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RECENT ADVANCES IN CARDIAC SURGERY: MINIMALLY INVASIVE TECHNIQUES AND ROBOTIC ASSISTANCE

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ABSTRACT: Minimally invasive cardiac surgery (MICS) has emerged as a transformative approach in cardiovascular medicine, aiming to reduce surgical trauma and improve patient outcomes compared to traditional open-heart procedures. Originating nearly a century ago, MICS has undergone significant advancements, evolving from rudimentary instruments to sophisticated robotic-assisted and AI-driven techniques. This evolution has enabled surgeons to perform complex cardiac surgeries through small incisions, minimizing damage to surrounding tissues and organs. Key procedures such as aortic and mitral valve replacements, coronary artery bypass grafting (CABG), and maze surgeries for atrial fibrillation have been successfully adapted to MICS. These procedures leverage innovations like robotic systems that enhance precision, minimize human error, and provide better visualization of the operative field. As a result, patients experience reduced post-operative pain, shorter hospital stays, faster recovery times, and improved cosmetic outcomes due to smaller surgical scars. Recent studies and clinical trials underscore the safety, feasibility, and efficacy of MICS across diverse patient populations. The adoption of MICS continues to expand globally, driven by its potential to mitigate complications associated with traditional sternotomy, such as infections, bleeding, and longer recovery periods. Moreover, advancements in sutureless anastomotic devices and other technologies support the growth of minimally invasive approaches in cardiac surgery, promising even better outcomes in the future. In conclusion, MICS represents a paradigm shift in cardiac surgery, offering a blend of technological innovation and surgical expertise to optimize patient care. Future developments in MICS are expected to further refine techniques, expand indications, and enhance overall patient satisfaction and quality of life following cardiac interventions.

INTRODUCTION: Minimally invasive approaches have become the prime aspect of surgical practice and has been gaining global attention due to its low surgery associated complications. This developing approach is considered safer compared to conventional surgical techniques.

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The idea and practical application dates back to around 1931. Over the years, it has attained tremendous changes and development. It revolves around surgical instruments upgradation from crude instruments to artificial intelligence-oriented approaches, robotic assisted surgeries and advanced gadgets [1].

The proposal of minimal invasive procedures has come to wide acceptance as it greatly reduces the incidence of post- operative stress and complications compared to a conventional approach. Also, it does not compromise of the overall therapeutic outcome. Recently, mainstream focus has shifted to minimally invasive cardiac

surgery techniques. Unlike the goals of minimal invasion in other surgeries, the main target tends to be consideration of extracorporeal circulation as it is the prime cause of morbidity [2].

Currently techniques are being tried and tested revolving around mitral valve replacement, aortic valve replacement, transcatheter involving procedures for mitral and aortic valves. Extensively, hybrid coronary revascularization procedures and coronary bypass surgery are assisted by robots and innovative gadgets [3]. With developments in the field every day, minimal invasion has come to show less surgery associated trauma, lesser pain post operation and quicker recovery. We also witness better results from minimal invasive cardiac surgeries than conventional surgery [4, 5].

Conventional cardiac surgeries often involve complications and atrial fibrillation has been reported with a higher incidence. Post-operative atrial fibrillation (POAF) has traditionally been considered a temporary, benign, and self-limiting complication of cardiac surgery, easily managed and well-tolerated by patients. However, recent studies indicate that POAF may be more serious than previously thought, with links to increased long-term mortality and morbidity. Since 1993, a variety of minimally invasive surgical techniques have been developed. These methods aim to reduce surgical invasiveness and trauma, resulting in better outcomes and lower perioperative morbidity compared to traditional full sternotomy [6].

Upon, reduction of complications associated with conventional techniques of surgery, minimal invasive procedures provide other advantages. Minimal invasive procedures do not generally require very few small incisions to guide through instruments and camera to access the site of surgery. On the other hand, in conventional surgical procedures, we note a larger incision being made centrally over the breastbone. This also helps to minimize the post operative infective complications.

Traditional cardiac surgery, often referred to as open-heart surgery, encompasses several crucial elements that define its approach and impact on patients. One of the primary steps in this type of surgery is a sternotomy, where the surgeon splits the breastbone to gain direct access to the heart. This significant incision allows the surgical team to have a clear and comprehensive view of the heart and its surrounding structures, which is essential for conducting intricate procedures.

During the operation, the patient is connected to a heart-lung machine. This sophisticated device temporarily assumes the functions of both the heart and lungs, maintaining blood circulation and oxygenation throughout the body while the heart is stopped. The heart-lung machine is a pivotal component, as it enables surgeons to operate on a non-beating, bloodless heart, which is crucial for precision during complex repairs or replacements.

The extensive exposure provided by the sternotomy is particularly advantageous for performing a wide range of cardiac surgeries, such as coronary artery bypass grafting (CABG), where blocked arteries are bypassed to restore blood flow to the heart muscle. It also facilitates valve repairs and replacements, and the correction of congenital heart defects. The ability to see and access the entire heart allows for meticulous surgical work, which can be lifesaving.

However, the invasiveness of traditional cardiac surgery leads to a longer hospital stay and an extended recovery period for patients. The healing process is more prolonged because it involves not just the heart, but also the breastbone, which can take several weeks to months to fully mend. During this recovery time, patients must be cautious with physical activities to allow proper healing of the sternum.

Moreover, the large incision and the physical act of spreading the rib cage to access the heart contribute to significant postoperative pain and discomfort. Managing this pain effectively requires strong analgesics and comprehensive supportive care, which includes monitoring for complications, assisting with mobility, and providing emotional support to help patients cope with the discomfort and the challenges of a prolonged recovery period. This combination of extensive surgical exposure and the resultant postoperative pain underscores the intensity and the demanding nature of traditional cardiac surgery [7].

In this study, we aim to understand the various approaches that have been recently adopted in minimally invasive cardiac surgeries. It will also cover the patient selection criteria, procedural success rates, complication rates, and long-term outcomes associated with these approaches. By examining recent studies, clinical trials, and case reports, we aim to provide a comprehensive understanding of the state-of-the-art in minimally invasive cardiac surgery. This study will serve as a valuable resource for clinicians, researchers, and healthcare policymakers to make informed decisions and foster further innovation in this critical area of medicine.

Aortic Valve Surgery: Aortic valve surgery is done when there is impaired aortic valvular function. Improper functioning of the aortic valve disrupts the heart rhythm and alters conduction in the system and affects the overall blood pressure and cardiac health. These new minimal invasion methods ensure speedy recovery lesser pain and better outcomes. The length of hospitalization is reduced and complexed surgical incisions is restricted. Also, these ensure maximum safety and do not compromise on the therapeutic outcome of the conventional surgery [8]. The standard approach to accessing and performing an aortic valve repair or replacement surgery has always been the full median sternotomy. In full median sternotomy, an inline vertical incision is made through the sternum and is then divided with a sternal saw. This method of incision and access provides wider access to the heart and lungs. In the last few years, various approaches have been developed and tested to replace the conventional full median sternotomy. Robotic- assistance has been the prime discussion as it carries numerous advantages over the traditional method. We observe reduced errors and morbidity rates, reduced operative duration, exposure to radiation and several other factors [9].

Several studies have been conducted to understand the safety and feasibility of the methods. And most studies support that the minimal invasive approaches are safe and can replace conventional surgery techniques provided, the methods are standardized and highly skilful overlook is provided [10].

Minimally invasive aortic valve replacement (MIAVR) provides access to various sections like the percutaneous methods, right parasternal incision, trans-sternal incision, ministernotomy or right anterior minithoracotomy. A descriptive procedure is illustrated in **Fig. 1.**

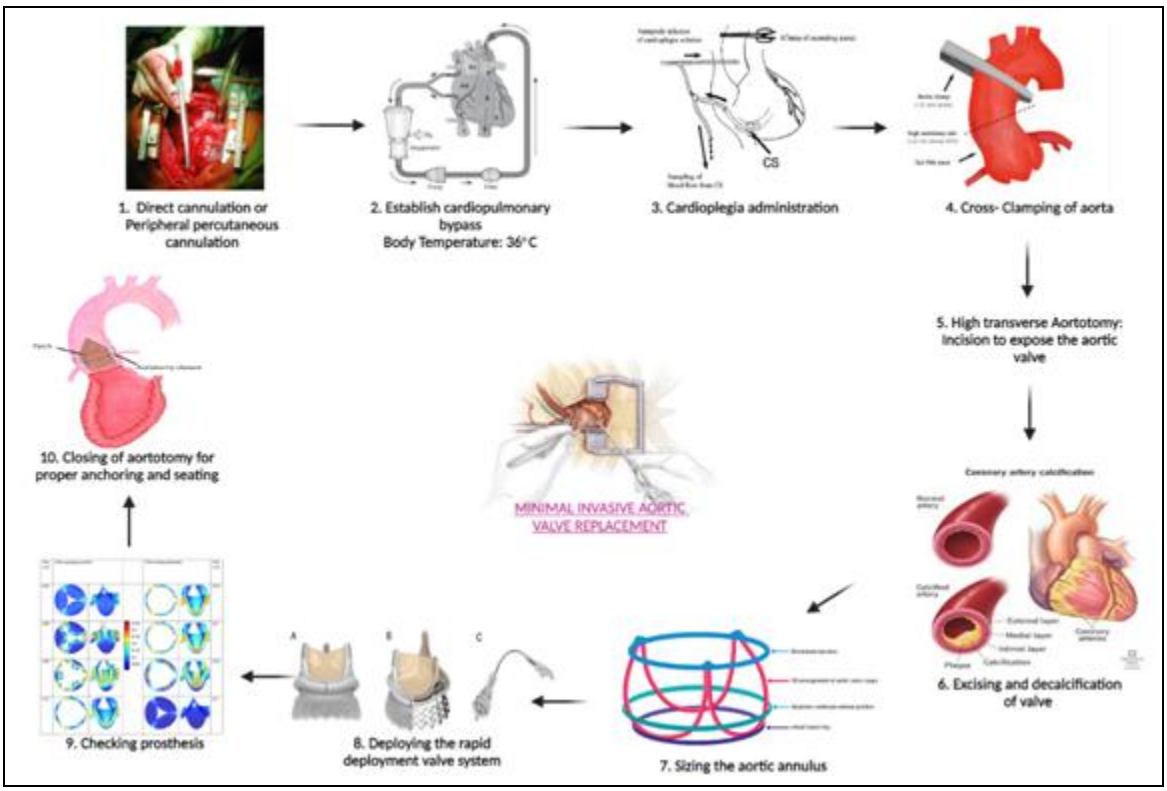

FIG. 1: MINIMAL INVASIVE AORTIC VALVE REPLACEMENT PROCEDURE

Advantages of MIAVR:

- Reduced risk of post- operative bleeding.
- Reduces the requirement of blood transfusions.
- Faster Post surgical recovery.
- Shorter duration of hospitalization.
- Shorter rehabilitation time [11, 12, 13, 14].

Cardiac Arrythmia Surgery: In recent years, there have been significant advancements in cardiac arrhythmia surgery. This is evident from the articles published in the past year, which focus on the surgical treatment of supraventricular and ventricular arrhythmias. The use of radiofrequency ablation for arrhythmia treatment has become increasingly common, particularly in the Maze procedure for atrial fibrillation. The outcomes of this procedure have been consistently excellent. Additionally, the introduction of implantable cardioverter-defibrillators has revolutionized the therapy for ventricular tachycardia and sudden cardiac death. This has allowed for a more precise selection of patients for direct ventricular tachycardia surgery, resulting in a surgical mortality rate of only 4%.

Furthermore, patients who undergo curative procedures experience excellent long-term survival and remain free from arrhythmia recurrence. Lastly, the implantable cardioverter-defibrillator has also been explored as a bridge to cardiac transplantation, showing promising intermediate-term results [15].

Arrhythmia surgery in patients with congenital disease faces challenges due to the various anatomical variations, types of arrhythmias, and the location of scar tissue within the heart muscle. Both experimental and clinical studies have shed light on the underlying mechanisms of arrhythmias, including accessory connections, atrial fibrillation, atrial reentry tachycardia, nodal re- entry tachycardia, focal or automatic atrial tachycardia, and ventricular tachycardia. There are numerous surgical and transcatheter options available, and it is crucial for congenital heart surgeons to possess a comprehensive understanding of all types of arrhythmias and potential methods of ablation [16].

Atrial fibrillation, the most prevalent sustained arrhythmia, carries significant risks such as thromboembolism, stroke, congestive heart failure, and mortality. The management of atrial fibrillation has witnessed notable advancements, encompassing pharmacologic therapies, antithrombotic therapies, and ablation techniques. Surgical interventions, both concomitant and stand-alone, have proven to be effective in restoring sinus rhythm for atrial fibrillation patients.

The emerging field of minimally invasive surgical ablation aims to achieve superior outcomes compared to the traditional Cox-Maze procedure, while minimizing morbidity, expediting recovery, and enhancing patient satisfaction. These innovative techniques employ endoscopic or minithoracotomy approaches, along with various energy sources, to achieve electrical isolation of the pulmonary veins and other ablation lines. Various approaches have been developed and tested to carry out an AF surgery, among them are [17]:

- Cryomaze procedure
- Radiofrequency maze procedure
- Video assisted thoracoscopic AF surgery
- Robot- assisted AF surgery
- Endoscopic AF surgery

CABG- Coronary Artery Bypass Grafting: The primary objective of developing minimally invasive direct coronary artery bypass surgery was to minimize chest trauma and expedite patient recovery. With the advent of mechanical stabilizers and positioning devices, off-pump coronary artery bypass has become a safe option for patients with multi-vessel disease. Robotic technology has further opened doors for myocardial revascularization through limited access using endoscopic principles. Currently, there is a significant focus on the advancement of suture less anastomotic devices, which have the potential to revolutionize myocardial revascularization and promote wider acceptance of minimally invasive CABG procedures.

Suture less Anastomotic Devices: Currently U-clip anastomotic devices are widely used and it

comprises of 3 segments namely the needle, the flexible member and the U- shaped clip, which is made of nitinol, an alloy that allows self- closure. This device has been recently approved by the FDA and is being investigated clinically.

Robotic- Assisted Coronary Artery Bypass Surgery: Robotic- assistance enables surgeons to perform anastomoses with limited access. Currently approved and under investigation are Da Vinci System by Intuitive Surgical, Inc. and Zeus Microsurgical System by Computer Motion, Inc.

Symmetry Bypass System: This is an aortic connector system that is useful in the construction of proximal anastomoses. This is considered beneficial as it helps to avoid aortic manipulation like the involvement of clamps. This is FDA approved and under clinical investigation.

Magnetic Vascular Positioner: This is a magnetic device used for distal coronary artery anastomoses. This device is only under clinical investigation in Europe [18].

Minimally Invasive CABG: In minimally invasive CABG, a new component was introduced called the off- pump CABG, which ensured minimised invasion and also greatly reduced the need for cardiopulmonary bypass, which again leads to complications. With the introduction of minimally invasive CABG, we could potentially eliminate the unwanted effects caused by cardiopulmonary bypass [19, 20].

Procedure: A detailed procedure for minimally invasive CABG has been depicted in **Fig. 2.**

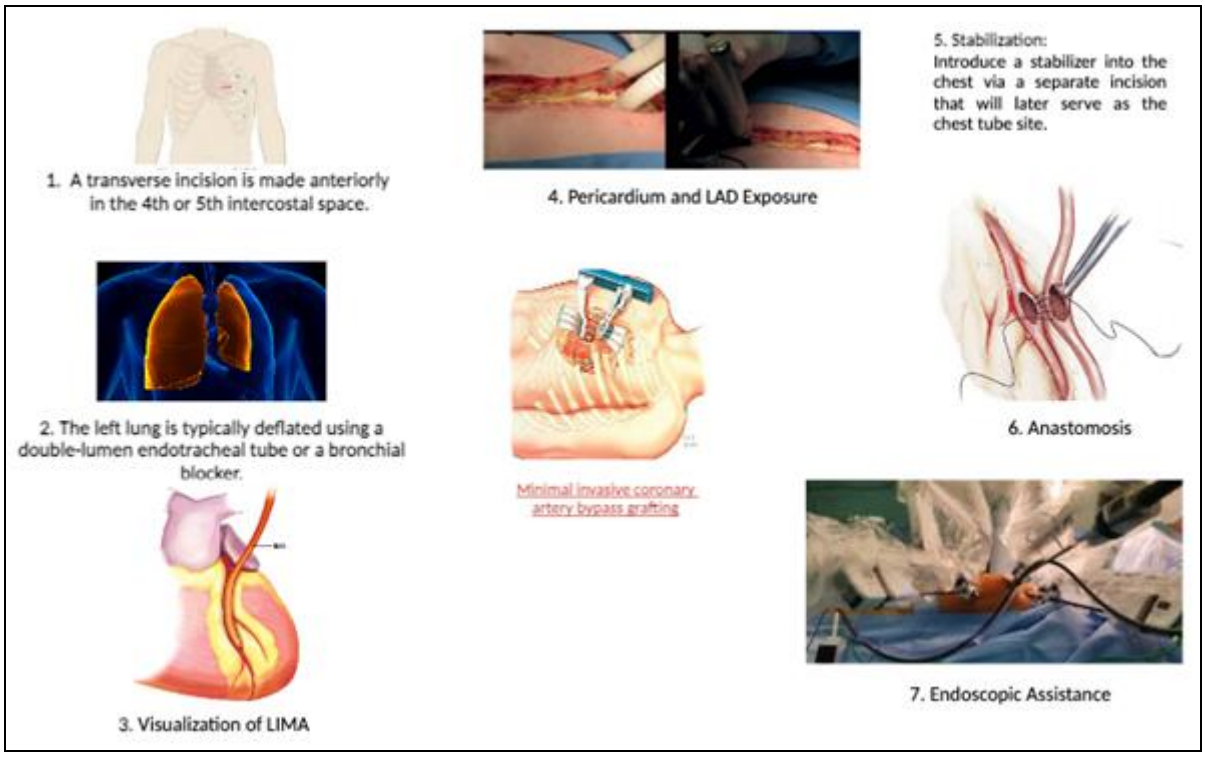

FIG. 2: PROCEDURE DEPICTING MINIMAL INVASIVE CABG

The use of minimal invasive technique is currently lower and it is believed to be because of the complexity and skill required to implement newer aspects to surgical procedures. It is also essential that we combine experience, knowledge and training in the use of newer technology into performing a successful surgery [21, 22].

Maze Surgery: Maze surgery is easily the most common approach for atrial fibrillation. Traditionally for an atrial fibrillation existing for less than one year in a patient either catheter ablation or hybrid ablation is chosen. In atrial fibrillation lasting for more than one year paired with minimally enlarged left atrium, hybrid ablation is the choice of surgery. In atrial fibrillation lasting for more than a year along with highly enlarged left atrium, cox maze surgery or the maze surgery is chosen. A maze surgery is also

opted for recurring atrial fibrillation. Major benefits associated with maze surgery includes reduced time for recovery and low risk of infection due to minimal invasion. Usually, maze is done with a very small thoracotomy incision generally between 4-5cm. Length of hospitalisation is generally over 5-7 days. A detailed procedure is depicted in **Fig. 3** [23].

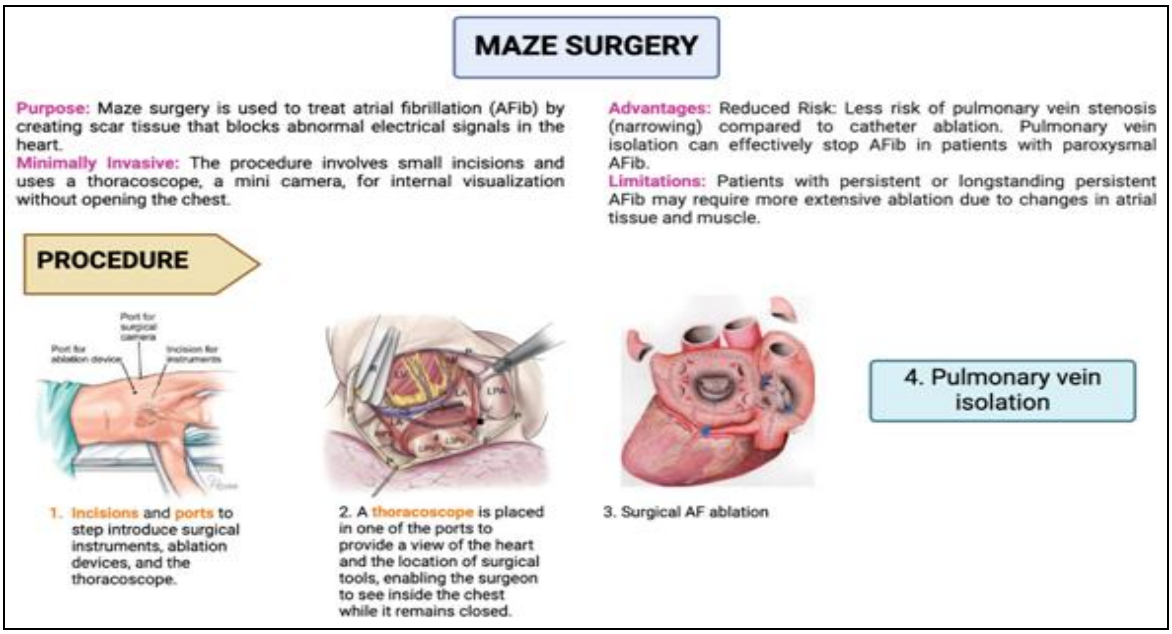

FIG. 3: MAZE SURGERY PROCEDURE

Implantable Cardioverter Defibrillator: An implantable cardioverter defibrillator is typically used in children and infants with sudden cardiac death or highly fatal arrythmias. Minimal invasive techniques now enable limited access to interior regions and are restricted to the epicardium. These epicardial implantable cardioverter defibrillators are free of venous occlusions risk. Thus, epicardial ICDs offer vast advantages over the traditional ICDs [24].

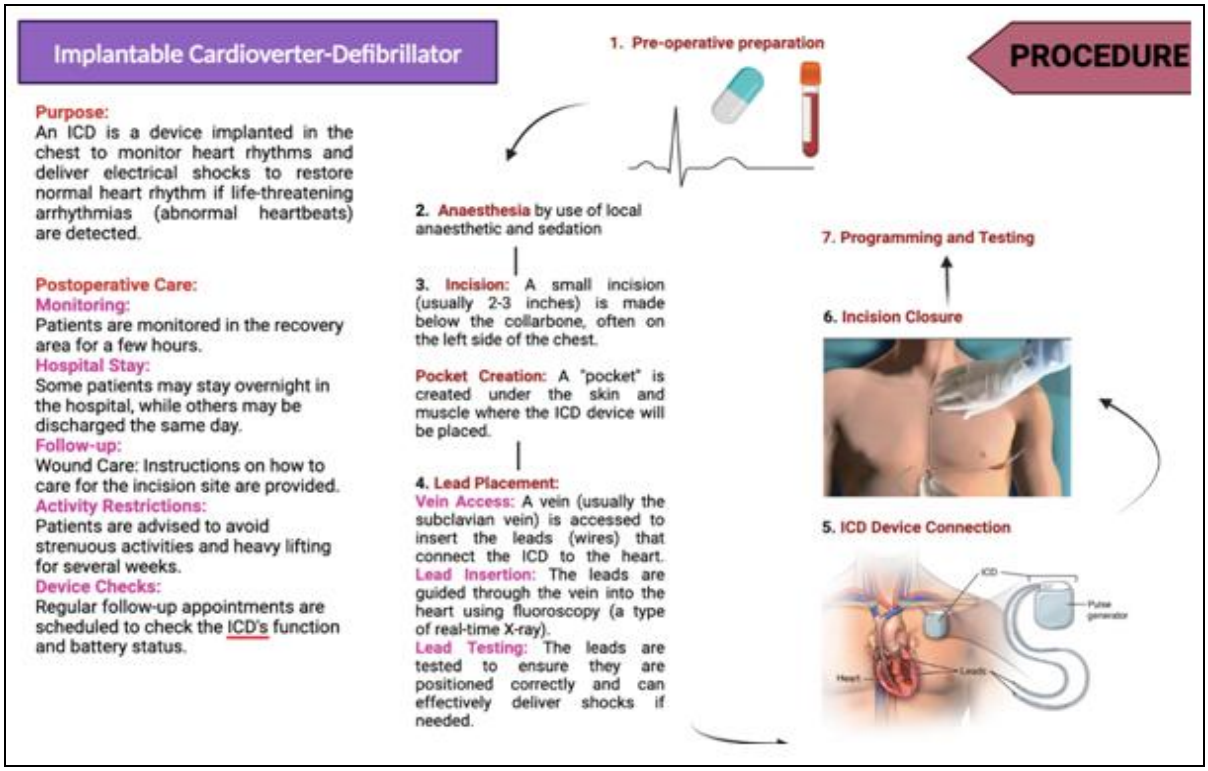

FIG. 4: IMPLANTABLE CARDIOVERTER DEFIBRILLATOR INSTALLATION AND CARE

Over the last few years ICDs have undergone numerous changes and development. The main complication associated with conventional ICD use is the occurrence of venous occlusion. In the past few decades, various other access options have been proposed, developed and undertaken into practice. The common access into clinical practice now includes, subcutaneous ICD coil, epicardial or pericardial ICD- these are available as coils and patches, substernal ICD coil, extra-pleural ICD coil and hybrid ICDs.

The selection of newly developed ICD systems make room for individualization of therapy and allows combination of various accesses and techniques which ensure lower risk of complications, lesser chance of infection, better safety and enhanced overall outputs [25].

These minimal invasive ICD coils are designed to fit specific and personalized choice of positions and meet individual requirements. Also, the room for combinations and alternative selections enhance the treatment output with overall additive effects and patient safety. Although, there is limited data on the use and in detail report of minimally invasive ICDs, there is a promise this could be the future with developments made further and skilled personnel to monitor and conduct overall procedures. A detailed process of implantation is illustrated in **Fig. 4** [26].

Ventricular Assist Devices: In patients with potential risk of complete heart failure, a mechanical circulatory system is established in order to prevent complete organ shut down or dysfunction. Due to unavailability of donors, we observe an increase in the use of mechanical support system for circulation [27]. Similar to other minimal invasive methods, these ventricular assist devices also lower the complications that are associated with cardiopulmonary bypass [28].

Ventricular assist devices incorporated via minimal invasive approach resulted in little or no need for follow up blood transfusions, shorter length of hospitalization, shorter recovery period and low rate of ventricular failure or dysfunction [29, 30]. There are two mainly used techniques namely the hemi- sternotomy and the sternum sparing technique. In most clinical setups, the minimal invasive techniques have been adopted and practised as standard options for various cardiac concerns [31, 32, 33]. A detailed procedure explaining the process of ventricular assist device has been depicted in **Fig. 5.**

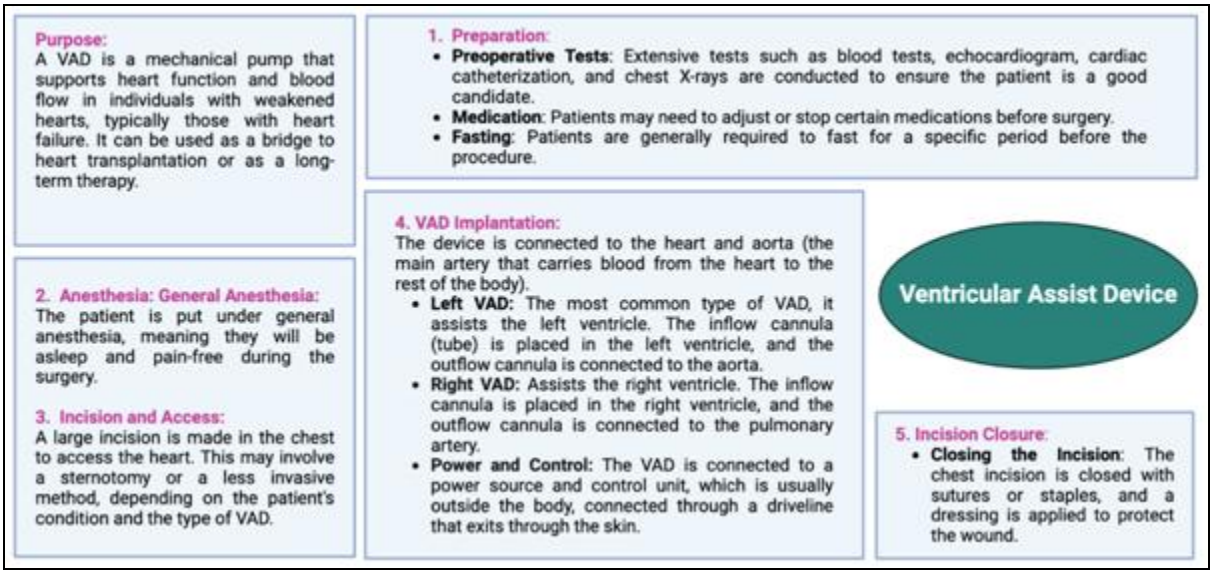

FIG. 5: VENTRICULAR ASSIST DEVICE IMPLANTATION PROCEDURE

Robotic Assistance in Minimally Invasive Cardiac Surgery: Advances in surgical techniques have led to the development of minimally invasive procedures, particularly in cardiac surgery. Endoscopic surgery, utilizing small incisions and cameras, offers patients reduced trauma and quicker recovery times. Surgical robots further enhance precision, enabling complex procedures like mitral valve repair, atrial septal defect closure, and coronary artery bypass grafting to be

performed with minimal invasion. These innovations have shifted cardiac surgeries from traditional sternotomy approaches to entirely endoscopic methods, promising improved outcomes and patient recovery [34].

Robotic technology enables the least invasive approach to performing mitral valve surgeries. Various methods for robotic repair and replacement of the mitral valve are now feasible and their indications have recently expanded. Enhanced precision in handling instruments, advanced 3D and high-definition visual capabilities, the introduction of a robotic retractor for the left atrium, and supporting technologies allow for complex minimally invasive mitral valve procedures through small incisions on the patient's right chest wall. Utilizing robotics significantly minimizes surgical trauma while ensuring safety and maintaining high standards for surgical outcomes in mitral valve surgery [35].

Robot-assisted coronary surgery spans a range of procedures, from harvesting the internal mammary artery (IMA) for hand-sewn connections to performing totally endoscopic coronary artery bypass grafting (CABG) with or without the heart-lung machine. Surgical robots have been specifically designed to improve surgical precision and capability. They are utilized not only for coronary artery bypass grafting but also for addressing various structural heart conditions such as mitral valve repair, closure of atrial septal defects, resection of cardiac tumors, and minimally invasive direct coronary artery bypass grafting. **Fig. 6** explains the advantages and disadvantages of robotic assisted cardiac surgery.

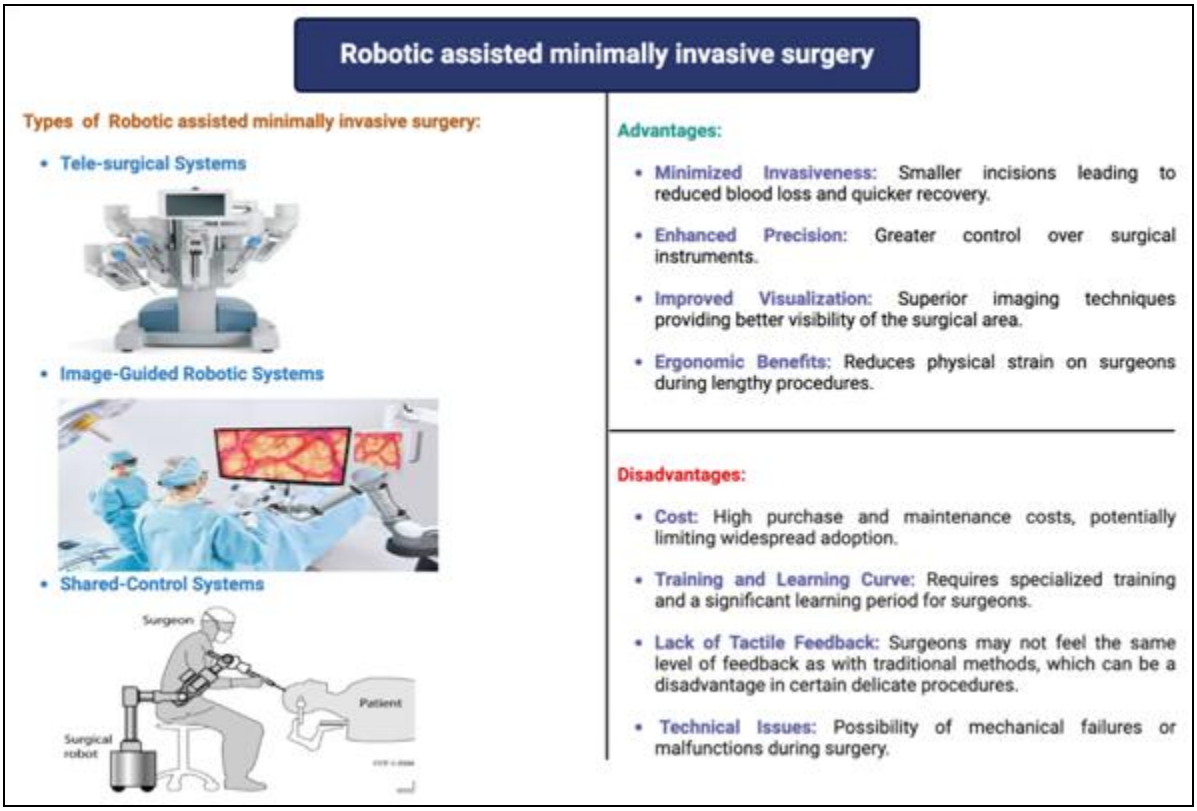

FIG. 6: ROBOT ASSISTED MINIMAL INVASIVE CARDIAC SURGERY

One significant application involves harvesting both internal mammary arteries using robotic assistance, followed by performing multivessel bypass surgery. This approach minimizes trauma and enhances surgical outcomes by utilizing small incisions and advanced robotic tools. The most common robotic applications in cardiac surgery include mitral valve repair and totally endoscopic CABG. These procedures benefit from the enhanced dexterity and visual clarity provided by robotic systems, resulting in improved patient recovery and reduced post-operative complications compared to traditional open-heart surgeries [34, 36].

CONCLUSION: In recent years, the field of cardiac surgery has undergone a profound evolution with the advent of minimally invasive techniques and robotic assistance. These advancements have redefined the treatment landscape for cardiovascular diseases by offering procedures that are less invasive and more precise than traditional open-heart surgeries.

Minimally invasive cardiac surgery involves making smaller incisions, typically on the chest wall, through which specialized instruments and cameras are inserted. This approach contrasts sharply with conventional methods that require large incisions and sternotomy, where the breastbone is divided to access the heart. By minimizing the size of surgical openings, minimally invasive techniques reduce trauma to surrounding tissues, leading to decreased post-operative pain, shorter recovery times, and lower risks of complications such as infections and bleeding. Patients also benefit from improved cosmetic outcomes with smaller scars, which can enhance their overall quality of life following surgery.

The integration of robotic assistance has further propelled the capabilities of minimally invasive cardiac procedures. Surgical robots offer surgeons enhanced visualization with high-definition cameras and magnified 3D views of the operative field. They also provide instruments that mimic the movements of a surgeon's hand with greater precision, enabling delicate maneuvers in confined spaces within the heart. Robotic systems have made complex surgeries such as mitral valve repair, atrial septal defect closure, and coronary artery bypass grafting feasible through small ports on the chest wall. This technological advancement not only expands the scope of what is achievable in cardiac surgery but also improves surgical outcomes by reducing human error and variability. Looking ahead, the continued refinement and adoption of minimally invasive and robot-assisted cardiac surgery promise to further enhance patient care. As technology advances and surgeons gain more experience with these techniques, the field is poised to deliver even better results in terms of patient recovery, long-term outcomes, and overall quality of life for individuals undergoing cardiac interventions. The future of cardiac surgery is increasingly defined by these innovative approaches, marking a new era of safer, more effective, and patient centered cardiovascular care.

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REFERENCES:

1. Ochsner JL: Minimally invasive surgical procedures. Ochsner J 2000; 2(3): 135-6.
2. Mack MJ: Minimally invasive cardiac surgery. Surg Endosc 2006; 20 2: 488-92.
3. Easterwood RM, Bostock IC and Nammalwar S: The evolution of minimally invasive cardiac surgery: from minimal access to transcatheter approaches. Future Cardiol. 2017; 14(1):75–87.
4. Sierra J, Lahlaidi Sierra N, Bednarkiewicz M and Montessuit M: Chirurgie cardiaque minimalement invasive [Minimal invasive cardiac surgery]. Rev Med Suisse 2015; 11(464): 543-5.
5. Wendt D, Thielmann M, Melzer A, Tsagakis K, Adam Piotrowski J and Jakob H: Towards trends in minimal invasive cardiac surgery. Minerva Chir 2011; 66(5): 409-22.
6. Maimari M, Baikoussis NG, Gaitanakis S, Dalipi-Triantafillou A, Katsaros A, Kantsos C, Lozos V and Triantafillou K: Does minimal invasive cardiac surgery reduce the incidence of post-operative atrial fibrillation? Ann Card Anaesth 2020; 23(1): 7-13.
7. Karangelis D, Androutsopoulou V, Tzifa A, Chalikias G, Tziakas D, Mitropoulos F and Mikroulis D: Minimally invasive cardiac surgery: in the pursuit to treat more and hurt less. J Thorac Dis 202; 13(11): 6209-6213.
8. Goebel N, Bonte D, Salehi-Gilani S, Nagib R, Ursulescu A and Franke UFW: Minimally Invasive Access Aortic Arch Surgery. Innovations (Phila) 2017; 12(5): 351-355.
9. Lin JC, Kaul SA, Bhandari A, Peterson EL, Peabody JO and Menon M: Robotic-assisted aortic surgery with and without minilaparotomy for complicated occlusive disease and aneurysm. J Vasc Surg 2012; 55(1): 16-22.
10. Risteski P, El-Sayed Ahmad A, Monsefi N, Papadopoulos N, Radacki I, Herrmann E, Moritz A and Zierer A: Minimally invasive aortic arch surgery: Early and late outcomes. Int J Surg 2017; 45: 113-117.
11. Brown ML, McKellar SH, Sundt TM and Schaff HV: Ministernotomy versus conventional sternotomy for aortic valve replacement: a systematic review and meta-analysis. J Thorac Cardiovasc Surg 2009; 137(3): 670-679.e5.
12. Moustafa MA, Abdelsamad AA, Zakaria G and Omarah MM: Minimal vs median sternotomy for aortic valve replacement. Asian Cardiovasc Thorac A 2007; 15(6): 472-5.
13. Doll N, Borger MA, Hain J, Bucerius J, Walther T, Gummert JF and Mohr FW: Minimal access aortic valve replacement: effects on morbidity and resource utilization. Ann Thorac Surg 2002; 74(4): 1318-22.
14. Brinkman WT, Hoffman W, Dewey TM, Culica D, Prince SL, Herbert MA, Mack MJ and Ryan WH: Aortic valve replacement surgery: comparison of outcomes in matched sternotomy and PORT ACCESS groups. Ann Thorac Surg 2010; 90(1): 131-5.
15. Goldblatt JC and Ferguson TB: Cardiac arrhythmia surgery. Curr Opin Cardiol 1993; 8(2): 283-9.

16. Mavroudis C, Deal B, Backer CL and Stewart RD: Operative techniques in association with arrhythmia surgery in patients with congenital heart disease. World J Pediatr Congenit Heart Surg 2013; 4(1): 85-97.
17. Nakamura Y, Kiaii B and Chu MW: Minimally invasive surgical therapies for atrial fibrillation. ISRN Cardiol 2012; 2012: 606324.
18. Byrne JG, Karavas AN, Filsoufi F, Mihaljevic T, Aklog L, Adams DH, Cohn LH and Aranki SF: Aortic valve surgery after previous coronary artery bypass grafting with functioning internal mammary artery grafts. Ann Thorac Surg 2002; 73(3): 779-84.
19. Sellke FW, Chu LM and Cohn WE: Current state of surgical myocardial revascularization. Circ J 2010; 74(6): 1031-7.
20. Czerny M, Baumer H, Kilo J, Lassnigg A, Hamwi A, Vukovich T, Wolner E and Grimm M: Inflammatory response and myocardial injury following coronary artery bypass grafting with or without cardiopulmonary bypass. Eur J Cardiothorac Surg 2000; 17(6): 737-42.
21. Holzhey DM, Jacobs S, Walther T, Mochalski M, Mohr FW and Falk V: Cumulative sum failure analysis for eight surgeons performing minimally invasive direct coronary artery bypass. J Thorac Cardiovasc Surg 2007; 134(3): 663-9.
22. Rodriguez ML, Lapierre HR, Sohmer B, Glineur D and Ruel M: Mid-Term follow-up of minimally invasive multivessel coronary artery bypass grafting: is the early learning phase detrimental? Innovations (Phila) 2017; 12(2): 116-120.
23. Wolf RK and Burgess S: Minimally invasive surgery for atrial fibrillation-Wolf Mini Maze procedure. Ann Cardiothorac Surg 2014; 3(1): 122-3.
24. Zahedivash A, Hanisch D, Dubin AM, Trela A, Chubb H, Motonaga KS, Goodyer WR, Maeda K, Reinhartz O, Ma M, Martin E and Ceresnak SR: Implantable cardioverter defibrillators in infants and toddlers: indications, placement, programming, and outcomes. Circ Arrhythm Electrophysiol 2022; 15(2):010557.
25. Schneider AE, Burkhart HM, Ackerman MJ, Dearani JA, Wackel P and Cannon BC: Minimally invasive epicardial implantable cardioverter-defibrillator placement for infants and children: An effective alternative to the transvenous approach. Heart Rhythm 2016; 13(9): 1905-12.
26. Tonko JB and Rinaldi CA: Non-traditional implantable cardioverter-defibrillator configurations and insertion techniques: a review of contemporary options. Europace 2022; 24(2): 181-192.
27. Frazier OH, Rose EA, McCarthy P, Burton NA, Tector A, Levin H, Kayne HL, Poirier VL and Dasse KA: Improved mortality and rehabilitation of transplant candidates treated with a long-term implantable left ventricular assist system. Ann Surg 1995; 222(3): 327-36.
28. Collart F, Feier H, Metras D and Mesana TG: A safe, alternative technique for off-pump left ventricular assist device implantation in high-risk reoperative cases. Interact Cardiovasc Thorac Surg 2004; 3(2): 286-8.
29. Strueber M, Meyer AL, Feussner M, Ender J, Correia JC and Mohr FW: A minimally invasive off-pump implantation technique for continuous-flow left ventricular assist devices: early experience. J Heart Lung Transplant 2014; 33(8): 851-6.
30. Jawad K, Sipahi F, Koziarz A, Huhn S, Kalampokas N, Albert A, Borger MA, Lichtenberg A and Saeed D: Less-invasive ventricular assist device implantation: A multicenter study. JTCS 2022; 164(6): 1910-18.
31. Chatterjee A, Mariani S, Hanke JS, Li T, Merzah AS, Wendl R, Haverich A, Schmitto JD and Dogan G: Minimally invasive left ventricular assist device implantation: optimizing device design for this approach. Expert Rev Med Devices 2020; 17(4): 323-330.
32. Al-Naamani A, Fahr F, Khan A, Bireta C, Nozdrzykowski M, Feder S, Deshmukh N, Jubeh M, Eifert S, Jawad K, Schulz U, Borger MA and Saeed D: Minimally invasive ventricular assist device implantation. J Thorac Dis 2021; 13(3): 2010-2017.
33. Mohite PN, Sabashnikov A, Raj B, Hards R, Edwards G, García-Sáez D, Zych B, Husain M, Jothidasan A, Fatullayev J, Zeriouh M, Weymann A, Popov AF, De Robertis F and Simon AR: Minimally Invasive Left Ventricular Assist Device Implantation: A Comparative Study. Artif Organs 2018; 42(12): 1125-1131.
34. Ishikawa N and Watanabe G: Robot-assisted cardiac surgery. Ann Thorac Cardiovasc Surg 2015; 21(4): 322-8.
35. Bonatti J, Kiaii B, Alhan C, Cerny S, Torregrossa G, Bisleri G, Komlo C and Guy TS: The role of robotic technology in minimally invasive surgery for mitral valve disease. Expert Rev Med Devices 2021; 18(10): 955-970.
36. Athanasiou T, Ashrafian H, Rowland SP and Casula R: Robotic cardiac surgery: advanced minimally invasive technology hindered by barriers to adoption. Future Cardiol 2011; 7(4): 511-22.

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