Minimally Invasive Mitral Surgery
Patient Selection and Technique

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KEYWORDS

• Minimally invasive • Mitral valve • Thoracotomy • Robotic-assisted

KEY POINTS

- Patient selection is critical to successful minimally invasive mitral valve procedures.
- A formal assessment based on select echocardiographic and computed tomography features guides the selection process.
- Patient safety is the number one guiding principle.
- Appropriately selected patients should be able to undergo the full range of mitral valve repair or replacement techniques.

INTRODUCTION

Although minimally invasive approaches have become standard of care in many surgical specialties, cardiac surgery has traditionally lagged behind in the adoption of minimally invasive techniques, apart from certain highly specialized centers. Owing to excellent exposure and a high degree of procedural control, the sternotomy is the default for most cardiac surgical procedures. With respect to minimally invasive surgery, the guiding principle is that it is preferable, provided the same or better results can be achieved. However, as we move to a less invasive approach, we necessarily relinquish a certain degree of control. The balance between access and control is fundamental to ensuring patient safety and excellent results.

Mitral valve repair surgery is particularly amenable to a minimally invasive approach, with the expected benefits identical to a conventional approach: superior survival and decreased risks of thromboembolism, endocarditis, anticoagulant-related hemorrhage, and reintervention relative to valve replacement.[1–5] Several approaches have been developed in the last 25 years, most of which continue to be used in some capacity today. The spectrum of minimally invasive mitral valve approaches includes partial sternotomy, right minithoracotomy, and robotic assisted. Of these techniques, robotic-assisted mitral valve repair is the approach favored by the Cleveland Clinic for patients with isolated degenerative mitral valve disease. In this article, we briefly describe the different minimally invasive mitral valve surgical approaches. Building on this analysis, we discuss the process of patient selection, procedure performance, technical challenges, and clinical outcomes in robotic assisted minimally invasive mitral valve surgery.

History and Development

Highly specialized institutions began describing minimally invasive approaches to the mitral valve in the mid-1990s. These procedures began with partial sternotomy or parasternal access.[6–8] The parasternal approach has since been abandoned, but the partial sternotomy approach is still in use. Dr Carpentier first described a thoracotomy-based approach with video assistance in 1996.[9] This approach evolved to include an endoaortic balloon occlusion device and port access

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technology.[10] The minithoracotomy approach has more recently evolved to include a totally endoscopic approach with stereoscopic visualization, rivalling surgical robotics for degrees of visualization and invasiveness.[11,12]

Adapting surgical robotics to cardiac surgery has been, in our opinion, the largest leap forward in minimally invasive mitral valve surgery. The minithoracotomy approach relies on long shafted instruments and video assistance, necessarily limited by the lack of depth perception with 2-dimensional video and limited dexterity with long shafted surgical instruments. Robotic assistance avoids these limitations. There have now been several generations of surgical robotic systems. These devices humbly began with a voice-activated camera arm, and have progressed through multiple generations of telemanipulation systems. The current generation system is the DaVinci Xi (Intuitive Surgical Inc., Sunnyvale, CA), the fourth generation of DaVinci systems. This system provides superior visualization of the mitral valve, with a highly magnified, high-definition 3-dimensional view. With the robotic approach, dexterity is unrivaled. Telemanipulation with tremor reduction provides the surgical robot with the capability of 7° of freedom. The surgeon is provided with a full, stable, unimpinged range of motion. The nonrobotic, totally endoscopic approach with stereoscopic visualization may rival the robotic approach, but the dexterity advantage in current surgical robotics is undeniable.

Intimately involved in the evolution of cardiac surgery, the first robotic-assisted cardiac procedure was described by Dr Carpentier in 1998; this procedure was the repair of an atrial septal defect.[13] Adapting surgical robotics to mitral valve repair, using the early DaVinci system, was pioneered by Dr Chitwood in 2000. Dr Chitwood and his team were able to use the full range of mitral valve repair techniques and demonstrated excellent results.[14] The experience of Dr Chitwood has been the model from which modern robotic mitral valve surgery has evolved.

CENTRAL DISCUSSION: ROBOTIC-ASSISTED MITRAL VALVE SURGERY

Patient Selection

Most patients with isolated degenerative disease can have their mitral valve repaired using a robotic approach, although, in practice, not all patients should. Patient selection is essential to the success of robotic assisted mitral valve surgery. Complications most commonly stem from improper patient selection. The Cleveland Clinic has adopted a relatively conservative screening algorithm for robotic-assisted mitral valve surgery, which has helped to decrease incident complications (**Fig. 1**).[15] We consider patients with significant coronary artery disease requiring revascularization, or a prior sternotomy, precluded from a robotic approach. Regarding coronary disease, although minimally invasive coronary artery bypass grafting, or even hybrid revascularization could be attempted in the setting of a robotic-assisted mitral valve operation, this technique greatly increases both operative time and complexity, and would likely be executed more safely and efficiently from a sternotomy approach. Regarding the patient with a prior sternotomy, we perform reoperations almost universally through a sternotomy approach to maximize patient safety and surgical control. The patient with a high body mass index should still be considered for robotic-assisted mitral valve surgery. However, meticulous care should be taken with incision, port placement, and ensuring postprocedure hemostasis, because bleeding complications can be challenging to address.

In the absence of these factors, the decision of whether to offer a robotic approach depends on the results of preoperative imaging studies, with every patient considered undergoing a preoperative transthoracic echocardiogram and contrast-enhanced computed tomography (CT) scan (see **Fig. 1**).[15]

Echocardiographic Features

Echocardiographic features influencing the decision to offer robotic assisted mitral surgery are mitral annular calcification (MAC), aortic insufficiency, significant left or right ventricular dysfunction, and severe pulmonary hypertension. MAC complicates the performance of an adequate complete repair; if required, MAC debridement can greatly increase the complexity and surgical risk of a mitral valve repair. This process not only prolongs the operation, but can predispose to injury. The requirement to debride and patch the mitral annulus, and the associated risk of annular complications, steers us away from a minimally invasive approach when confronted with significant MAC. Even if debridement and patching are not required, the annulus is stiffened and can cause problems with exposure. Patients with severe MAC are best served by a sternotomy-based approach, although those with mild MAC may be candidates for robotic surgery and the MAC burden should be confirmed by the preoperative CT scan. For these reasons, it is essential to understand the condition of the mitral annulus before the operation.

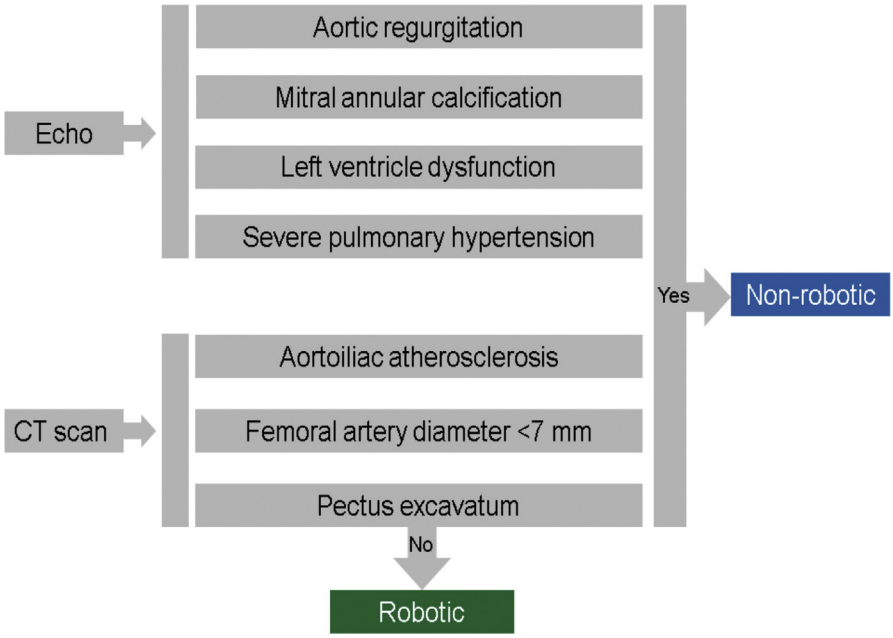

Fig. 1. Algorithm for patient selection in robotic-assisted mitral valve surgery.

We favor antegrade single dose Del Nido cardioplegia for robotic-assisted mitral surgery. Greater than mild aortic insufficiency makes antegrade cardioplegia problematic, and increases the risk of both ventricular distension and inadequate myocardial protection. That being said, some groups rely on percutaneous retrograde cardioplegia cannulas during robotic surgery; great care must be taken to ensure that these cannulas do not become dislodged during surgery, particularly in the patient with aortic insufficiency that is moderate or greater.

We believe that a sternotomy approach should be used for patients with severe left or right ventricular dysfunction to optimize both myocardial protection and operative time. If there are inadequate or inconclusive results from the transthoracic echocardiogram, a preoperative transesophageal echocardiogram (TEE) is completed for clarification.

Computed Tomography Features

A contrast-enhanced CT scan of the chest, abdomen, and pelvis informs cannulation and perfusion strategies, as well as an understanding of the patient's thoracic anatomy for incision and port placement. Significant aortoiliac atherosclerosis, particularly if there is soft plaque present, precludes safe retrograde perfusion via the femoral artery, increasing the risk of cerebrovascular events.[16] Small femoral arteries (<7 mm diameter) or heavily calcified femoral arteries can preclude the safe insertion of an adequately sized femoral arterial cannula, or the safe side grafting of the femoral artery. The CT scan will define which side is preferable for femoral access, based on areas of disease and/or tortuosity. Aberrant vascular anatomy influencing perfusion strategy (discontinuous inferior vena cava, persistent left superior vena cava, or a retroesophageal left subclavian artery) will be identified with a preoperative CT scan, and often precludes a robotic-assisted approach.

Patients with significant pectus excavatum should also be addressed with a sternotomy-based approach. The issue here becomes exposure of the valve itself. With the anterior–posterior diameter of the chest focally decreased , the ability to retract the interatrial septum to expose the mitral valve is compromised. With inadequate exposure, the safety and adequacy of the operation may be compromised. Because the goal of robotic-assisted mitral repair is a repair of the same quality and durability as one performed by sternotomy, exposure concerns are especially problematic.

Anesthesia and Perfusion

To achieve single lung ventilation, intubation is completed using a double lumen endotracheal tube or a single lumen tube with bronchial blocker. A TEE probe is placed in every case to confirm preoperative findings, better define the mitral anatomy, guide the peripheral cannulation, and

confirm adequate results postoperatively. Central venous access is obtained via the right internal jugular vein, followed by an inferior double stick catheter to facilitate wire placement for bicaval cannulation. Defibrillator pads are placed on the right posterior and left anterolateral hemithorax, avoiding the right anterolateral region used for port placement. Interspaces, incision sites at the lateral fourth interspace and over the femoral vessels, and the sternum midline are marked before positioning. The right side of the patient is elevated 30°, and the right arm is supported in internal rotation off the side of the bed. The patient is prepped from the neck to the ankles and draped to expose the right anterolateral hemithorax, sternum (in case of conversion), and femoral arteries.

The femoral vessels are exposed via an oblique 2- to 3-cm incision. Once isolated and adequate size is confirmed, arterial and venous purse string sutures are placed. After heparinization, the femoral vessels are cannulated directly using Seldinger technique, with wire placement confirmed by TEE. The femoral venous cannula is placed so that the tip sits 2 to 3 cm into the superior vena cava. After TEE confirmation of the arterial wire in the aorta, the arterial cannula is placed such that the tip sits in the distal abdominal aorta or iliac artery. Inadequately sized femoral arteries can lead to inadequate systemic flows, as well as to distal limb ischemia. To mitigate this feature, alternative perfusion strategies must be considered. Perfusion via a femoral artery side graft will prevent distal limb ischemia, although the artery still must be adequately sized to support systemic flow. Although not used at our institution, antegrade perfusion via direct aortic cannulation or axillary artery cannulation has been described. Our approach, however, has been to abandon the robotic-assisted approach when faced with inadequately sized femoral arteries.

In patients with a body surface area of 2.0 m^2 or more, a bicaval venous cannulation approach is used. The inferior right internal jugular catheter is used to pass a guide wire into the right atrium under TEE guidance. An additional 15F to 18F venous cannula is then placed percutaneously into the superior vena cava.

Port Placement

After confirmation of femoral vessel size, the right lung is deflated and a 3- to 4-cm working incision is created in the right fourth intercostal space, bisecting the anterior axillary line. In women, the right breast is retracted medially and superiorly, so the incision can be placed in the breast crease. Gentle spreading of the ribs allows visualization of the pericardium and confirmation of position relative to the cardiac structures. If required, a diaphragmatic retraction suture can be placed and run out in an inferior interspace anteriorly. The robotic ports are then placed in a triangular configuration around the working incision. The atrial retractor port is placed through the fourth intercostal space at the midclavicular line. The right robotic instrument arm is placed through the sixth intercostal space just posterior to the anterior axillary line. The left robotic instrument arm is placed in the second intercostal space roughly in between the anterior axillary and midclavicular lines. The completed setup is shown in Fig. 2.

Useful guidelines for port placement include the following:

1. Imagine the ports as the base of a cone, with the apex of the cone located in between the right superior and inferior pulmonary veins.
2. The left robotic instrument port should be roughly equilateral to the retractor port and the right instrument port.
3. The distance between port sites may need to be increased or decreased based on the patient's body habitus to optimize robotic arm range of motion and avoid arm conflicts.

Clamping and Cardioplegia

Once port placement has been completed, cardiopulmonary bypass is commenced and the heart is decompressed; the patient is cooled to 30°C. Through the working incision, the pericardial fat is excised, and the pericardium is opened longitudinally starting near the diaphragm and extending cranially to expose the aorta. This incision should

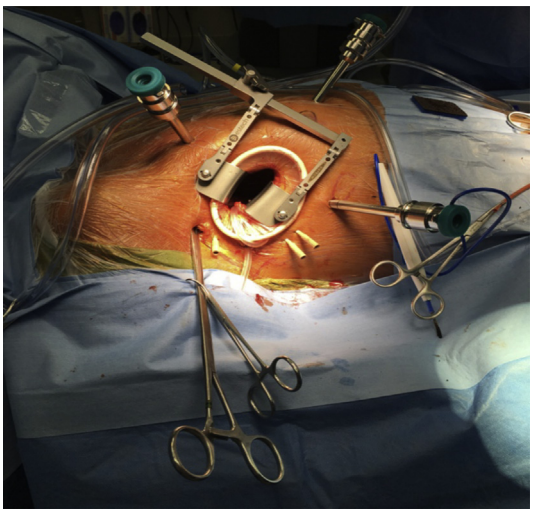

Fig. 2. Final patient setup before robot docking.

be initiated at least 3 cm anterior to the phrenic nerve. It is useful to mark the phrenic nerve in ink to ensure it is avoided. Autologous pericardium is harvested from the anterior aspect of this incision. Pericardial retraction sutures are placed on the posterior aspect of the pericardial incision in the region of the superior vena cava and inferior vena cava, and the sutures are taken out posteriorly through the chest wall.

Two strategies have been described to achieve aortic occlusion and subsequent cardioplegia delivery in minimally invasive mitral valve operations. The first involves placing a separate aortic root cannula for cardioplegia delivery and aortic root venting, along with a transthoracic clamp. The cardioplegia cannula is placed via the working incision. The transthoracic clamp is placed through the third interspace in the midaxillary line. The clamp lies in the transverse sinus and is oriented so the concavity of the clamp is directed cranially. Care must be taken to avoid the pulmonary trunk, left atrial appendage, and left main coronary artery when clamping the aorta. Proper positioning of the transthoracic clamp is essential. This technique will avoid excess tension on the aorta and minimize the rotation and on the aorta after clamping. Additionally, the clamp must lie posterior enough such that the left robotic arm does not exert undue pressure on the clamp during the procedure, predisposing to aortic injury.

The second strategy uses endoaortic balloon occlusion with integrated cardioplegia delivery and venting capability, all facilitated by a catheter introduced via the femoral artery. Balloon positioning is confirmed by TEE and, in some institutions, by fluoroscopy. Bilateral upper extremity arterial lines are required, because the balloon may migrate distally, which can be detected by a decrease in the right upper extremity blood pressure. Because of the possibility of the balloon becoming malpositioned, placing a retrograde cardioplegia catheter via the internal jugular vein is prudent to ensure adequate myocardial protection. Using the endoaortic balloon allows the working port to be reduced in size or eliminated in a totally endoscopic approach. However, it increases procedural complexity and costs.[17] In addition to being somewhat unpredictable and temperamental, the endoaortic balloon also seems to increase the risk of aortic dissection.[18]

Our preferred approach is to use a transthoracic clamp and deliver direct antegrade cardioplegia via the aortic root. We use single dose Del Nido cardioplegia at 20 mL/kg. Additional cardioplegia is given at 60 minutes if the cross-clamp time is expected to exceed 90 minutes. This strategy, one may argue, is not fundamentally different in terms of setup than a nonrobotic minithoracotomy approach. However, this assertion is not incorrect. The advantages are retained in visualization and dexterity, and we believe the transthoracic clamp approach to be safe and predictable. Also, it allows for valve replacement without sternotomy conversion if repair is unsuccessful, although the working incision may need to be extended to accommodate a prosthetic.

Mitral Valve Repair

All advanced mitral valve repair techniques used in sternotomy approaches can be used with a robotic-assisted approach.[19] Only minor modifications are required to accommodate the robotic instruments, and we have described several techniques that have been developed to improve surgical efficiency.[20] The mitral valve is approached through a left atriotomy, using the robotic atrial retractor to optimize valve exposure. As with any mitral valve repair, initial valve inspection takes place, and the repair technique is tailored to the specific valve lesion(s) and morphology.

Posterior leaflet resection and the creation of artificial chordae are both routinely performed with robotic assistance. Narrow regions of prolapse can be addressed with a triangular resection using robotic-adapted scissors and Resano forceps. Interrupted figure-of-eight 4-0 polypropylene sutures re-approximate free leaflet edges. Excessively tall and bulky regions of prolapse are managed by quadrangular resection and sliding plasty, again using 4-0 polypropylene suture for valve reconstruction. This eliminates the prolapse and decreases the height of the posterior leaflet, reducing the risk of systolic anterior motion. The remaining cases of posterior prolapse are managed with artificial chordae.

Posterior neochordae are fashioned using CV-4 polytetrafluoroethylene (PTFE) sutures. These are premeasured based on the affected leaflet, knotted at the tail end, and marked at 1.5 cm from the terminal knot (**Fig. 3**). This marking facilitates an estimation of the chordal length. The PTFE suture is first passed through the valve leaflet (atrial to ventricular). It is then passed through the fibrous region of the corresponding papillary muscle, then back through the valve leaflet (ventricular to atrial), approximately 1 cm from the knotted tail. The suture is then passed twice more (ventricular to atrial) to finish adjacent to the knotted tail on the atrial side. The chord length is then adjusted to eliminate prolapse and ensure a favorable zone of coaptation, and the suture is tied. Care is taken to ensure that the chordae are adequately short to mitigate the risk of

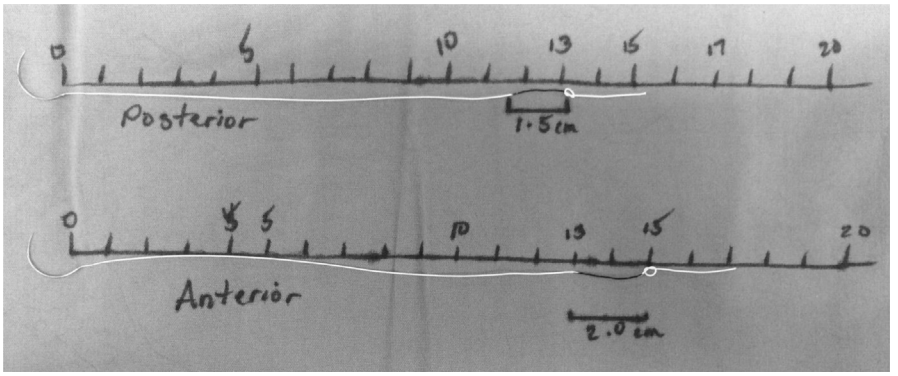

Fig. 3. PTFE neochordae constructed based on the affected valve leaflet.

systolic anterior motion. For a typical P2 prolapse, 2 sets of chordae are used. As required, deep indentations between adjacent P1/2 or P2/3 scallops are closed with interrupted figure-of-eight 4-0 polypropylene sutures. Alternatively, these indentations can be spanned by neochordae. We prefer to use free-hand chordal adjustment, although the use of premeasured neochordae is equally effective.[21]

For the repair of an isolated anterior leaflet prolapse, artificial chordae are preferred. The technique is identical to that previously described, although the PTFE sutures are longer and marked at 2 cm from the terminal knot (see **Fig. 3**). Two sets of chords are fashioned. These chords are oriented on either side of the leaflet midline and are anchored posteriorly to the corresponding lateral or medial papillary muscle. Chord length is adjusted such that prolapse is eliminated and the coaptation zone is moved posteriorly. An isolated A1 or A3 prolapse is typically corrected with commissuroplasty.

Bileaflet prolapse can be managed with a combination of techniques. A true Barlow valve with an exceptional amount of redundant tissue can be managed with a posterior resection and 2 sets of anterior chords. Recently, we have adopted a 4 chords approach to these complex valves.[22] The anterior leaflet is addressed first to optimize papillary muscle exposure, followed by the posterior leaflet. In all cases, each chord corresponds to the medial or lateral aspect of each leaflet, and does not cross the midline. Neochordae are anchored to posterior aspects of the corresponding papillary muscles. Indentations in the posterior leaflet are managed as described previously. Great care is taken to optimize leaflet height. Neochordae must both eliminate prolapse and also move the coaptation zone adequately posterior to mitigate against systolic anterior motion. To this end, posterior leaflet neochordae are left intentionally short (<1 cm).

In line with standard mitral valve repair practices, all repairs should include an annuloplasty. Regardless of the annuloplasty device used, excellent results can be expected.[23,24] We prefer a flexible band annuloplasty owing to its ease of manipulation within the left atrium. There are 3 methods of annuloplasty fixation available: interrupted sutures manually tied with a knot pushing device, interrupted sutures fixed with titanium fasteners, and a running suture fixation. The running annuloplasty uses three 2-0 braided polyester sutures measuring 16, 14, and 9 cm. Each has a preknotted tail to anchor the suture, decreasing the number of robotically tied knots required (**Fig. 4**). Beginning at the posteromedial trigone, the suture is run clockwise to the midportion of the annulus, tied to the second suture, and the second suture continued until the suture reaches the anterolateral trigone. At this point, a third suture is passed though the annuloplasty band, anchored to the anterolateral trigone, and brought back through the band. This third suture is then tied in close proximity to the second. All knot tying is completed with the robotic instruments. This technique was developed at the Cleveland Clinic to optimize surgical efficiency for robotic cases.[20] On completion of the annuloplasty, the valve repair is then tested using conventional saline insufflation.

Left atrial closure is simplified by using 2 CV-4 PTFE sutures fashioned with small loops at each tail and 5-8 pretied knots (**Fig. 5**).[20] This loop creates a snare at the terminal end of the suture, avoiding additional robotic knot tying. One suture is used at each terminal end of the left atriotomy, and run toward the center. A drop suction is placed across the mitral valve before left atrial closure, and removed once the heart begins to eject during weaning from cardiopulmonary bypass, expediting de-airing.

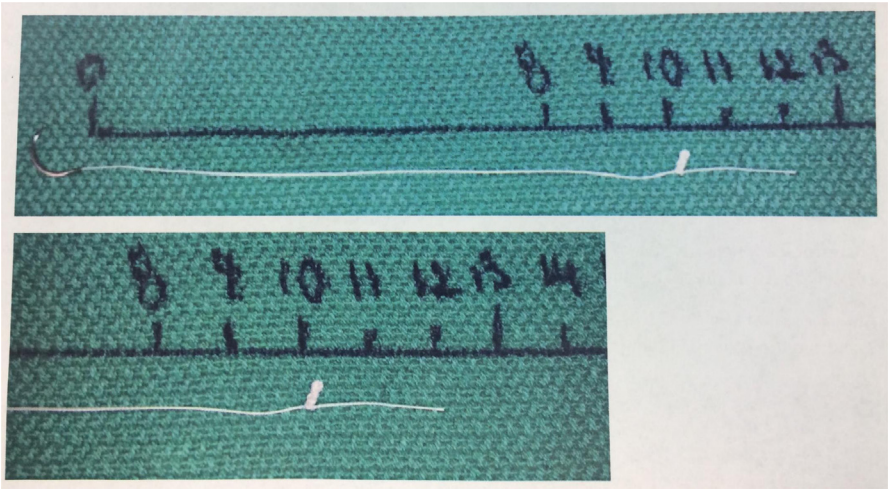

Fig. 4. Preknotted sutures for running mitral annuloplasty.

PITFALLS AND CHALLENGES

Learning Curve

Any mitral valve surgeon can transfer to the robotic platform, although the robotic platform presents several challenges. A lack of tactile feedback requires the surgeon to pay exceptionally close attention to surrounding tissues, which are susceptible to injury. This lack of feedback can also lead to broken sutures while suturing or tying. Although visualization and dexterity are superior using the robotic platform, the surgeon must necessarily relearn how to angle/pass needles and manipulate instruments, because the telemanipulation system does not exactly mirror the movements used in open surgery. Similarly, knot tying can be quite challenging when beginning to use the robotic platform given the reasons highlighted elsewhere in this article.

Equally important is team training and experience. A dedicated robotically assisted cardiac surgery team is recommended, if not essential, requiring dedicated members from anesthesia, nursing, and perfusion who are experienced and comfortable with the procedure. A bedside surgeon is required as well, who must be comfortable with both the robotic technology and the ability to pass sutures, help expose, and generally facilitate the operation. The entire team must negotiate the requisite learning curve. With experience, comfort with the platform improves, as does operative efficiency, which steadily improves until reaching a plateau at approximately 150 to 200 cases.[15,25] Simulation, as an evolving adjunct, helps to decrease this learning curve.[26]

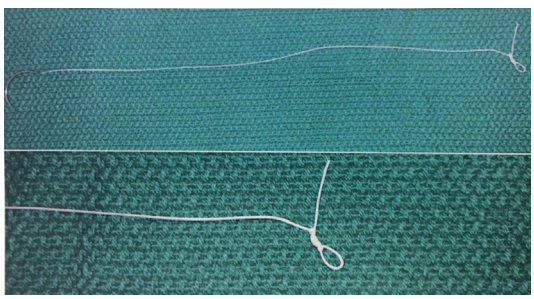

Fig. 5. PTFE suture with end snare, used for left atriotomy closure.

Intraoperative Injury

Cardiac structures are uniquely susceptible to injury during a robotic-assisted procedure owing to placement of the requisite instruments and their interactions during the case. Transthoracic clamping carries the risk of aortic, pulmonary artery, left atrial appendage, or left main coronary artery injury. The transverse sinus must be adequately visualized while placing the clamp to mitigate injury to any of these structures. The transthoracic clamp can also be inadvertently manipulated and torqued by the left robotic instrument if the port is placed with inadequate clearance of the cross-clamp, increasing the risk of aortic injury. Similarly, the left instrument can interact with the antegrade cardioplegia cannula and cause aortic injury.

An endoaortic occlusion balloon can mitigate the risk of pulmonary artery, left atrial appendage, and left main coronary artery injury, as well as eliminate the risk of inadvertent aortic manipulation. However, the endoaortic occlusion balloon seems to increase the risk of aortic dissection and conversion to sternotomy.[17,18] Additionally, aortic occlusion and cardioplegia can be

unpredictable, because the balloon is less stable and prone to dislodging.[27]

Phrenic nerve injury can be mitigated by incising the pericardium at least 3 cm anterior to the phrenic nerve. Marking the phrenic nerve in ink before incising the pericardium serves as a useful technique for avoiding the nerve. The risk of phrenic injury can further be decreased by ensuring that excessive traction is not placed on the posterior pericardial retraction sutures.

Postoperative Bleeding

Weaning from cardiopulmonary bypass typically requires reexpansion of the right lung. Protamine administration and decannulation take place in the usual fashion. Subsequently, the right lung is again deflated and the surgical sites are checked for hemostasis. Major surgical sites (atriotomy, cardioplegia cannula site, pericardial edge, and pericardial fat) are examined under direct vision, with hemostasis achieved using extra sutures or cautery as appropriate. An endoscope is inserted through the atrial retractor port and the left and right instrument ports are removed. Port sites are examined endoscopically and hemostasis is achieved with cautery as required. The atrial retractor port is then removed and the endoscope is inserted through the working port to examine this port site in the same manner. Chest tube drainage is achieved using the right instrument port site.

Meticulous care must be taken with hemostasis, as with any cardiac surgical case. A low threshold to return to the operating room to address postoperative bleeding should be adopted. Prevention is the best way to address postoperative bleeding, because visualization, exposure, and repair can be quite challenging in the context of postoperative hemorrhage in the robotic-assisted minimal access patient.

CLINICAL OUTCOMES

Since the early 2000s, robotic-assisted mitral valve surgery has consistently shown excellent results.[14,27] The entire spectrum of mitral repair techniques are possible.[14,15,28] Cardiopulmonary bypass and cross-clamp times are longer than for sternotomy, especially in the early stages of robotic adoption, but this does not seem to translate into an increase in morbidity or mortality.[28] Intensive care unit and total hospital length of stay are decreased and return to work time is improved.[28–30] Incident stroke and operative mortality consistently measure at less than 1% in major series.[28,31,32] With adoption of the described screening algorithm, the Cleveland Clinic was able achieve a 50% relative decrease our incidence of intraoperative stroke.[15] Infectious complications are similarly low.[15,28,32] Finally, and very important to the patient, the cosmetic result is excellent.

SUMMARY

Once the requisite learning curve has been negotiated, robotic-assisted mitral surgery is safe and effective, producing results of the same quality compared with a sternotomy-based approach. The inevitable reality is that as one becomes less invasive, complexity is increased, and control is relinquished. Using the approaches described for patient selection as well as procedure execution, in robotic assisted mitral valve repair, we believe we have balanced these factors and can offer a safe, predictable, and durable complete repair.

CLINICS CARE POINTS

- Patient safety and repair quality are the 2 main guiding principles in minimally invasive mitral valve surgery.
- Formal echocardiographic and CT assessment is essential to proper patient selection, mitigating surgical risk and making the correct intervention possible via minimal access.
- In minimally invasive mitral valve surgery, all typical mitral valve repair techniques are possible, along with replacement.
- Although we favor the robotic-assisted approach, the general principles are the same between all right chest approaches.
- With any minimally invasive approach to mitral valve surgery, team experience is essential, although there will be a necessary learning curve to overcome.

DISCLOSURE

D.J.P. Burns is a consultant for Medtronic. P. Wierup is a consultant to Medtronic, Edwards Lifesciences, and CryoLife. A.M. Gillinov is a consultant to Medtronic, Edwards Lifesciences, Abbott, CryoLife, Johnson and Johnson, AtriCure, and ClearFlow; and has a right to equity from ClearFlow.

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