MINIMALLY INVASIVE MITRAL VALVE REPAIR: FROM TOTAL ENDOSCOPIC TO CLOSED-CHEST ROBOTIC

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INTRODUCTION

Minimally invasive cardiac surgery has evolved over the past few decades, thanks to advancements in technology and surgical techniques. These advancements have allowed surgeons to perform cardiac interventions through small incisions, reducing surgical trauma and improving patient outcomes[1]. However, despite these advancements, thoracoscopic mitral repair has not been widely adopted by the cardiac surgery community, possibly due to the lack of familiarity with video-assisted procedures[1].

Over the years, various minimally invasive mitral valve surgery (MIMVS) techniques have been developed to achieve comparable or better results while minimizing surgical trauma. These techniques have evolved from direct-vision procedures performed through a right thoracotomy with a rib retractor to video-directed approaches using long-shafted instruments[1].

Robotic surgery, introduced in the late 90s, has also played a significant role in mitral valve repair. The da Vinci system, the only robotic platform currently used for cardiac surgery, provides surgeons with enhanced dexterity and high-definition 3D visualization, allowing for precise and accurate procedure[2], and is now the preferred approach for mitral repair in many programs[3]. The first mitral repair using the da Vinci system was performed in Europe by Carpentier and Mohr in 1998, followed by the first mitral replacement by Chitwood in the USA in 2000[2-4].

The advantages of robotic technology allow surgeons to perform complex repair techniques such as papillary muscle repositioning and sliding leaflet plasty[4]. Studies have shown that robotic mitral surgery results in shorter ICU and hospital stays, better quality of life postoperatively, and improved cosmesis compared to conventional surgery[5,6].

In our experience, we have also observed significant benefits with robotic surgery, including reduced blood loss and the need for transfusions. This can be attributed to the closed-chest technique, which eliminates the need for a thoracotomy and rib retractor, reducing the risk of bleeding associated with these approaches[7].

In this article, we will compare the surgical steps of endoscopic and robotic mitral valve repair, providing detailed information on patient selection, operative techniques, and the requirements for building a successful program. By understanding the advantages and challenges of both approaches, surgeons can make informed decisions and provide the best possible care for their patients.

Combined ablation and multivalvular procedures are mostly performed in few centers by minimally invasive techniques.

Figure 1 *CPB with cannulation of the right common femoral vessels*

Figure 2 *Periareolar approach*

PREOPERATIVE EVALUATION

Before undergoing surgery, all patients receive a thorough medical history and physical examination. They also undergo a computed tomography (CT) scan of the chest, abdomen, and pelvis to check for any anatomical issues that could affect the placement of ports or restrict the movement of the robotic arms. These issues may include scoliosis, pectus escavatum, pleural thickening, phrenic nerve palsy, intrathoracic herniation of abdominal organs, previous thoracic surgery, radiation therapy, or thoracic trauma. The CT scan also evaluates the aorta and the remaining vascular system, including femoral arteries and veins. Additionally, all patients undergo a comprehensive transthoracic echocardiographic evaluation to assess their heart function, and the coronary anatomy is evaluated through the CT scan or angiography in selected patients.

Indications and Contraindications

Minimally-invasive mitral surgery follows the same indications as conventional surgery, as outlined in the guidelines published by major European and American scientific societies of cardiac surgery and cardiology[8,9]. However, there are specific contraindications for endoscopic and robotic procedures, including severe peripheral vascular disease or aneurysms of the descending thoracic or abdominal aorta, dilatation of the ascending aorta greater than 45 mm or calcification, previous right chest surgery, coronary artery disease requiring revascularization, severe chest wall deformities, severe pulmonary dysfunction or pulmonary hypertension, moderate to severe aortic stenosis or regurgitation, and severe calcification of the mitral annulus.

FUNDAMENTALS IN MINIMALLY INVASIVE CARDIAC SURGERY

Minimally invasive cardiac surgery techniques, such as thoracoscopic and robotic approaches, have revolutionized the field of mitral valve repair. These approaches share common techniques, tools, and anesthetic management, as well as similar patient selection and postoperative care strategies.

Both thoracoscopic and robotic approaches utilize retrograde peripheral perfusion and offer options for myocardial protection during surgery. The use of thoracic ports is common, although the uniportal concept is gaining popularity. Instead of direct vision, these approaches rely on thoracoscopic visualization, which provides a clear view of the surgical site. Additionally, specially designed surgical instruments are used to facilitate the repair process.

Beyond the technical aspects, both approaches emphasize patient selection and postoperative management to ensure successful outcomes and faster recovery. The goal

Figure 3 *Setup for Uniportal VATS approach for mitral valve repair*

is to enable patients to return to their normal activities as quickly as possible after surgery.

OPERATIVE TECHNIQUE

Common Steps for Endoscopic Surgery and Robotic: Patient Preparation and Cardiopulmonary Bypass

Once the patient is under anesthesia, intubation is performed, and a transesophageal echocardiography (TEE) probe is inserted. Intubation can be done using either a double-lumen endotracheal tube or a single-lumen tube with a bronchial occluder balloon. The patient is positioned in a supine position, with the right side of the surgical table as close as possible. A blanket roll is placed along the right hemithorax to slightly elevate the right chest, and the right arm is positioned below the right chest to expose the lateral chest and axilla. Care is taken to protect the arm and prevent neural injuries from compression against the table structure.

Cardiopulmonary bypass (CPB) is typically initiated by cannulating the right common femoral vessels. A small 3 cm incision is made to expose both vessels while minimizing dissection to avoid damage to surrounding neural structures and reduce the risk of seroma formation after surgery. Only the anterior wall of the vessels is exposed, and two 5/0 polypropylene purse-strings are placed in a rectangular fashion along the long axis of both vessels. After heparinization, the femoral vein is cannulated using the Seldinger technique, and a guidewire is advanced under TEE guidance into the superior vena cava. The puncture site is then sequentially enlarged using dilators, and a 25F multiperforated venous cannula is introduced and positioned with its tips 3 to 5 cm inside the superior vena cava (SVC) under TEE guidance. The venous cannula is secured to the skin with stay sutures. Arterial cannulation is performed using the same technique, with TEE used to verify the position of the guidewire in the descending aorta. The size of the arterial cannula is determined by the diameter of the vessel and typically ranges from 15F to 19F.

With this technique, routine cannulation of the jugular vein is not necessary for mitral surgery. However, it is important to use vacuum-assisted drainage in the venous line and ensure that the venous cannula is correctly positioned inside the superior vena cava to prevent occlusion by the Chitwood clamp when the atrial retractor is placed in the left atrium and pulled anteriorly to expose the valve.

Endoscopic Surgery

Port Placement and Initial Steps

During left-lung ventilation, the working port is created in the 4th intercostal space, with a 3-4 cm incision made around the level of the anterior axillary line (infra-mammary line in female patients). In male patients, we prefer to make a peri-areolar incision for cosmetic purposes (Figure 2).

To prevent the introduction of fatty tissue or debris into the cardiac chambers, a soft-tissue retractor is placed during the introduction of surgical instruments, sutures, or valvular prostheses. We also introduce a 10 mm 30-degree videothoracoscopic 4K or 3D camera through the same working port to guide the procedure. The camera is held by an articulated arm placed on the right side of the headpiece of the surgical table (Figure 3).

Throughout the entire operation, CO^2 is continuously insufflated at a rate of 4 L/min. This creates an intrathoracic CO^2 environment that reduces the risk of air embolism after releasing the aortic clamp.

A small incision is made in the 6^{th} intercostal space, mid-axillary line. This incision is used to exteriorize retraction sutures placed in the diaphragm and lower portion of the pericardium, as well as to introduce the left atrial vent line. After the procedure is completed, a 28F chest tube is passed through this incision and left in the pleural space. If diaphragmatic retraction is needed (in more than 75% of

Figure 4 *Introduction of the mitral ring through the working port*

Figure 5 *Position of robotic trocars and AirSea® valveless trocar*

Figure 6 *operative field with all four robotic arms connected to the trocars*

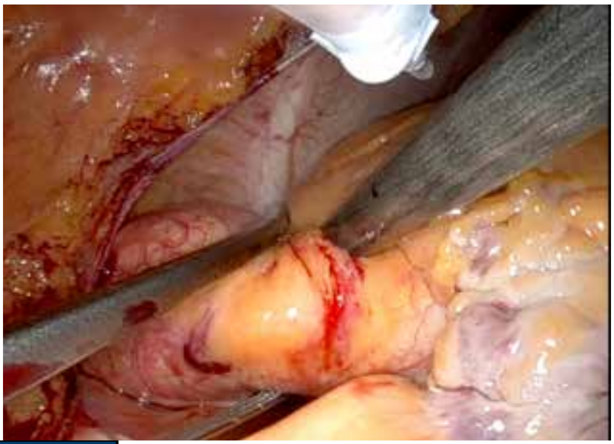

Figure 7 *Aorta clamping with Chitwood clamp*

cases), a pledgeted "2/0" polyester suture is placed and tied in the central tendon, taking care not to damage the liver. The traction suture is then exteriorized through the incision and tension is applied to improve exposure. The pericardium is completely opened in its lateral aspect with a longitudinal incision performed at least 3 cm anterior to the phrenic nerve. Two polyester stay sutures are placed near the cranial and caudal ends of the posterior edge of the pericardium and exteriorized using the incision for the caudal suture and a transthoracic puncture just cranial and posterior to the working port, in the mid-axillary line.

After opening the pericardium and placing the stay sutures in the diaphragm and pericardium, the aortic cross-clamp is inserted through a 5 mm incision in the 3rd intercostal space, mid-axillary line (Figure 3). A curved Chitwood clamp is advanced inside the pericardium and placed across the ascending aorta, with its lower jaw placed inside the transverse sinus under thoracoscopic vision. Blunt instruments, typically a thoracoscopic suction cannula, are used to push the aorta anteriorly. Once the aortic clamp is in place, a pledgeted purse string using a 4/0 polypropilene suture is placed in the ascending aorta, and a long cardioplegic needle is inserted through the working port under thoracoscopic vision. Cardiopulmonary bypass is then initiated, and upon reaching full systemic flow, the ventilator is disconnected, and the aorta is cross-clamped.

Our technique for myocardial protection involves the antegrade administration of a single-dose crystalloid cardioplegia (Custodiol®. Dr. Franz Köhler Chemie, Germany) in the aortic root after cross-clamping the aorta. This provides more than 120 minutes of myocardial protection with one shot, which is typically enough for a mitral valve repair procedure. During cardioplegia infusion, the left atrium is opened just below the interatrial septum, and the left atrial vent is introduced and placed in the left pulmonary veins to maintain a bloodless surgical field. The size of the left atrial retractor blade is selected at this moment, and the stem of the retractor is placed under thoracoscopic control, typically through the 5th intercostal space along the midclavicular line. The retractor is then assembled inside the thorax and placed inside the left atrium. Retraction is applied to achieve adequate exposure of the mitral valve. The atrial retractor is held in place using a second articulated arm placed on the left side of the table (Figure 4).

COMPLETION OF THE OPERATION

Once the mitral repair or replacement is completed, the left atriotomy is closed using monofilament sutures, such as barbed 3/0 polybutester or a double layer of simple 3/0 polypropylene. Two sutures are secured at both ends of the atriotomy and sutured towards the center. During this step, the left atrial vent line is removed to allow blood to fill the left cardiac chambers and start the de-airing process.

To remove as much air as possible from the heart and pulmonary veins, suction is applied in the root vent line, and both lungs are manually inflated. The venous line can be intermittently clamped to allow blood to fill the right heart and lungs, pushing air out from the heart. Once de-airing is complete, the patient is positioned in trendelenburg, and the aortic clamp is released to reperfuse the heart.

Pacing wires are not routinely placed after isolated mitral repair in patients without previous rhythm abnormalities. If needed, they can be placed in the right atrial wall and/or right ventricular wall. After restoring normal rhythm and ensuring satisfactory valvular and ventricular function through echocardiographic evaluation, the patient is weaned from cardiopulmonary bypass.

The aortic root vent is removed after completing the echocardiographic evaluation under a short period of full-flow cardiopulmonary bypass. This facilitates the removal of the cannula and repair of the entry site with low aortic pressure and reduced pulsatility. Once this is done satisfactorily, the patient is weaned from cardiopulmonary bypass, decannulated, and given protamine to reverse the effects of heparin.

Draining tubes, such as a pericardial drain (19F Blake drain) and pleural drain (28F curved chest tube), are implanted through the incisions made. The pericardium is loosely approximated with interrupted sutures to avoid the low risk of cardiac herniation and facilitate reoperation if needed in the future.

After removing the cannulas from the femoral vessels, the purse strings are tied, and the cannulation sites are reinforced with polypropylene sutures. Once hemostasis is achieved, all incisions are closed with intradermic sutures. The patient is usually extubated in the operating room immediately after the operation is completed. (Figure 5)

ROBOTIC SURGERY

Trocar Placement and Initial Steps

In robotic surgery, the trocars are placed in specific locations. The second arm trocar is placed in the fourth intercostal space near the anterior axillary line. CO^2 insufflation is connected to create a controlled capnothorax with a 10 m hug pressure. The camera is then inserted to confirm lung deflation and check for pleural adhesions. Two guidewires are placed along the posterior axillary line for pericardial retraction sutures. The fourth arm trocar is placed slightly posterior to the camera trocar in the sixth intercostal space, and the first arm trocar is placed in the third intercostal space, in line or slightly anterior to the camera trocar. The trocar for the third arm is placed in the fifth intercostal space, mid clavicular line. To create a closed-chest robotic approach, a 12mm AirSeal® valveless trocar is inserted in the fourth intercostal space, 3-4 cm posterior to the camera trocar, to serve as a working port and for continuous CO^2 insufflation. This maintains the capnothorax pressure throughout the case, eliminating the need for retraction sutures to retract the diaphragm caudally. (Figure 6)

Before docking the robotic system, heparin is administered, and the femoral vessels are cannulated under transesophageal echocardiographic guidance. Once the robot is docked and the instruments are inserted, cardiopulmonary bypass (CPB) is initiated. The aorta is clamped transthoracically using a Chitwood clamp (Figure 8), and myocardial protection is achieved by administering a single-dose crystalloid cardioplegia (Custodiol®) in the aortic root through the AirSeal trocar. (Figure 9)

The mitral valve is accessed through a left atrial incision and exposed using the robotic atrial retractor placed in the third arm. (Figure 10).

The valve is examined using both robotic arms, and the repair is performed. A "water-test" is used as needed, using a flexible tube introduced through the working port. Once the repair is considered satisfactory, the left atrium is closed using barbed 3/0 V-Loc sutures, the aortic clamp is removed, and the cardioplegia entry site is repaired with a suture. A 19F Blake silicone drainage is placed in the pericardial space through the third arm entry site, and the pericardium is loosely closed. The robotic arms are removed, ventilation is restarted, and cardiopulmonary bypass is discontinued. The repair is assessed using transesophageal echocardiography. After confirming a satisfactory repair, the femoral cannulas are removed, and protamine is administered. Hemostasis is carefully checked using the camera under single-lung ventilation. Finally, a 24F chest tube is inserted in the right pleural cavity through the fourth trocar site, and all wounds are closed.

Several modifications were made to the mitral repair procedure to perform the entire operation with the 12 mm trocar as a working port. Flexible bands are preferred for mitral prolapse repair, as they can easily fit through the port once removed from the holder. For annuloplasty band implantation, a running suturing technique using two 3/0 V-Loc polybutester sutures anchored on both trigones is used. (Figure 11,12)

Figure 8 *Administration of antegrade cardioplegia*

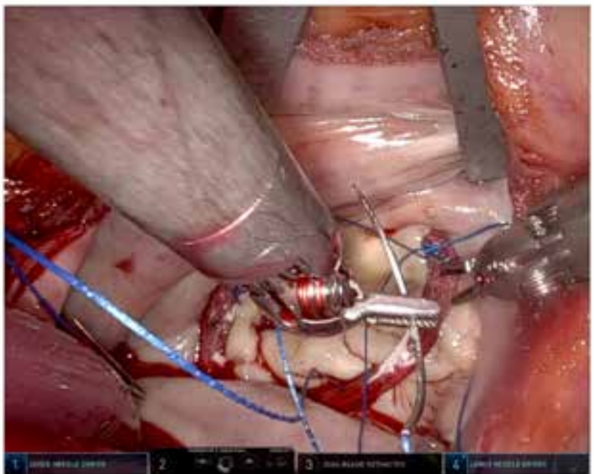

Figure 9 *running suturing technique using two 3/0V-Loc® polybutester sutures*

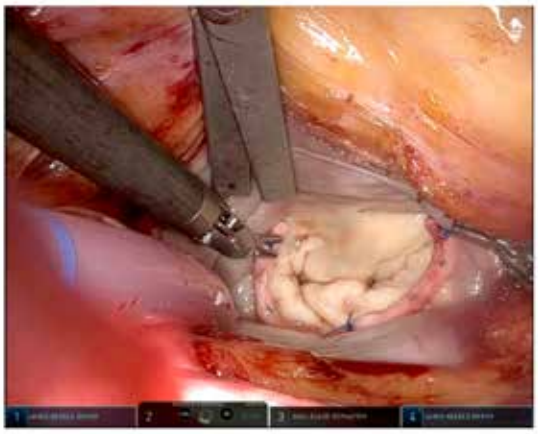

Figure 10 *Flexible bands for the repair of mitral prolapse (Cosgrove-Edwards annuloplasty system® Edwards Lifesciences: CA. USA)*

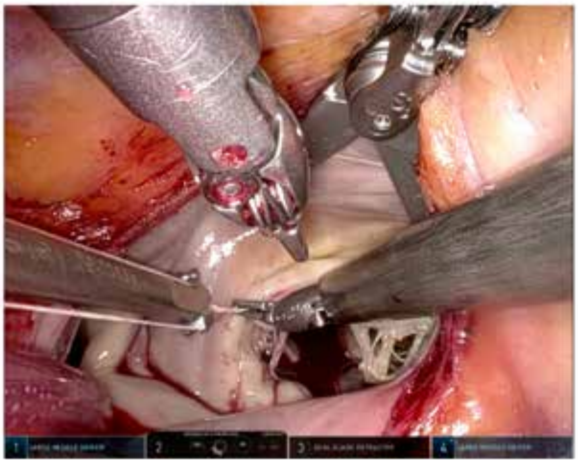

Figure 11 *Using a knot pusher through the working port.*

Figure 12 *UMICS Academy minimally invasive cardiac course in NOVA Medical School, Lisbon*

Suture knotting, such as neochords, annuloplasty, and atriotomy, is performed with the robotic instruments.

In the endoscopic group, suture knotting is performed by the bedside surgeon using a knot pusher through the working port.

RESULTS

The main objective of minimally-invasive mitral repair is to achieve a successful and long-lasting valve repair, similar to open surgery. Despite its perceived technical complexity, experienced centers have reported excellent results with 95% of patients being free from mitral regurgitation at 5 years, even in cases of complex mitral pathology [10,11].

In addition to a durable repair, minimally-invasive mitral surgery aims to provide a faster recovery and higher patient satisfaction due to smaller incisions. Recent studies have shown that patients who undergo minimally invasive surgery have a higher quality of life and are able to return to work earlier[12]. Furthermore, several publications have demonstrated that despite longer cardiopulmonary bypass and aortic-clamp times, minimally invasive surgery is associated with a very low complication rate, reduced blood loss, and shorter stays in the intensive care unit and hospital[1,14].

In our experience, the robotic technique has resulted in shorter stays in the intensive care unit and hospital. Patients undergoing mitral valve repair and atrial septal defect closure were discharged home in less than 72 hours, while those undergoing single coronary bypass surgery were discharged in 48 hours.

STARTING A NEW PROGRAM

The most successful centers in minimally-invasive mitral surgery are typically high-volume referral centers with extensive experience in mitral repair when they began their programs. However, transitioning to minimally invasive and robotic surgery requires the development of new skills and techniques. Surgeons who are already experienced in video-assisted thoracic surgery (VATS) may find it easier to evolve into minimally invasive cardiac procedures, such as total endoscopic mitral valve repair and closed-chest robotic surgery.

It is not just the surgeon who needs to learn these new techniques, but the entire operating team, including anesthesiologists, perfusionists, and operating room nurses. Based on our own experience, we have found that transitioning from open to thoracoscopic surgery increases the complexity for the entire team, and this complexity becomes even steeper when moving to robotic surgery. Therefore, we believe that it is essential for the entire surgical team to undergo specific and in-depth training in thoracoscopic and robotic cardiac surgery before starting a successful program. This training should include theoretical knowledge acquisition as well as the progressive development of technical skills.

To develop these technical skills, the team should start by practicing on simulators and engaging in dry lab training. Once this step is completed, they can progress to higher fidelity wet labs and training on live, large animal, and/or human cadaveric models. After this basic training, the surgical team members should observe cases in experienced institutions and have the support of expert proctors during the initial phases of their experience to ensure patient safety and a valuable learning experience.

To establish a successful program, it is important to avoid overlapping learning curves. Results are typically better during the initial phases if the program is started by teams with extensive experience in mitral repair and a strict patient selection protocol. As the program gains experience, there may be a tendency to expand the indication to more complex patients. Surgeons should closely monitor their results and adjust their inclusion criteria accordingly to detect any changes in the appearance of complications.

Our team at UMICS Academy organizes several courses on minimally invasive techniques in thoracic and cardiac surgery every year. These courses use the same instruments and setup as those used in actual procedures and utilize HD cameras for training in fresh cadavers at NOVA Medical School in Lisbon. We believe that the cadaveric lab is the best way to train surgeons interested in these techniques, and we recommend completing this type of training before initiating a minimally invasive program to learn the steps and tips and tricks of the procedure.

Figure 13 *Shurui uniportal robot in training room.*

Our courses focused on minimally invasive cardiac surgery include a module on mitral valve repair, aortic valve with rapid deployment prosthesis, and single coronary revascularization. In the near future, we will also begin offering courses on robotic technology in the cadaveric lab.

NEW TECHNOLOGY ON THE HORIZON

In our opinion, the future of robotic surgery lies in the uniportal approach, which involves using the fewest number of incisions possible in the patient. A groundbreaking project has been developed in Shanghai, known as the Shurui uniportal robot, which is considered the most advanced robotic system in the world. This revolutionary robot allows surgeons to operate inside the thorax through a minimal 15mm incision and offers greater mobility angles within the thorax, thanks to its nitinol technology. Additionally, it is equipped with a flexible 3D camera, similar to a fiberscope, which provides better viewing angles inside any cavity. (See Figure 15)

Cardiac surgery has seen numerous advancements, including the emergence of transcatheter devices for treating aortic stenosis. These developments have also paved the way for repairing or replacing the mitral valve[19,20]. In the future, we can expect further advancements in this field, which will greatly enhance the treatment options available for patients. Additionally, the possibility of training new surgeons with this specific uniportal robotic system, which is currently not permitted with other robotic platforms, adds to the advantages of this approach.

The authors declare no conflict of interests.

REFERENCES

1. Fann JI, Pompili MF, Burdon TA, Stevens JH, St Goar FG, Reitz BA. Minimally invasive mitral valve surgery. Semin Thorac Cardiovasc Surg 1997;9: 320-30. PMID: 9352947
2. Carpentier A, Loulmet D, Aupècle B, Kieffer JP, Tournay D, Guibourt P et al. Computer assisted open heart surgery. First case operated on with success. C R Acad Sci III 1998;321:437-42. doi: 10.1016/s0764-4469(98)80309-0
3. Mohr FW, Falk V, Diegeler A, et al. Computer-enhanced coronary artery bypass surgery. J Thorac Cardiovasc Surg 1999; 117:1212-4 PMID: 10343274
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 doi: 10.1067/mtc.2000.110177.
5. Gillinov AM, Mihaljevic T, Javadikassari H, Suri RM, Mick SK, Navi JL et al. Early results of robotically assisted mitral valve

surgery: Analysis of the first 1000 cases. J Thorac Cardiovasc 2018: 155 (1) 82-91 e2. doi: 10.1016/j. jtcvs.2017.07.037
6. Suri RM, Antiel RM, Burkhart HM, Huebner M, Li Z, Eton DT et al. Quality of life after early mitral valve repair using conventional and robotic approaches. Ann Thorac Surg 2012: 93: 761-9. doi: 10.1016/j.athoracsur.2011.11.062.
7. Mihaljevic T, Koprivanac M, Kelava M, Goodman A, Jarrett C, Williams SJ et al. Value of robotically assisted surgery for mitral valve disease. JAMA Surg 2014;149(7):679–86. doi: 10.1001/jamasurg.2013.5680.
8. Baumgartner H, Falk V, Bax JJ, De Bonis M, Hamm C, Holm PJ et al. 2017 ESC/EACTS Guidelines for the management of valvular heart disease. Eur Heart J 2017; 38: 2739-2791. doi: 10.1093/eurheartj/ehx391.
9. Otto CM, Nishimura RA, Bonow RO, Carabello BA, Erwin III JP, Gentile F et al. 2020 ACC/AHA Guideline for the management of patients with valvular heart disease. J Am Coll Cardiol. 2021 Feb 2;77(4):e25- e197. doi: 10.1016/j.jacc.2020.11.018
10. Perier P, Hohenberger W, Lakew F, Batz G, Diegler A. Rate of repair in minimally invasive mitral valve surgery. Ann Cardiothorac Surg 2013: 2 (6): 751-757. doi: 10.3978/j.issn.2225-319X. 2013.10.12.
11. Taui T, Ishikawa N, Horikawa T, Seguchi R, Shigematsu S, Kiuchi R et al. First Major Clinical Outcomes of totally endoscopic robotic mitral valve5 repair in Japan. Circ J 2019; 83: 1668-1673. doi: 10.1253/circj.CJ-19-0284.
12. Seeburger J, Borger MA, Falk V, Kuntze T, Czesla M, Walther T et al. Minimally invasive mitral valve repair for mitral regurgitation: results of 1339 consecutive patients. Eur J Cardiothorac Surg 2008 Oct 34(4): 760-5. doi: 10.1016/j. ejcts.2008.05.015.
13. Suri RM, Taggarse A, Burkhart HM, Daly RC, Mauermann W, Nishimura RA et al. Robotic mitral valve repair for simple and complex degenerative disease. Midterm clinical and echocardiographic quality outcomes. Circulation 2015; 132: 1961-1968. doi: 10.1161/ CIRCULATIONAHA.115.017792.
14. Ascaso M, Sandoval E, Quintana E, Vidal B, Castella M, Pereda D. Early and mid-term outcomes of mitral repair due to leaflet prolapse in a national referral center. Rev Esp Cardiol (Engl Ed) 2020; Nov 4: S1885-5857. doi: 10.1016/j. rec.2020.10.002.
15. Lehr EJ, Guy TS, Smith RL, Grossi EA, Shemin RJ, Rodriguez E, et at. Minimally Invasive Mitral Valve Surgery III. Training and Robotic-Assisted Approaches. Innovations 2016;11: 260–267 doi: 10.1097/IMI.0000000000000299.
16. Rodriguez E, Nifong LW, Bonatti J, Casula R, Falk V Folliguet TA, et al. Pathway for surgeons and programs to establish and maintain a successful robot- assisted adult cardiac surgery program J Thorac Cardiovasc Surg 2016;152:9-13 doi: 10.1016/j.athoracsur.2016.02.085.
17. Goodman A, Koprivanac M, Kelava M, Mick SL, Gillinov AM, Rajeswaran J et al. Robotic mitral valve repair. The learning curve. Innovation 2017; 12: 390-7 doi: 10.1097/ IMI.0000000000000438.
18. Kesävuori R, Raivio P, Jokinen JJ, Sahlman A, Teittinen K, Vento A. Early experience with robotic mitral valve repair with intra-aortic occlusion. J Thorac Cardiovasc Surg 2018; 155: 1463-71. doi: 10.1016/j. jtcvs.2017.10.076.
19. Ramlawi B, Gammie JS. Mitral valve surgery: Current minimally invasive and transcatheter options. Methodist Debakey Cardiovasc J 2016; (1): 20-6. doi: 10.14797/mdcj-12-1-20.
20. Fiocco A, Nadali M, Speziali G, Colli A. Transcatheter mitral valve chordal repair: Current indications and future perspectives. Front Cardiovasc Med 2019; 6: 128. doi: 10.3389/ fcvm.2019.00128