et al. Robotic mitral valve repair: trapezoidal resection and prosthetic annuloplasty with the da vinci surgical system. J Thorac Cardiovasc Surg 2000;120:1171-2.
5. Cheng DC, Martin J, Lal A, et al. Minimally invasive versus conventional open mitral valve surgery: a meta-analysis and systematic review. Innovations (Phila) 2011;6:84-103.

6. Ailawadi G, Agnihotri AK, Mehall JR, et al. Minimally Invasive Mitral Valve Surgery I: Patient Selection, Evaluation, and Planning. Innovations (Phila) 2016;11:243-50.
7. Burns DJP, Wierup P, Gillinov M. Minimally Invasive Mitral Surgery: Patient Selection and Technique. Cardiol Clin 2021;39:211-20.
8. Moodley S, Schoenhagen P, Gillinov AM, et al. Preoperative multidetector computed tomograpy angiography for planning of minimally invasive robotic mitral valve surgery: impact on decision making. J Thorac Cardiovasc Surg 2013;146:262-8.e1.
9. Chemtob RA, Wierup P, Mick SL, et al. A conservative screening algorithm to determine candidacy for robotic mitral valve surgery. J Thorac Cardiovasc Surg 2022;164:1080-7.
10. Hameed I, Geirsson A. Commentary: Building a successful robotic mitral surgery program-one size does not fit all. J Thorac Cardiovasc Surg 2022;164:1089-90.
11. Mehaffey JH, Hawkins RB. Commentary: Robotic mitral valve surgery selection criteria: Screening algorithm or quantifying selection bias? J Thorac Cardiovasc Surg 2022;164:1088-9.
12. Senay S, Cacur O, Bastopcu M, et al. Robotic mitral valve operations can be safely performed in obese patients. J Card Surg 2021;36:3126-30.
13. Loulmet DF, Ranganath NK, Neragi-Miandoab S, et al. Advanced experience allows robotic mitral valve repair in the presence of extensive mitral annular calcification. J Thorac Cardiovasc Surg 2021;161:80-8.
14. Ranganath NK, Loulmet DF, Neragi-Miandoab S, et al. Robotic Approach to Mitral Valve Surgery in Septo-Octogenarians. Semin Thorac Cardiovasc Surg 2020;32:712-7.
15. Rosen JL, Prochno KW, Yost CC, et al. Use of Percutaneous Cannulation in Robotic Mitral Valve Surgery. Innovations (Phila) 2022;17:92-4.
16. Bastopcu M, Senay S, Güllü AÜ, et al. Percutaneous cannulation for cardiopulmonary bypass in robotic mitral valve surgery with zero groin complications. J Card Surg 2022;37:280-4.
17. Kitahara H, Nisivaco S, Bhasin R, et al. 550 Robotic Totally Endoscopic Mitral Valve Surgeries Within a Comprehensive Robotic Cardiac Program. Ann Thorac Surg 2025;119:1270-7.
18. Yost CC, Rosen JL, Mandel JL, et al. Endoaortic balloon occlusion versus transthoracic cross-clamp for totally endoscopic robotic mitral valve surgery: a retrospective cohort study. J Robot Surg 2023;17:2305-13.
19. Kaneyuki D, Yost CC, Round K, et al. Endoaortic Balloon Occlusion in Totally Endoscopic and Percutaneous Robotic Cardiac Surgery. Innovations (Phila) 2023;18:90-6.
20. Ergi DG, Rowse PG, Daly RC, et al. Single-Center Prospective Study of Cross-Clamp vs Balloon Occlusion in Robotic Mitral Surgery. Ann Thorac Surg 2024;118:412-9.
21. Balkhy HH, Grossi EA, Kiaii B, et al. A Retrospective Evaluation of Endo-Aortic Balloon Occlusion Compared to External Clamping in Minimally Invasive Mitral Valve Surgery. Semin Thorac Cardiovasc Surg 2024;36:27-36.
22. Bolcal C, Kadan M, Erol G, et al. Robotic-assisted beating heart mitral valve surgery: Preliminary report. J Card Surg 2022;37:4790-6.
23. Kitahara H, Nisivaco S, Piech R, et al. Ventricular Fibrillatory Arrest: A Safe Option in Robotic Totally Endoscopic Intracardiac Surgery. Ann Thorac Surg 2023;115:1438-44.
24. Ramzy D, Trento A, Cheng W, et al. Three hundred robotic-assisted mitral valve repairs: the Cedars-Sinai experience. J Thorac Cardiovasc Surg 2014;147:228-35.
25. Gillinov AM, Mihaljevic T, Javadikasgari H, et al. Early results of robotically assisted mitral valve surgery: Analysis of the first 1000 cases. J Thorac Cardiovasc Surg 2018;155:82-91.e2.
26. Arghami A, Jahanian S, Daly RC, et al. Robotic Mitral Valve Repair: A Decade of Experience With Echocardiographic Follow-up. Ann Thorac Surg 2022;114:1587-95.
27. Eqbal AJ, Gupta S, Basha A, et al. Minimally invasive mitral valve surgery versus conventional sternotomy mitral valve surgery: A systematic review and meta-analysis of 119 studies. J Card Surg 2022;37:1319-27.
28. Husen TF, Kohar K, Angelica R, Saputro BIL. Robotic vs other surgery techniques for mitral valve repair and/or replacement: A systematic review and meta-analysis. Hellenic J Cardiol 2023;71:16-25.
29. Al Shamry A, Jegaden M, Ashafy S, et al. Minithoracotomy versus sternotomy in mitral valve surgery: meta-analysis from recent matched and randomized studies. J Cardiothorac Surg 2023;18:101.
30. Yokoyama Y, Kuno T, Takagi H, et al. Conventional sternotomy versus right mini-thoracotomy versus robotic approach for mitral valve replacement/repair: insights from a network meta-analysis. J Cardiovasc Surg (Torino) 2022;63:492-7.

31. Mori M, Parsons N, Krane M, et al. Robotic Mitral Valve Repair for Degenerative Mitral Regurgitation. Ann Thorac Surg 2024;117:96-104.
32. Albano G, Agnino A, Parrinello M, et al. Early Postoperative Complications of Robotic-assisted Versus Minimally Invasive Mitral Valve Surgery: A Propensity Score-matched Analysis. J Cardiothorac Vasc Anesth 2024;38:1996-2001.
33. Hadaya J, Chervu NL, Ebrahimian S, et al. Clinical Outcomes and Costs of Robotic-assisted vs Conventional Mitral Valve Repair: A National Analysis. Ann Thorac Surg 2025;119:1011-9.
34. Hodges K, Burns D, Gillinov AM, et al. Commentary: Surgical treatment of atrial fibrillation at the time of cardiac surgery: Just do it. JTCVS Tech 2021;10:82-3.
35. Mihaljevic T, Koprivanac M, Kelava M, et al. Value of robotically assisted surgery for mitral valve disease. JAMA Surg 2014;149:679-86.
36. Kadan M, Kubat E, Erol G, et al. Early- and mid-term results of cryoablation of atrial fibrillation concomitant with robotic mitral valve surgery. Anatol J Cardiol 2021;25:266-72.
37. Arslanhan G, Baştopçu M, Özcan ZS, et al. Concomitant Tricuspid Valve Surgery Is Not Associated With Increased Operative Risk During Robotic Mitral Valve Surgery. Innovations (Phila) 2024;19:72-9.
38. Raikar C, Wolfe S, Lagazzi LF, et al. Minimally Invasive Valve Surgery for Patients With Infective Endocarditis: A Comparative Study. Ann Thorac Surg 2025;119:1020-6.
39. Murphy DA, Jonsson AA, Halkos ME. Endoscopic Robotic Mitral Valve Surgery in Patients With Previous Sternotomy Cardiac Surgery. Innovations (Phila) 2022;17:297-303.
40. Rowe G, Gill G, Trento A, et al. Robotic Mitral Valve Repair After Failed Transcatheter Edge-to-Edge Repair. Ann Thorac Surg 2022;113:e223-5.
41. Khairallah S, Rahouma M, Gambardella I, et al. Trends in the Management of Anterior Mitral Leaflet Regurgitation. JAMA Netw Open 2024;7:e246726.
42. Doenst T, Berretta P, Bonaros N, et al. Aortic cross-clamp time correlates with mortality in the mini-mitral international registry. Eur J Cardiothorac Surg 2023;63:ezad147.
43. Güllü AÜ, Senay S, Kocyigit M, et al. An analysis of the learning curve for robotic-assisted mitral valve repair. J Card Surg 2021;36:624-8.
44. Sandoval E, Bhoera RA, Tomšič A, et al. Learning curve of robotic mitral repair: prospective two-centre study of proficiency and clinical outcomes. Eur J Cardiothorac Surg 2024;66:ezae426.
45. Xue A, Chen S, Ranade A, et al. How to implement a clinical robotic mitral valve surgery program. Ann Cardiothorac Surg 2022;11:504-9.
46. Patel NC, Macoskey AR. Complications and their management in robotic mitral valve surgery from the surgical assistant's perspective. Ann Cardiothorac Surg 2022;11:510-24.
47. Lehr EJ, Guy TS, Smith RL, et al. Minimally Invasive Mitral Valve Surgery III: Training and Robotic-Assisted Approaches. Innovations (Phila) 2016;11:260-7.
48. Torregrossa G, Amabile A, Oosterlinck W, et al. The epicenter of change: Robotic cardiac surgery as a career choice. J Card Surg 2021;36:3497-500.
49. Halkos ME, Jonsson A, Badhwar V, et al. Developing Proficiency in Robotic Cardiac Surgery. Ann Thorac Surg 2025;119:523-34.
50. Mick SL, Kohlbacher B, Gillinov AM. Robotic mitral valve repair: The steps to success. JTCVS Tech 2023;22:49-52.
51. Wyler von Ballmoos MC, Hui DS, Mehaffey JH, et al. The Society of Thoracic Surgeons 2023 Clinical Practice Guidelines for the Surgical Treatment of Atrial Fibrillation. Ann Thorac Surg 2024;118:291-310.
52. Caliskan E, Eberhard M, Falk V, et al. Incidence and characteristics of left atrial appendage stumps after device-enabled epicardial closure. Interact Cardiovasc Thorac Surg 2019;29:663-9.
53. Petersen J, Böning H, Yildirim S, et al. Efficacy of four different left atrial appendage closure techniques during cardiac surgery-A transesophageal echocardiography follow-up study. JTCVS Tech 2024;26:43-9.
54. Lee R, Vassallo P, Kruse J, et al. A randomized, prospective pilot comparison of 3 atrial appendage elimination techniques: Internal ligation, stapled excision, and surgical excision. J Thorac Cardiovasc Surg 2016;152:1075-80.
55. Hodges K, J.P. Burns D, Gillinov AM. Use of Detachable Aortic Cross Clamp for Robotic Cardiac Surgery. CTSNet, Inc.; 2023.
56. Cox JL, Malaisrie SC, Kislitsina ON, et al. The electrophysiologic basis for lesions of the contemporary Maze operation. J Thorac Cardiovasc Surg 2019;157:584-90.
57. 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.
58. Gammie JS, Chu MWA, Falk V, et al. Concomitant Tricuspid Repair in Patients with Degenerative Mitral Regurgitation. N Engl J Med 2022;386:327-39.
59. Chen Q, Roach A, Trento A, et al. Robotic degenerative mitral repair: Factors associated with intraoperative revision and impact of mild residual regurgitation. J Thorac Cardiovasc Surg 2024;167:944-954.e6.

Cite this article as: Romary DJ, Jefferson HL, Hodges KE. Robotic degenerative mitral valve repair: an evolution. Ann Cardiothorac Surg 2026;15(1):4. doi: 10.21037/acs-2025-dmv-0175