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Narrative Review on the Different Approaches for Minimally Invasive Mitral Valve Replacement

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Abstract

Minimally invasive mitral valve replacement (MIMVR) has emerged as an alternative to traditional open mitral valve surgery, offering reduced morbidity and faster recovery times. This review explores the primary MIMVR approaches, including mini-thoracotomy, robotic-assisted surgery, and transcatheter mitral valve replacement (TMVR). Each method provides distinct advantages, such as reduced postoperative pain, lower infection risks, and improved cosmetic outcomes, though challenges remain, including steep learning curves and cost. While early outcomes, particularly for robotic and TMVR techniques, are promising, further research is required to assess long-term durability and optimize patient selection.

Keywords: Minimally Invasive Mitral Valve Replacement; Minithoracotomy; Ministernotomy; Transcathether Mitral Valve Replacement; Robotic Mitral Valve Replacement

Abbreviations

MR: Mitral Regurgitation; MS: Mitral Stenosis; MVR: Mitral Valve Replacement; MIMVR: Minimally invasive Mitral Valve Replacement; MIS: Minimally Invasive Surgery; TEE: Transesophageal Echocardiography; TMVR: Transcatheter Mitral Valve Replacement; TAVR: Transcatheter Aortic Valve Replacement; LVOT: Left Ventricular Outflow Tract.

Introduction

Mitral valve disease, including mitral regurgitation (MR) and mitral stenosis (MS), is a significant cause of morbidity and mortality worldwide. Traditionally, open mitral valve replacement (MVR) has been the standard treatment for patients with severe symptomatic mitral valve disease who are not candidates for repair [1]. However, advances in surgical techniques and technology have led to the development of minimally invasive mitral valve replacement (MIMVR) approaches that reduce the morbidity associated with traditional sternotomy while still providing effective treatment. This review discusses the different approaches for minimally invasive mitral valve replacement, highlighting their advantages, disadvantages, and outcomes based on current evidence.

Conventional Open Surgery for Mitral Valve Replacement

Before exploring minimally invasive approaches, it's important to understand traditional open mitral valve replacement. This involves a full sternotomy, cardiopulmonary bypass,

and extensive dissection. Despite its effectiveness, this approach is associated with significant postoperative complications, including prolonged recovery time, increased infection risk, and postoperative pain.

Evolution of Minimally Invasive Mitral Valve Replacement

Minimally invasive surgery (MIS) techniques have been developed to reduce the trauma of traditional surgery. These methods aim to provide the same clinical outcomes as open surgery but with fewer complications, reduced hospital stays, quicker recovery, and better cosmetic outcomes.

A. Mini-Thoracotomy Approach The mini-thoracotomy approach is one of the most established methods for MIMVR. This technique uses a small incision (5-10 cm) in the right thorax, typically in the 4th or 5th intercostal space, allowing for access to the mitral valve through a lateral route. Cardiopulmonary bypass is still required, but peripheral cannulation (via femoral artery and vein) is used instead of direct cannulation through the sternum [2].

Advantages:
- Reduced postoperative pain
- Lower risk of sternal infection and dehiscence
- Better cosmetic outcome

Disadvantages:
- Requires specialized surgical expertise
- Limited exposure of the mitral valve, potentially leading to technical challenges
- Requires advanced imaging modalities such as transesophageal echocardiography (TEE) to guide the procedure.

B. Robotic-Assisted Mitral Valve Replacement Robotic-assisted surgery has emerged as a promising approach to MIMVR, especially in the field of mitral valve repair and replacement. The Da Vinci surgical system is the most commonly used platform, offering enhanced dexterity, visualization, and precision during the surgery.

The robotic system allows the surgeon to control robotic arms equipped with instruments and a camera, which provide high-definition, 3D visualization of the surgical field. The procedure is performed through small incisions, with the robotic arms mimicking the surgeon's hand movements in real-time [3].

Advantages:
- Superior visualization and precision
- Reduced blood loss
- Shorter recovery time and reduced postoperative complications

Disadvantages:
- High cost of equipment and training
- Longer operative times, particularly during the surgeon's learning curve
- Increased procedure complexity, especially in valve replacement compared to repair.

Outcomes: Studies show that robotic-assisted mitral valve procedures, especially for repair, have excellent outcomes with reduced hospital stays and fewer complications compared to open surgery. However, data on robotic-assisted mitral valve replacement are more limited, with some concerns about the procedure's technical difficulty [4-6].

C. Transcatheter Mitral Valve Replacement (TMVR) TMVR is a relatively new, catheter-based approach for mitral valve replacement that offers a minimally invasive alternative for patients deemed high-risk for surgery. Similar to transcatheter aortic valve replacement (TAVR), this method allows the delivery of a bioprosthetic mitral valve via transapical, transseptal, or transvenous access [7].

TMVR is especially useful for patients with severe mitral regurgitation who are not candidates for conventional surgery due to comorbidities or previous cardiac surgeries.

Advantages:
- Avoids the need for cardiopulmonary bypass
- Useful in high-risk and inoperable patients
- Reduced recovery time compared to traditional surgery

Disadvantages:
- Higher rates of residual mitral regurgitation compared to surgical techniques
- Risk of valve malpositioning and left ventricular outflow tract (LVOT) obstruction
- Limited long-term data on valve durability.
- Outcomes: Early results from clinical trials such as the COAPT and MITRAL trials have shown promising outcomes for TMVR in high-risk populations, with improvements in symptoms and quality of life. However, the technique remains limited to specialized centers with experience in structural heart interventions [8,9].

Comparative Outcomes of Minimally Invasive Techniques

A. Mortality and Morbidity Several studies have compared minimally invasive approaches to traditional sternotomy-based mitral valve replacement. Overall, mortality rates for MIMVR are comparable to open surgery, especially

when performed in high-volume centers. However, MIMVR is associated with lower morbidity, including reduced postoperative pain, fewer transfusions, and lower rates of atrial fibrillation [10].

B. Hospital Stay and Recovery Minimally invasive techniques, particularly robotic-assisted and mini-thoracotomy approaches, have been associated with shorter hospital stays and faster recovery times compared to traditional surgery. Robotic-assisted surgery, in particular, has been shown to reduce hospital stays by 1–3 days [11].

C. Patient Satisfaction and Quality of Life Cosmetic outcomes are generally better with minimally invasive approaches, contributing to higher patient satisfaction. Furthermore, patients undergoing these procedures often report quicker return to normal activities and improved quality of life [12].

Limitations and Challenges

Despite the advantages, MIMVR has several limitations:

- **Learning Curve**: Minimally invasive techniques require advanced training and expertise, particularly in robotic and TMVR approaches.
- **Long-Term Outcomes**: While short-term results are promising, more data are needed on the long-term durability of minimally invasive techniques, particularly TMVR.
- **Cost:** The high cost of robotic systems and transcatheter valves can be prohibitive, limiting widespread adoption in some centers [13].

Comparison table between different types of minimally invasive mitral valve replacement (MIMVR) procedures: (Table 1).

Parameter	Minithoracotomy	Robot-Assisted Surgery	Transcatheter Mitral Valve Replacement (TMVR)	Mini-Sternotomy
Incision Site	Small incision on the side of the chest	Small incisions between ribs; robotic arms	Via catheter through femoral vein/artery or apex	Small incision in the upper part of sternum
Surgical Approach	Direct view of the valve via thoracotomy	Remote control using robotic arms	Through catheter using fluoroscopic and echocardiographic guidance	Limited exposure through partial sternum incision
Heart-Lung Bypass	Yes	Yes	No (in some cases)	Yes
Recovery Time	Shorter than full sternotomy (2-4 weeks)	Typically faster (2-4 weeks)	Very fast (few days to 1 week)	Similar to minithoracotomy (3-5 weeks)
Hospital Stay	3-5 days	3-5 days	1-3 days	5-7 days
Use of Robotic Technology	No	Yes	No	No
Postoperative Pain	Moderate	Minimal	Minimal	Moderate
Risk of Infection	Lower than full sternotomy	Lower than full sternotomy	Very low (due to no major incision)	Lower than full sternotomy
Candidates	Patients with low-to-moderate complexity	Patients requiring precise, delicate work	High-risk patients or those unsuitable for open surgery	Suitable for most candidates
Durability of Repair/ Replacement	High	High	Depends on device type and patient's condition	High
Complication Risk	Moderate	Moderate	Low-to-moderate (device migration, embolization)	Moderate-to-high
Advantages	Direct control, smaller incision than full sternotomy	High precision, reduced trauma	No open-heart surgery, quicker recovery	Familiar approach for surgeons, smaller incision than full sternotomy
Limitations	Requires specialized skills, some pain	Expensive, not widely available	Limited availability, new technology	Similar risks as minithoracotomy, less exposure for surgeon

Table 1: Comparison table between different types of minimally invasive mitral valve replacement (MIMVR).

Conclusion

Minimally invasive mitral valve replacement has emerged as a viable alternative to conventional open surgery, offering reduced morbidity, faster recovery, and improved patient satisfaction. Approaches such as mini-thoracotomy, robotic-assisted surgery, and transcatheter mitral valve replacement each have their advantages and challenges. The choice of technique should be individualized based on patient characteristics, surgical expertise, and institutional capabilities. Further studies are required to establish long-term outcomes, particularly for transcatheter approaches, and to optimize patient selection criteria. As technology and surgical expertise continue to evolve, it is likely that minimally invasive techniques will become increasingly favored for mitral valve replacement.

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