https://doi.org/10.48047/AFJBS.6.2.2024.3874-3884

African Journal of Biological Sciences

Journal homepage: http://www.afjbs.com

Research Paper Open Access

Approaching the Mitral Valve by minimally invasive techniques

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Article History

Volume 6, Issue 2, Apr-Aug 2024

Received: 5 August 2024

Accepted: 15 August 2024

Published: 15 August 2024

doi:

10.48047/AFJBS.6.2.2024.3874-3884

Abstract: Minimally invasive approaches to mitral valve surgery represent a significant advancement in cardiac surgery, offering potential benefits over traditional sternotomy. This abstract reviews the current landscape of minimally invasive mitral valve repair and replacement techniques, highlighting their advantages, limitations, and evolving role in patient care. Techniques such as right mini-thoracotomy, left mini-thoracotomy, and robotic-assisted approaches are explored, each presenting a unique surgical field and access strategy to the mitral valve. These techniques aim to reduce surgical trauma, leading to decreased postoperative pain, shorter hospital stays, faster recovery times, and improved cosmetic outcomes compared to conventional sternotomy.The choice of minimally invasive approach is tailored to individual patient characteristics and the specific mitral valve pathology. While minimally invasive repair remains the preferred approach when feasible, the suitability of minimally invasive replacement techniques is continuously being refined. Technological advancements, such as improved robotic platforms, smaller instruments, and enhanced imaging modalities, are crucial in expanding the applicability of these techniques to more complex cases. However, limitations persist. The restricted surgical field and limited maneuverability can pose challenges, potentially requiring conversion to sternotomy in some instances. Furthermore, the learning curve associated with these techniques necessitates specialized training and experience.Despite these limitations, the accumulating evidence suggests that appropriately selected patients undergoing minimally invasive mitral valve procedures experience comparable or superior clinical outcomes to those undergoing conventional surgery. Ongoing research focuses on identifying optimal patient selection criteria, improving surgical techniques, and developing novel technologies to further minimize invasiveness and enhance the safety and efficacy of these procedures. The future of minimally invasive mitral valve surgery likely lies in the continued refinement of existing techniques, the development of new approaches, and a more widespread adoption based on rigorous clinical evidence and patient-specific considerations.

Keywords: *Mitral Valve, minimally invasive techniques*

Introduction.

The key to successful thoracic surgical procedures is adequate and proper exposure. A well-chosen thoracic incision provides effortless and excellent exposure for almost any procedure. However, an ill-chosen or improperly placed or performed incision often leads to a difficult and frustrating procedure [1]. Proper positioning of the patient on the operating table is essential to achieve a safe and satisfactory procedure. The patient must be positioned in a safe and stable manner; pressure points of nerves and vascular structures must be padded and protected to prevent injury during the operation. The electrocautery ground plate must be applied securely and must be kept dry when the skin is prepared [1].

Several techniques are available for sterile preparation of the skin at the site of the incision. The surgeon must ensure that the area of operative exposure does not include any areas of ongoing sepsis, even to the most minor degree of skin scratches or irritation. The area of skin prepared must be adequate for the primary incision as well as for vascular access (the most suitable is the groin area). The patient must be draped to preserve the sterility of the wound throughout the surgical procedure. Large clear plastic adhesive drapes that are impregnated with iodine provide complete access to the operative site while ensuring a draping system that is impervious and resistant to displacement until the procedure is complete [1].

The incision itself should be placed carefully so that it is located precisely where the operative procedure is to be done. Entry into an interspace that is higher or lower than intended may lead to unsatisfactory exposure. The incision must be long enough to provide complete exposure without too much tension on the tissues. Meticulous hemostasis throughout the operative procedure is essential; it should be done during the procedure and should not be postponed until later. Careful use of electrocautery is essential to obtain satisfactory hemostasis during thoracic procedures and to ensure future healing [2].

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Patients are positioned supine with the right shoulder elevated and with the right arm at the patient's side. Alternatively, the right arm may be supported over the head [3].

Anesthesia

Anesthetic management of right anterior thoracotomy mitral patients differs from that of sternotomy patients in the need to obtain single-lung ventilation if aortic cannulation is planned. These patients should be intubated with a dual-lumen endotracheal tube or with an endobronchial blocker placed in the right mainstem bronchus [4].

Incision

The incision is placed in the inframammary crease directly inferior to the nipple and just lateral to the mammary artery. This incision has the advantages of placing the surgeon closer to the mitral valve and of causing less medial paresthesia. Disadvantages include less access to the ascending aorta and a less favorable angle to view the mitral valve and subvalvular apparatus. So this incision may need slight extension laterally to avoid previous disadvantages. The more medial incision is often used with femoral arterial cannulation. Incisions can be made as small as 6 cm if the femoral artery is cannulated, and cannulation of the ascending aorta generally requires an 8 cm incision [5].

Pericardium opening

The pericardium is opened vertically from the diaphragm to the ascending aorta, keeping the incision at least 1–2 cm anterior to the phrenic nerve. If the ascending aorta is to be cannulated, the incision should be carried up to the innominate vein. Three lateral retraction sutures are placed on the posterior pericardial edge. The first is placed over the right superior pulmonary vein and is secured to the lateral corner of the skin incision. The second is placed halfway to the diaphragm and is passed through the chest wall. The third suture is placed at the level of the superior vena cava and is passed through the third intercostals space as laterally as possible.

If the ascending aorta is to be cannulated, the medial pericardium at the mid-ascending aorta is secured to the posterior sternum to provide aortic exposure.

Femoral vessels cannulation

Femoral arterial cannulation is performed through a small 3- to 4-cm transverse incision in the groin between the inguinal crease and the inguinal ligament. The femoral artery and femoral vein are exposed and encircled with tapes, although tape placement is not necessary in a scarred and previously operated groin. Two concentric purse strings are placed in the femoral vein and artery using 5-0 polypropylene suture secured using tourniquets [6]. The femoral venous cannula is generally placed first. After heparinization, a guidewire is passed up the femoral vein into the superior vena cava using echocardiography, direct palpation, or direct vision. The 22 or 25 fr femoral venous cannula is then passed over the wire and through the purse strings to place the tip of the cannula 2 cm into the superior vena cava. The two 5-0 polypropylene suture tourniquets are then secured, and tapes on the proximal and distal vein are released, allowing continuous venous drainage of the leg and excellent hemostasis. Two concentric 5-0 polypropylene sutures are similarly placed in the common femoral artery, being careful that the diameter of the purse strings is less than one-half the diameter of the vessel to avoid vessel stenosis. After controlling the artery proximally and distally, an arteriotomy is made within the purse strings and is dilated to a diameter large enough to pass the arterial cannula. A 19 or 21 fr arterial cannula is then passed over a wire into the femoral artery, placing the cannula tip at least 2 cm into the femoral artery and away from any plaques or bends in the femoral artery. The 5-0 polypropylene tourniquets are then secured, and all tapes on the femoral artery are released so that the leg will be continuously perfused around the cannula. Both the arterial and venous cannulas can be placed as above if no difficulties are apparent; otherwise, fluoroscopy may be necessary. Fluoroscopy is rarely needed for port access in experienced centers today.

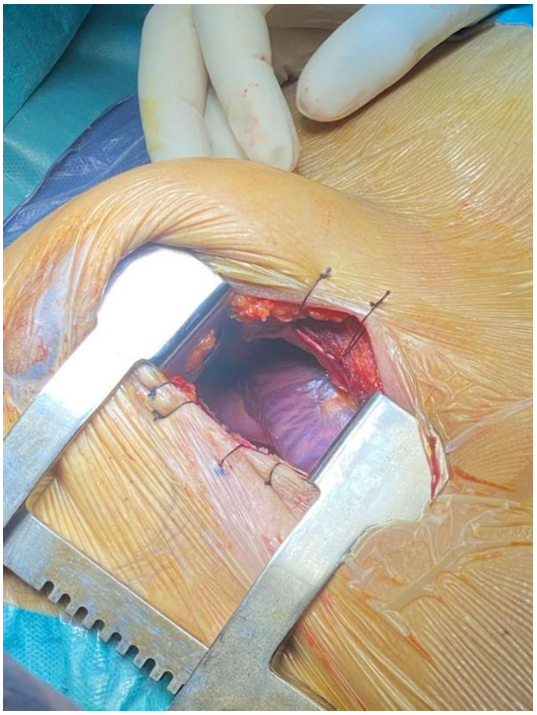

Figure 1 Minimal invasive incision with opened pericardium

Central aortic cannulation

Central aortic cannulation has the advantages of eliminating endoclamp balloon migration, avoiding embolization and/or dissection due to aortic or peripheral vascular disease, avoiding femoral arterial injury, limb ischemia, and groin incision complications (seroma, infection, hematoma) [7]. Central aortic cannulation has the disadvantage of requiring a somewhat larger incision and requiring the additional hardware of a specifically designed aortic cannula. Once the thoracotomy incision is made, the chest wall retractor is placed. A reusable-type retractor may be desirable here, as opposed to the earlier soft tissue retractor, to provide greater exposure of the ascending aorta by lifting upward on the superior chest wall. The arterial cannula should enter the aorta 1–2 cm proximal to the innominate artery with the aortic cannula directed toward the aortic valve. Angulation toward the aortic valve ensures that the endoclamp will pass toward the aortic valve and not down the aortic arch.

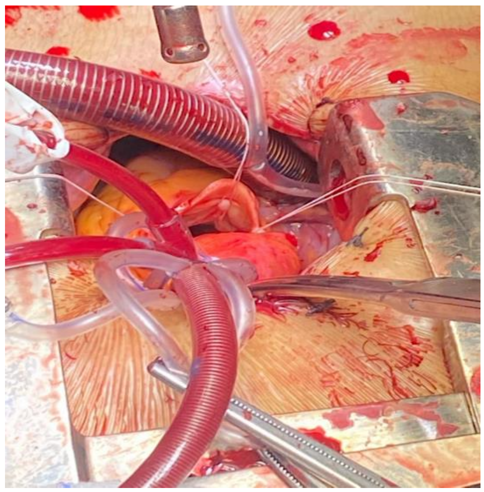

Figure 2 Central aortic cannulation

Alternative venous cannulation

This includes placement of a second venous catheter into the superior vena cava via the right internal jugular vein [5]. This is generally a 17 fr arterial-type cannula placed over a wire. Otherwise, a 28 fr angled plastic venous cannula can be placed through the chest wall or through the thoracotomy incision to provide standard cannulation of the superior vena cava. In this instance, a standard purse-string suture would be placed in the right atrium or in the superior vena cava after withdrawing the femoral venous cannula into the body of the right atrium. In those patients in whom femoral venous cannulation is not possible or desirable, the inferior vena cava can be cannulated through a right atrial purse-string suture with the cannula passed through the chest wall or through the thoracotomy incision. It is important that venous cannulation provide adequate drainage of the superior vena cava when the left atrium is retracted anteriorly, so that obstruction of the superior vena cava does not result. Assisted venous return should generally be used either via vacuum assist or by use of a Biomedicus centrifugal pump in the venous line.

Aortic occlusion

Several alternatives exist for aortic occlusion. The ascending aorta can be occluded with an external clamp of either the Cosgrove or Chitwood [6] variety. These aortic clamps can be passed through the incision or through a separate stab wound lateral to the incision.

Finally, the aorta can be occluded using an endoclamp passed through the aortic or femoral arterial cannula. Once the arterial cannula is placed, an endoclamp is passed through the "Y"-limb in the arterial cannula to position the end of the clamp in the ascending aorta just above the aortic valve. Transesophageal echo or fluoroscopy can be used. If a femoral arterial cannula is employed, the endoclamp is passed over a wire. For direct cannulation of the ascending aorta, a wire is unnecessary. Once the endoclamp is positioned, cardiopulmonary bypass is initiated using assisted venous drainage. With the transaortic endoclamp, the balloon is partially inflated, pulled back snugly against the tip of the aortic cannula, and then inflated to a volume sufficient to occlude the ascending aorta as demonstrated by transesophageal echo and/or direct palpation and inspection. With femoral cannulation, the endoclamp is inflated using transesophageal echo or fluoroscopy to ascertain positioning at least 1 cm above the aortic valve but proximal to the innominate artery. Once in place, slack on the femoral endoclamp catheter is tightened enough to prevent proximal balloon migration, without being so tight as to cause distal endoclamp balloon migration.

Many centers believe that intra-aortic balloon occlusion is associated with unnecessary increases in cost and complexity. Instead, we favored transthoracic aortic clamp occlusion as a safe, economical, and simple method for performing routine limited-access procedures [8].

Cardioplegia

If an external clamp is used, anterograde cardioplegia may be delivered through a standard cardioplegia cannula secured with purse-string sutures in the ascending aorta. Alternatively, a single dose of anterograde cardioplegia can be given using a spinal needle passed through the chest wall into the ascending aorta. Similarly, cardioplegia delivery can be handled in several ways. Ventricular fibrillation is an option when aortic occlusion cannot be obtained or when anterograde and retrograde cardioplegia are not feasible. Anterograde cardioplegia can be delivered through the endoclamp catheter or through a needle in the aortic root if an external clamp is used. Finally, retrograde cardioplegia can be delivered through a percutaneous coronary sinus catheter or through a retrograde coronary sinus catheter placed directly through a purse string in the right atrium.

Figure 3 Valve Exposure

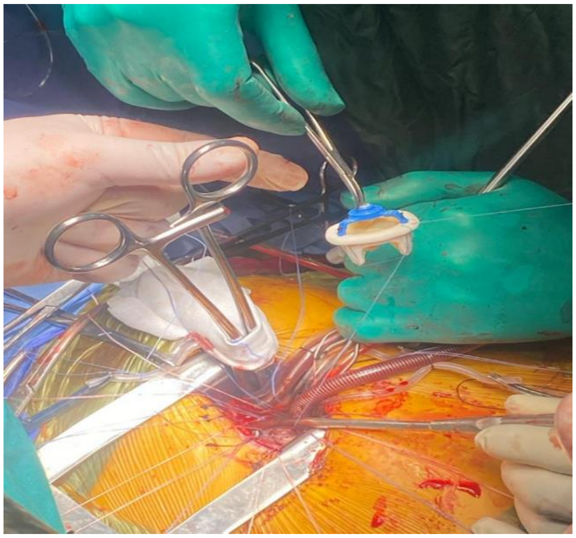

Figure 4 Mitral valve replacement

Valve exposure

With the heart arrested on cardiopulmonary bypass, the left atrium is opened adjacent to the interatrial groove. If needed, the left atriotomy can be extended superiorly behind the superior vena cava and inferiorly behind the inferior vena cava. The view of the left atrium and mitral valve is generally excellent and sufficient to perform replacement of the mitral valve, especially by using a minimally invasive atrial retractor. The mitral procedure itself is performed in a manner identical to that with sternotomy.

Deairing, closure, weaning from CPB

Upon completion of the mitral procedure, the left atrium is closed in a standard fashion with a left ventricular vent passed through the left atrial incision, through the mitral valve, and into the left ventricle. Several important adjuncts are used to air the heart. First, the entire thoracotomy field may be flooded with carbon dioxide throughout the case [9]. Second, with the left atrium closed around the left ventricular vent by a tourniquet, suction is applied to the left ventricular vent with the aorta still clamped. Ideally, some of the vent cannula holes should be in the left ventricle, and some holes should also be in the left atrium. Third, the patient is turned side to side while the perfusionist fills the heart with blood.

Once the heart appears to be adequately de-aired on transesophageal echo, the patient is placed in the Trendelenburg position, suction is applied to the aortic root vent, and the aorta is unclamped. The patient is maintained in the Trendelenburg position for 2 min after weaning from cardiopulmonary bypass. Any residual air on echo can be aspirated through the aortic root vent or cleared down the right coronary artery. Once the heart is well de-aired on echo, the ventricular vent is removed, closure of the left atriotomy is completed, and the patient is weaned from cardiopulmonary bypass.

Aortic decannulation is performed by tying the dual aortic purse-string sutures directly through the thoracotomy incision. The percutaneous venous cannula is simply withdrawn and the subcutaneous tissue closed with absorbable suture. If a groin incision is used, the arterial and venous purse strings are tied, and the groin incision is closed in a standard fashion. The surgeon should have a low threshold to repair or patch any small, diseased, or narrowed femoral artery. A single 19 fr rubber drain may be placed in the pericardium and brought through the chest wall. The drain is placed so that both the pericardial space and the pleural space are drained postoperatively. A single 36 fr chest tube is left in the pleural space for the first 12–24 h. The fourth rib is repaired with a #4 sternal wire if the rib was divided. The skin incision and any other port sites are closed with absorbable sutures.

Figure 5 Final result of minimal invasive incision

Postoperative care

Postoperative management differs little from that of standard sternotomy patients. Because bleeding is generally minimal, the pleural drain is usually removed within 24 h and the 19 fr drain is removed after 3–5 d. Postoperative pain appears to be similar to sternotomy for the first 1–3 d, and thereafter appears to be less than with sternotomy [10]. Patients appear to have greater arm use and earlier mobility than with sternotomy [7].

Complications & contraindications

Different groups of patients have different concerns and demands for less-invasive surgery. Will I awake after the surgery? How much pain will there be? When will I be able to return to work, physical and sports activities? How long will it take for my incision to heal, and what will the scar be like? Most of these concerns and demands are focused on comforts, cosmesis, and rehabilitation, all of which are affected by the degree of invasiveness. The objective factors affecting the degree of invasiveness of cardiac surgery are the surgical approach. The surgical approach is composed of and will determine:

• The length of the skin incision and the associated amount of visible scar tissue.
• The degree of aggression to muscle, connective, and bone tissue, which is affected by the amount of contusion and coagulation.
• The deformation of the thoracic cavity.
• The loss of blood.
• The amount of pain and discomfort.
• The ventilatory problems.
• The amount of anesthetic or analgesic drugs needed.
• The occurrence of devastating complications, such as sternitis and mediastinitis [5].

1-Sternal Wound Complications:

Minimally invasive thoracic incisions are gaining popularity in cardiac surgery, but most cardiac operations are still done through a midline sternotomy incision because of its versatility and familiarity to surgeons. This incision provides excellent exposure of vital chest structures, is rapidly performed, and is well tolerated by most patients. However, sternotomy wound complications and prolonged healing periods are persistent problems that have not been addressed or solved in a scientific manner [11]. Postoperative sternal wound complications are the major problem with sternotomy incisions, and such complications have been reported to occur in 1 to 5% of patients undergoing sternotomy [12]. Median sternotomy wound complications range from prolonged incisional pain to dehiscence and mediastinitis. These problems are often preceded by sternal instability, which has been shown to compromise wound integrity and promote bacterial infection [11]. Sternal wound complications include the following: (a) Sterile serosanguineous drainage with a stable sternum, (b) Unstable sternum with or without sterile wound drainage, (c) Sternal dehiscence without evidence of mediastinitis, (d) Superficial wound infection, (e) Subcutaneous wound infection associated with unstable sternum and communications with the retrosternal space, and (f) Mediastinitis with or without sternal or skin separation [13].

2-Post-operative Pain:

Pain is a unique, highly subjective, multidimensional experience encompassing many sensory and affective components. Sensory components characterize spatial and temporal elements of the stimulus, whereas affective or evaluative components underlie emotional reactivity to the painful experience. A multitude of factors influences the manner in which individuals experience pain and appreciate the effectiveness of medication provided for its relief. Psychological processes and reinforcement patterns of behavior appear to have a major influence upon affective and sensory components of pain, whereas patient age, sex, socio-economic status represent important variables influencing analgesic therapy [14]. After cardiac operations, pain and quality of life are important endpoints for all patients. Pain reflects the individuals' physical and psychological health. Thus, it is very important for the surgeon to analyze these aspects to further improve the surgical approach. In general, post-surgical pain is transient. Maximal pain levels can be anticipated to occur immediately postoperatively until the third postoperative day. As surgical wound healing progresses, pain levels usually decrease [15]. Pain perception is individual rather than standardized. Thus, postoperative pain is not easy to assess, and reliable data are difficult to collect because it is entirely a subjective sensation. Several subjective and objective methods for pain assessment were described. A double-blind technique using both subjective and objective methods may be essential to overcome any bias of the assessment [16]. So we will discuss the most important, much-used subjective method for pain scoring, which is the Visual Analog Scale (VAS). The visual analog scale is a very useful pain assessment tool. It is an extremely simple, sensitive, and reproducible instrument that allows patients to express the severity of pain as a numerical value. The VAS can be performed quickly, with minimal patient distraction, and can easily be adapted to individual situations. In addition to measuring the level of pain, it can also be used to measure other subjective variables such as nausea, pain relief, and patient satisfaction [17]. The VAS is represented as a straight line, usually 10 centimeters in length. At either end of the line are two poles or anchors that are defined as the extreme limits of pain. For example, the phrase "No pain" appears on the extreme left side of this continuum, whereas "Worst possible pain" is indicated on the extreme right. The patient is instructed to draw a single line intersecting the VAS at a point that depicts his or her perceived level of pain at that particular moment in time. From this marking, a concrete measurement in centimeters can be obtained and used for analysis [18]. Although the VAS is easy to use, it is essential to ensure complete patient understanding. Whenever possible, it is advisable to instruct the patient in its use during preadmission or preoperatively in order to limit any confusion and thereby improve the reliability of results. VAS has been shown to be more sensitive than observer scores and simple descriptive pain scales [19].

3-Pulmonary Functions:

In the natural history of mitral valve disease and with the progression of the disease, pulmonary arteriolar constriction arises secondarily to elevation of pulmonary venous pressure, thereby leading to pulmonary hypertension [20]. At first, the vascular changes are functional and reversible, but later anatomic changes appear with hyalinization of arterioles and capillaries. With sustained pulmonary hypertension, the brunt of the pressure load is directed to the right ventricle, thus giving rise to right ventricular failure [21]. Studies on the pulmonary function in mitral valve disease have demonstrated abnormalities of several parameters due to chronic congestion of the lungs [21]. These disturbances in the pulmonary functions were classified by Miller et al. [22] and the severity of respiratory impairment graded according to Conrad [23] [21]. Miller's prediction quadrant was used to classify the ventilatory disturbances as follows: 1-Restrictive pulmonary impairment: observed vital capacity value less than 80% of the predicted value. 2-Obstructive pulmonary impairment: observed vital capacity value more than 80% of predicted and FEV1/FVC ratio less than 70%. 3-Mixed pulmonary impairment: observed vital capacity value less than 80% of the predicted value and FEV1/FVC ratio less than 70% [22]. The severity of pulmonary impairment was graded by Conrad's criteria: 1-Mild respiratory impairment: observed spirometric value (vital capacity, forced expiratory value at one second FEV1 ranging from 61% to 79% of the predicted value. 2-Moderate respiratory impairment: observed value of vital capacity and FEV1 ranging between 40-60% of the predicted value. 3-Severe respiratory impairment: observed vital capacity and FEV1 values less than 40% of the predicted value [21]. In patients with acute or chronic mitral valve disease, pulmonary extravascular fluid accumulation may lead to premature airway closure and to a decrease in pulmonary compliance, airway conduction, and lung volumes. In addition, with severe cases of mitral valve disease, low cardiac output can lead to ventilation-perfusion mismatch and hypoxemia [24]. Post-cardiac surgery imbalance between pulmonary performance and ventilatory demands can occur, the etiology of which is multifactorial and includes postoperative pain, phrenic nerve injury, capillary leak syndrome, and increased extravascular lung water content due to the inflammatory reaction and complement activation by the foreign surfaces of the cardiopulmonary bypass pump, and mechanical effect of median sternotomy or the thoracotomy approach [25]. Thus, patients with mitral valve disease have a variable degree of impaired pulmonary functions preoperatively due to restrictive lung disease; these functions even become worsened immediately postoperatively due to more impairment by several other factors [25].

4-Cosmetic Appearance of the Scar:

The concept of cosmesis in cardiac surgery started only when the safety of open-heart surgery was beyond any doubt. The right submammary thoracotomy offers excellent cosmetic results, at no increased risk, and is usually invisible with most conventional clothes and bathing suits. The median sternotomy involves the use of a vertical skin incision. The incision is cosmetically unsatisfactory, as it tends to widen with time and may be conspicuous with normal female clothing. The vertical skin incision generally used is at right angles to the lines of Langer and tends to spread with time. Because of the increased tension, skin sutures are generally left for at least 7 days, and prominent suture hole scars result with an increased incidence of keloid formation.

5-Nerve Injuries Associated With Both Approaches:

1-Brachial plexus injury: Brachial plexus injury has been reported to occur in a varied number of patients following sternotomy [26] and is usually manifested by numbness in the fourth and fifth fingers. Initially, this was felt to be due to stretching of the brachial plexus from sternal retraction or from arm positioning. 2-Phrenic nerve damage: Phrenic nerve damage can be an unfortunate consequence of cardiac operations and can produce significant respiratory morbidity [27]. Phrenic nerve damage increases postoperative complications by prolonging the duration of ventilation, which may increase the risk of chest infection and barotrauma. The etiology of phrenic nerve damage is multifactorial; reported factors include cold injury, traction on the nerve, and direct injury [28]. There is a significant incidence of phrenic nerve damage in patients undergoing MIMVS. Possible causes of phrenic nerve damage include unclear visualization of the nerve posterior to the thymus, dissection, electrocauterization, or traction on the nerve during pericardial retraction. It is not necessary to uncover the great vessels by freeing the thymus. It is sufficient to perform the pericardiotomy and affix the pericardium to the chest wall by stay sutures. The surgeon must be aware of the course of the phrenic nerve on the pericardial surface in order to avoid damaging the nerve during the pericardiotomy or during electrocauterization for bleeding. Another precautionary measure is to avoid over-stretching of the pericardial edges [29].

6-Post-operative Blood Loss and Blood Transfusion

Post-operative bleeding after the median sternotomy approach is one of the complications. It is possible to stop bleeding from a smaller incision during entry, whereas sternal bleeding from a standard sternotomy continues throughout the operative procedures and shed blood is retrieved from the pericardial sac [30]. It is recognized that contact with a pleural-pericardial surface depletes fibrinogen. By avoiding this bleeding from the sternum, and avoiding its contact with the pleuropericardial surface, the clotting cascade is not activated during the surgical procedure. It is suspected that a sternotomy will continue to bleed into the mediastinum even after it has been reapproximated. A combination of these two factors likely accounts for the diminished bleeding and transfusion requirements with less invasive approaches [30]. Another potential advantage of the MIMVS is that the pericardium is not opened over the right ventricular outflow tract. This is the site that is most commonly injured during reoperation. Reoperation through a median sternotomy should be considered easier and safer if the pericardium in this area has not been interrupted. The potential for easier reoperation may influence the surgeon's choice of the procedure and the prosthesis. If morbidity and mortality of a reoperation are substantially reduced, the willingness of the patient and surgeon to consider valve repair or replacement by a bioprosthesis at the time of the initial procedure may increase [30].

7-Subxiphoid Hernia:

Subxiphoid hernia has been reported to occur in up to 4% of patients following a median sternotomy incision and can be prevented by careful surgical technique during closure [31].

8-Pericardial Collection:

During closure of minithoracotomy, the pericardium is approximated by 3–4 interrupted stitches. This wide pleuropericardial window reduces the risk of cardiac tamponade in the immediate and late postoperative period [32].

Contraindications of MIMVS

Absolute contraindications to this approach include severe peripheral vascular disease, a history of a prior right-sided thoracotomy/irradiation, concomitant coronary artery disease requiring surgical revascularization, or concomitant aortic valvular disease requiring replacement, and aneurysm of the ascending aorta [33].

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