Optimizing outcomes of robotic mitral valve repair for all prolapse anatomy: the Suri-Burkhart technique

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Submitted Sep 20, 2013. Accepted for publication Oct 11, 2013.
doi: 10.3978/j.issn.2225-319X.2013.10.05
Scan to your mobile device or view this article at: http://www.annalscts.com/article/view/2902/3818

"The first rule of any technology…is that automation applied to an efficient operation will magnify the efficiency. The second is that automation applied to an inefficient operation will magnify the inefficiency."

Bill Gates

Introduction

Early mitral valve (MV) repair is the evidence-based care standard for those with severe degenerative MV regurgitation and has been shown to improve long-term patient outcomes in comparison to non-surgical management (1). Despite evidence favoring the performance of MV repair prior to symptom onset or the appearance of left ventricular (LV) dysfunction, some physicians are hesitant to refer asymptomatic patients for MV repair involving traditional median sternotomy (2). Alternatively, cardiac surgical procedures including MV repair performed through small incisions utilizing videoscopic assistance are now common-place, and have been shown to be capable of sparing patients the physiological challenge of recuperating from a sternum-dividing operation (3,4). The spectrum of benefits potentiated by use of minimally invasive incisions is well documented in the literature (5). Several large health care delivery systems have embraced minimally invasive surgical approaches aiming to replicate the "gold standard" results of a trans-sternal (open) MV repair aiming to improve patient acceptance and facilitate earlier referral. This thereby minimizes the delayed but substantial costs associated with the evolution of chronic debilitating heart failure or the poor outcomes of rescue surgery once symptoms or LV dysfunction develop (3,6). Recent efforts to uphold the safety and efficacy of standard open operations while decreasing costs have launched robotic MV repair to the forefront of available treatment options for asymptomatic mitral regurgitation (MR).

Indications/contra-indications

Patients with severe MR are referred to Mayo Clinic for MV repair based upon the presence of class IIa indications including: asymptomatic status, preserved LV function (ejection fraction >60% and LV end-systolic dimension <40 mm), and ability to offer a repair rate of 99% with a mortality risk <0.2% (7). Contraindications for a robotic approach include (I) the presence of extensive coronary artery disease requiring coronary bypass grafting; (II) severe peripheral vascular disease precluding safe groin cannulation; and (III) prior median sternotomy or right thoracotomy. The presence of more than 50% coronary lumen stenosis on screening computed tomography (CT) necessitates the performance of cardiac catheterization to confirm the absence of severe coronary disease prior to the designation of candidacy for robot-assisted MV repair. The severity of annular mitral calcification is assessed and, if severe, may exclude the patient from a minimally invasive approach due to the inability to ascertain the location of calcific deposits due to the absence of tactile feedback. In contrast, the degree of prolapse (including anterior or bileaflet involvement) does not influence candidacy for robotic MV repair.

Preoperative imaging

A preoperative transthoracic echocardiogram (TTE) is performed on all patients to confirm severe MR and the absence of cardiac pathology that would otherwise contraindicate a robotic approach. Concomitant procedures including arrhythmia surgery, left atrial appendage ligation,

patent foramen ovale/atrial septal defect closure or tricuspid valve repair are also performed robotically as indicated.

A preoperative ECG-gated CT angiography of the chest, abdomen and pelvis to assess the coronary arteries and peripheral vasculature is performed on all patients considered for robotic mitral repair (8).

Anesthesia

To assist with postoperative pain management, all patients receive a right-sided paravertebral nerve block under ultrasound guidance (9). A total of 25-30 mL 0.5% bupivacaine with epinephrine (1:200 k) is injected through a 21-gauge regional block needle at 2-3 levels between T2 and T6. Patients then undergo general endotracheal anesthesia with single lung isolation capabilities. General anesthesia is induced with propofol, midazolam and fentanyl, while isoflurane, fentanyl and vecuronium are used for maintenance.

Monitoring lines

Monitoring devices include a central venous catheter, left radial arterial line and transesophageal echocardiography (TEE). A 6.5F introducer sheath is placed in the right internal jugular vein 1 to 2 cm cephalad to the clavicle. This sheath is then sterilely prepared into the surgical field for access to percutaneous venous cannulation for cardiopulmonary bypass. Often a 16-cm, 8.5F quadruple-lumen catheter for drug and fluid administration/central venous pressure monitoring is placed 3- to 5-cm cephalad to the introducer sheath in the same vein.

External patches for defibrillation and cardioversion are utilized in a left anterior-posterior orientation on all patients. When cardioverting, robotic instruments are withdrawn from the chest in order to prevent injury from patient movement. Rarely, a single pediatric-sized paddle may be inserted through a quickly enlarged working port incision to defibrillate in the event of intractable ventricular arrhythmia.

Positioning

The bedside team is stationed at the patient's right side while the surgical robot is positioned to the left of the operating table. To prevent injury while facilitating access of the robotic arms to the surgical site, careful positioning of the patient for robot-assisted MV repair must be performed. The right chest is elevated at a 25° to 30° angle above the operating room table utilizing an inflatable bolster. In order to expose the right axilla for transthoracic clamp placement, the right arm is secured at a level below the posterior axillary line. The chin should be securely positioned in line with the center of the chest to avoid brachial plexus strain. Furthermore, the operating table is tilted leftward to facilitate direct passage of repair materials through the working port into the left atrium.

Surgical protocol

Incisions

The right common femoral vessels are exposed through a 1- to 1.5-cm incision and heparin is administered. Rectangular-shaped purse-string sutures are placed in the common femoral artery and vein for cannulation (4).

At the same time, the right lung is deflated and right thoracic access ports are fashioned. Briefly, a camera port is placed 2-cm lateral to the right nipple in the fourth intercostal space. After insufflating the right thorax with CO_2 to 10 mmHg, correct positioning over the bifurcation of the right pulmonary veins is confirmed videoscopically, followed by the fashioning of a 1.5- to 2-cm working port lateral to the camera port. The 0.8-cm right and left arm ports are placed 2 interspaces inferior to and 1-2 interspaces above the working port, respectively. Finally, the left atrial retractor port is placed 3 to 4 cm medially to the camera port in the fourth interspace. The pericardium is opened 4 cm anterior to the phrenic nerve and suspended on stay sutures which are pulled through the right lateral chest wall posterior to the working port. At Mayo Clinic, two fully qualified cardiovascular surgeons are involved in every case, with one being stationed at the bedside and the other at the robotic console. The surgeons work in concert to complete the operation safely and expeditiously during cardiopulmonary bypass.

Patients are given 350 units/kg of heparin for anticoagulation prior to cannulation. Additional heparin (5,000-10,000 units) is administered to maintain an activated clotting time (Hemochron 401, ITC, Edison, NJ) >450 sec. Aminocaproic acid 100 mg/kg loading dose is given followed by an infusion of 30 mg/kg/hour. The cardiopulmonary bypass circuit is primed with 1,500 mL of balanced salt solution, 10 mEq sodium bicarbonate, 12.5 gm mannitol, 5 gm aminocaproic acid and 10,000 units of heparin.

Cannulation, bypass and cardioplegia

A 22F or 25F (Edwards Life sciences CardioVations, Irvine, California) multistage venous cannula is inserted using the Seldinger technique with echocardiographic guidance

and advanced 4 cm superior to the junction between the superior vena cava and right atrium. A 16F or 18F cannula is percutaneously exchanged over a wire inserted through the previously placed right internal jugular sheath into the superior vena cava, taking care to avoid crossing the two cannulas. An appropriately sized femoral arterial cannula is placed via the common femoral artery into the iliac artery or distal abdominal aorta under echocardiographic guidance. Simultaneously, full 2D and 3D image acquisition is performed using TEE to assess the MV regurgitation and delineate the anatomy.

Once fully anticoagulated, we proceed onto full cardiopulmonary bypass over two minutes, while monitoring the descending thoracic aorta by TEE to confirm laminar flow and the absence of a dissection flap. Once the patient is fully supported on bypass at a flow of 2.4 $L \cdot min^{-1} \cdot ms^{-2}$, a long tack vent cannula (Medtronic, Minneapolis, Minnesota) is placed in the ascending aorta just below the right pulmonary artery utilizing a non-absorbable polypropylene suture (Prolene; Ethicon Inc, Somerville, New Jersey) with a felt pledget. The tack vent is pulled through the chest wall backwards to create a straight line of trajectory to the purse-string suture. The tack is inserted into the ascending aorta and snared into place. The transthoracic clamp is inserted through the chest wall along a direct trajectory to the transverse sinus and the aorta is cross-clamped taking care to avoid the right pulmonary artery and left atrial appendage. The heart is arrested with 1 L of cold blood cardioplegia, which is re-administered at 20-minute intervals throughout the cross-clamp time. Cardioplegia instillation into the coronary ostia is confirmed using TEE.

Intracardiac repair

Once the heart is arrested, the left atrium is opened with an incision posterior to the interatrial groove to expose the MV. Standard published Mayo Clinic repair techniques are used in all robot-assisted MV repair cases, without modification or "short cuts" (10,11). Briefly, standard triangular resection with 2-layer polypropylene reconstruction is typically used for posterior leaflet disease while anterior leaflet prolapse is treated with polytetrafluoroethylene (PTFE, Gore-Tex; W. L. Gore & Associates, Inc, Flagstaff, Arizona) neochord resuspension. As previously described for open repairs at our institution, all repairs are protected using a standard-length 63 mm posterior annuloplasty band. When bileaflet pathology is present, a combination of these techniques is used.

All sutures are tied by the bedside surgeon. Repairs are inspected using saline insufflation, and the left heart is filled before closure, deairing, and cross-clamp removal. An intraoperative TEE is performed to assess the integrity of the repair [≤ mild residual (MR)] and adequacy of deairing. The patient is then returned temporarily to full support for removal of the cardioplegia tack vent and tying of the ascending aortic stitch. Decannulation and reversal of heparin are performed in the usual manner.

Drains and closure

Once hemostasis has been secured, a 19F soft silicone (Blake; Ethicon) drain is placed in the oblique sinus, and the pericardium is tacked together with three interrupted silk sutures, after which a 32F chest tube positioned in the right posterior diaphragmatic sulcus. The chest wounds are closed in layers with polyglactin 910 absorbable sutures (Vicryl; Ethicon). Ketorolac, 30 mg, is given intravenously immediately prior to skin closure. Local anesthetic (0.25% bupivacaine) is infiltrated at the femoral incision site, and also the surgical port sites if no paravertebral blocks were performed. Neuromuscular blockade is reversed with neostigmine and the isoflurane is discontinued.

Post-operative management

Patients are typically extubated in the operating room at the conclusion of surgery prior to intensive care unit transfer. Most patients transition to the step-down unit (ward care) the same evening of surgery. Warfarin thromboprophylaxis and beta blockade are initiated at that time.

The morning following surgery, central lines and the Foley catheter are typically removed. Chest tubes are discontinued once drainage is <300 cc/24 hours. A pre-discharge TTE is obtained and patients are routinely dismissed home on the third postoperative day without activity restrictions. All robotic patients are seen in follow-up 1 month after surgery and, at that time, undergo follow-up TTE examination (5).

Comments

The authors have maintained strict adherence to seven guiding principles in performing safe, efficient and effective robotic MV repair operations at Mayo Clinic (3-5). Firstly, we have taken great care not to "change the operation". The safety, efficacy and long-term durability of standard valvuloplasty techniques utilized at our Institution for over 30 years have now been duplicated in the closed chest milieu using robotic instrumentation. Second, as we migrated from open sternotomy, to mini-thoracotomy, to thoracoscopic and finally

port access incisions, we ensured that "safety and quality were at the forefront of our aims". The three aforementioned contraindications to a robotic approach in our program are respected–significant coronary disease requiring surgical revascularization, peripheral vascular disease precluding safe groin cannulation and prior sternotomy/right thoracotomy. In our view, the benefits of a port access approach using current robotic and perfusion technology do not currently outweigh more traditional surgical access in these situations. The development of permissive technical adjuncts may alter one or more of these in the future. Thirdly, in adhering to standard techniques of mitral valvuloplasty and above-articulated principles of safety we have been able to repair all categories of leaflet prolapse with predictability and outcomes indistinguishable to open operation. In general, we would encourage surgical teams to approach only those categories of mitral prolapse that they feel confident with, either using either standard sternotomy or less invasive port access approaches, particularly in light of the fact that a Class IIa indication for MV repair in asymptomatic patients mandates the ability to deliver reproducible results with >90% certainty. The repair rate for degenerative mitral prolapse in our robotic series to date has been 100% and "all categories of leaflet prolapse are considered as equally suitable for robotic MV repair". We have maintained close follow-up of robotic patients treated in our program to date. Most patients rapidly return to daily activities with normal NYHA functional status as one would expect from the results of early MV repair performed internationally prior to the onset of symptoms or LV dysfunction. Additionally, we routinely re-evaluate patients in clinic at 1-month and 1-year following robotic repair and then yearly thereafter in order to maintain the ability to "carefully track and report outcomes". During follow-up, we have incurred a <1% reoperation rate and with the accrual of team experience, we have noted "a steady diminution of cardiopulmonary bypass and cardiac ischemic times". Current cross clamp times for posterior leaflet repair are in the range of 30-45 minutes and 45-60 minutes for anterior and bileaflet disease. These times compare favorably to a recent report from the STS database detailing median a median cardiac ischemic time of 81 minutes for MV repair largely utilizing conventional approaches (13.7% robotic) (12). While those who do not perform robotic repair claim that the benefits to patients are uncertain, this has not been the case in our experience. We have found that while quality of life outcomes are very good following both open and robotic MV repair, a port-access approach is associated with earlier dismissal from hospital (3 *vs.* 5 days), quicker return to work and slight improvements in very early (first 2 months) quality of life compared to conventional open repair patients. There are therefore indeed "defined benefits for patients undergoing robotic and less invasive port access approaches". Finally, with recent escalation in US health care spending and forthcoming implementation of the Patient Protection and Affordable Care Act, incremental health care expenditures will require a heightened level of fiscal justification. Our ongoing financial analyses have documented that technical innovations using robotic equipment deployed in conjunction with systems innovations (surgical process improvement) in standard risk patients undergoing isolated MV repair has "decreased the cost of robotic repair such that it is now equal to that of standard sternotomy" (13). Further efforts to expedite care have been intentional and ongoing, including extubation in the operating room and transfer to ward-based care the same day of surgery. These strategies have contributed to the de-escalation in the acuity of care and further decreases in cost over time. Ultimately, the ability to decrease robotic equipment charges by the manufacturer will further aid in enhancing the affordability of future robotic operations in cardiac surgery and other subspecialties.

Several additional considerations are central to efforts aimed at improving the efficiency and value of less invasive cardiac surgical procedures utilizing new and less invasive surgical technology. Firstly, there is increasing recognition that certain technically specialized, highly experience-dependant procedures such as complex MV repair performed by surgeons at centers with a "minimum yearly volume" may be associated with improved outcomes. This is an a priori qualification necessary prior to the introduction of a technically advanced platform (such as minimally invasive or robotic MV repair), where critical decision making without the aid of traditional visual and tactile clues must be performed in a time sensitive manner to keep patients safe. Secondly, strict duplication of conventional open surgical techniques using port-access technology must be ensured and results must be carefully scrutinized using echocardiographic surveillance both immediately following separation from bypass and early postoperatively. Quality metrics should be indistinguishable between open and robotic approaches. Credentialing statements will be important guideposts to both surgical teams and institutions keen to adopt robotic surgical platforms. Finally, the systematic implementation of scaled postoperative care paradigms is crucial. Committing to the substantial investment involved with introduction of a high technology robotic platform while failing to appropriately de-escalate the intensity of postoperative care will inevitably deny patients the benefit of a port-access operation, unnecessarily inflate costs

and decrease health care value.

Conclusions

Robotic MV repair can be performed safely and effectively for all categories of leaflet prolapse. Surgeon and team based training is crucial, as is the adherence to seven underlying principles articulated above in order to decrease cost and increase value for both patients and the health care delivery system.

Acknowledgements

Disclosure: The authors declare no conflict of interest.

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Cite this article as: Suri RM, Burkhart HM. Optimizing outcomes of robotic mitral valve repair for all prolapse anatomy: the Suri-Burkhart technique. Ann Cardiothorac Surg 2013;2(6):841-845. doi: 10.3978/j.issn.2225-319X.2013.10.05

