Mitral Valve Approaching through Median Sternotomy

Sameh Elsayed Maih, Mohammed Samy Abd-Allah, Alaa Ibrahim Abdel-Hafiz, Ali Mohamed Refaat, Ahmed Mohammed Amin Bakry, Amr Tawfek

Cardiothoracic Surgery Department, Faculty of Medicine - Zagazig University, Egypt

Corresponding author: Mohammed Samy Abd-Allah

E-mail: samy2022farag@gmail.com

Conflict of interest: None declared.

Funding: No funding sources

Abstract

Median sternotomy remains the gold standard approach for mitral valve surgery, providing excellent exposure and facilitating complex repairs and replacements. This approach involves a longitudinal incision through the sternum, providing direct access to the heart and allowing for thorough visualization and manipulation of the mitral valve apparatus. The advantages of median sternotomy include superior exposure allowing for a comprehensive assessment of the mitral valve, surrounding structures, and associated pathologies. This facilitates complex repairs such as annuloplasty, leaflet repair, and chordal reconstruction, which may be challenging or impossible through minimally invasive approaches. The wide surgical field enables the surgeon to address concomitant cardiac issues, such as coronary artery disease or other valvular pathologies. The technique involves precise sternal division, cardiopulmonary bypass establishment, and cardiac arrest. The mitral valve is then exposed via direct visualization and manipulation. Following the completion of the valve procedure, the sternum is meticulously reconstructed using sternal wires or plates. While median sternotomy offers unmatched access, it is associated with significant postoperative morbidity, including prolonged hospital stays, increased pain, higher risk of infection, and a less aesthetically pleasing scar. Despite the development of minimally invasive techniques, median sternotomy remains the preferred approach for complex mitral valve pathologies requiring extensive surgical manipulation or in patients with significant comorbidities requiring a more robust and comprehensive surgical approach. The decision to utilize a median sternotomy approach is based on careful patient selection and consideration of the complexity of the mitral valve pathology. Despite its invasive nature, median sternotomy provides the surgeon with the tools and exposure necessary to address a broad range of mitral valve pathologies effectively and safely.

Keywords: Mitral Valve, Median Sternotomy

TobRegul Sci. ™ 2023; 9(1): 8549 - 8559

DOI: doi.org/10.18001 /TRS.9.1.605

Introduction

Mitral valve disease encompasses a range of conditions affecting the mitral valve, a crucial heart valve located between the left atrium and left ventricle. The two primary types are mitral regurgitation (MR), where the valve doesn't close properly, allowing blood to leak back into the left atrium during ventricular contraction, and mitral stenosis (MS), where the valve opening is narrowed, restricting blood flow from the left atrium to the left ventricle. Both conditions can lead to heart failure, atrial fibrillation, and other serious complications if left untreated. The severity of symptoms varies greatly depending on the extent and progression of the disease. **(Krishnamoorthy, 2020)**

Surgical intervention plays a vital role in managing severe mitral valve disease when medical management fails to provide adequate symptom relief or prevent disease progression. The goals of surgery are to restore normal valve function, alleviate symptoms, and improve patient prognosis. Surgical options include mitral valve repair, aiming to restore the valve's competence without replacement, and mitral valve replacement, involving the implantation of a prosthetic valve. **(Molina, 2018)**.

Historically, and for many years the predominant surgical approach for mitral valve procedures has been through a median sternotomy. This traditional open-heart surgical technique involves a vertical incision through the sternum, providing excellent exposure to the heart and mitral valve, allowing for complex repairs and replacements. While minimally invasive techniques are gaining traction, median sternotomy remains a widely used and highly effective method for many cases, particularly those requiring complex repairs or involving concomitant cardiac procedures. The choice between median sternotomy and minimally invasive approaches depends on various factors including the patient's overall health, the complexity of the valve pathology, and the surgeon's experience. **(Krishnamoorthy, 2020)**

Preoperative considerations for minimally invasive mitral valve surgery (MIMVS) are crucial for optimizing patient outcomes and selecting appropriate candidates. These considerations are more stringent than for traditional sternotomy due to the technical challenges and limitations of MIMVS. **(Krishnamoorthy, 2020)**

Patient Selection Criteria: The selection process focuses on identifying patients who can benefit from the less invasive approach while minimizing the risk of conversion to open surgery.

- **Severity of Mitral Regurgitation/Stenosis:** MIMVS is generally favored for patients with moderate to severe mitral regurgitation or stenosis. However, the complexity of the lesion significantly impacts suitability. Simple leaflet repairs are more readily performed minimally invasively than complex reconstructions. Severe calcification or significant left atrial enlargement may make MIMVS technically challenging.
- **Comorbidities:** Patients with significant comorbidities (e.g., chronic obstructive pulmonary disease, renal insufficiency, diabetes) may be at increased risk of complications following MIMVS. Careful assessment of these comorbidities is essential to determine operative risk. Patients with significant frailty may also be better suited to a less invasive approach, though the surgical complexity must still be considered.
- **Functional Capacity:** A patient's functional capacity, often assessed using the New York Heart Association (NYHA) classification, is a key factor. Patients with higher NYHA classifications (indicating more severe symptoms) may still be candidates for MIMVS, but the surgical approach

needs careful consideration balancing the benefits of reduced invasiveness against the potential for increased complexity.

Preoperative Investigations: A thorough pre-operative workup is critical.

- **Echocardiography:** Transthoracic and transesophageal echocardiography (TTE and TEE) are essential for detailed assessment of mitral valve anatomy, function, and associated pathologies. This helps determine the feasibility of a minimally invasive approach and guides surgical planning. Image quality is particularly important for MIMVS because of limited visual access.
- **Cardiac Catheterization:** Cardiac catheterization may be performed to assess coronary artery disease, left ventricular function, and hemodynamic parameters. This helps in identifying any additional cardiac issues requiring attention during the surgery and aids in risk stratification.
- **Other Investigations:** Other investigations may include pulmonary function tests, blood tests (including coagulation studies), and electrocardiograms to further evaluate overall health and risk factors.

Risk Assessment: A comprehensive risk assessment is performed using various scoring systems (e.g., EuroSCORE II, STS score) to predict the likelihood of perioperative complications. The risks associated with MIMVS, while generally lower than those of conventional sternotomy, must be carefully considered. The potential for conversion to open surgery adds to the risk assessment. **(Molina, 2018)**.

Preoperative Preparation: Preoperative preparation involves optimizing the patient's medical condition, including managing comorbidities and optimizing cardiac function. This may involve medication adjustments, nutritional support, and pulmonary rehabilitation. Thorough patient education about the procedure, potential risks, and expected recovery is also crucial. The patient's understanding of potential limitations of MIMVS versus sternotomy, and the possibility of conversion, is vital for informed consent. **(Molina, 2018)**.

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 an improperly placed or performed incision often leads to a difficult and frustrating procedure **(Krishnamoorthy, 2020)**

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. **(Krishnamoorthy, 2020)**

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 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 **(Krishnamoorthy, 2020)**

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 **(Molina, 2018)**

Approaching the Mitral Valve through Median Sternotomy

The patient is placed in a supine position on the operating table, and the arms can be either extended or placed by the patient's side. Although most anesthesiologists prefer to have one or both of the patient's arms extended for access to arterial and intravenous lines, it was found that by careful positioning and padding of the arms, it is possible to routinely place both arms at the patient's sides, thus improving the comfort of the operating team. By placing a small pad between the patient's scapula and tilting the head to one side, access to the upper end of incision is improved, especially in obese patients **(Hussein et al., 2021)**

The intended line of incision may be identified with ink or by pinpoint skin depressions defining the starting point, midpoint, and completion of the incision every effort should be made to ensure that the incision is straight and exactly in the midline over the sternum. The sternal notch and tip of the xiphoid process are identified by palpation. The incision is begun approximately 2 cm below the sternal notch and extended approximately 2 cm beyond the distal tip of the xiphoid process and is usually extended with the electrocautery down to the sternal periosteum. A midline approach can be ensured by careful attention to the insertion points of the pectoralis major muscles onto the sternum; the incision should lie directly midway between these insertion points. This is preferable to estimation of the midline by palpation of the intercostal notches **(Sellke et al., 2009)**

The incision is extended to the sternal periosteum and linea Alba with either a scalpel or electrocautery. Excessive use of electrocautery may increase the incidence of postoperative sternal infection **(Molina, 2018).** The periosteum is scored in the midline with electrocautery, the linea Alba is divided at the xiphoid, and a plane is created behind the sternum at the suprasternal notch. Using a blunt finger dissection, a pathway is created above the suprasternal ligament and continued beneath the manubrium. No attempt at direct division of the suprasternal ligament by scissors, electrocautery, or other means is necessary. These techniques are to be avoided because of the risk of injury to the innominate artery as it passes upward to the neck. Division of the suprasternal ligament with the sternal saw is quite simple and much safer **(Sellke et al., 2009)**.

In most cases, the sternum is divided in a cephalic to caudal direction. The nose plate of the sternal saw is hooked underneath the suprasternal ligament, and the saw is grasped with both hands for stability. As the sternum is split, upward lifting on the sternal saw allows safe passage and helps avoid injury to the underlying pleura and mediastinal structures. It may be helpful to retreat slightly within the midportion of the sternotomy to allow release of any gathered pleura before completing the sternotomy.

Alternatively, the sternum can be divided using an oscillating saw or a Lebske knife, but both of these techniques are much less satisfactory **(Sachdeva et al., 2021).**

It is useful to have the anesthesiologist temporarily deflate the lungs as the sternum is divided. This may help prevent entering the pleural spaces, particularly in those patients with COPD disease and hyperinflated lungs. Bleeding from the sternal periosteum is best controlled with electrocautery. In the past, bone wax was routinely used to control marrow bleeding, but its use has been abandoned on all but rare occasions because of the possibility of impaired wound healing.

The postoperative bleeding does not increase when bone wax is not used. Accordingly, it is reserved for those patients who have refractory bleeding from sternal fractures, and even then, it should be used sparingly. A sternal retractor with broad blades is carefully positioned and opened slowly. The cross arm of the retractor may be positioned in either the upper or the lower end of the incision, depending on the surgeon's preference. By opening the retractor only a few turns at a time, one is usually able to avoid sternal fractures, especially in older patients with osteoporosis. The sternum should be opened only as wide as is necessary to obtain adequate exposure **(Molina, 2018)**.

Initiation of Cardiopulmonary Bypass and Valve Exposure:

After sternotomy, the pericardium is opened; the heart is cannulated for cardiopulmonary bypass. Arterial inflow is established by cannulation of the distal ascending aorta near the pericardial reflection. Double venous cannulation of the venae cavae by way of the right atrium is generally employed. In most adults a size 32 Fr cannula in the superior vena cava and a size 34-38 Fr cannula in the inferior vena cava provide excellent venous drainage and easy fit. Encircling of the venae cavae and their generous mobilization aid in the subsequent exposure of the mitral valve.

Umbilical nylon tapes secured with tourniquets can be used for subsequent upward retraction on the cavae. They may be tightened following cardioplegic arrest in order to minimize blood return into the right atrium and its subsequent delivery through the right heart and pulmonary circuit into the left atrium. The inter-atrial groove is dissected just anterior to the right superior pulmonary vein. The dissection is carried all the way to the level of the atrial septum. During this dissection, the core temperature of the body is reduced at 28 °C. After the dissection is completed, the aorta is cross-clamped and cardioplegic solution delivered through the aortic root **(Gerosa et al., 2023)**.

After the cardioplegic solution is delivered, the tourniquets encircling the cavae are tightened and retracted upward to decrease the blood return from the right side. A transverse left atriotomy is performed and extended superiorly and inferiorly beneath the vena cavae. The mitral valve is then exposed by superior traction using a hand-held atrial retractor. **(Gerosa et al., 2023)**

Rewarming, removal of air, atrial closure and separation from cardiopulmonary bypass:

Once the operative procedure has been completed,(replacement of the mitral valve), rewarming of the patient is begun. In obese patients this process (rewarming) may have to start somewhat earlier.

Removal of air from the heart is accomplished primarily through the opened left atrium. However, supplementary de-airing is also performed through the aorta. In preparation for de-airing, the valve is kept incompetent by means of a ventricular vent that is passed through the orifice of the valve.

The atriotomy is then closed with the ventricular vent coming through the suture line or through a separate stab in the superior pulmonary vein. The vena caval tapes are loosened, and the perfusionist is instructed to restrict venous return to the pump so that the right heart fills with blood. The patient is rotated away from the surgeon and the head is declined so that air tends to rise towards the aortic root at the level of the cardioplegic cannula. The anesthesiologist then forces air out of the pulmonary veins into the left atrium by slow hyperexpansion of the lungs. Simultaneously, the surgeon gently massages the left ventricle and disturbs the left atrial appendage so that entrapped air evacuates through the vent. While cardiac filling and massage is ongoing, suction is placed on the aortic vent to evacuate air through the aorta. The aortic clamp is removed. Full venous return is then allowed to drain into the cardiopulmonary circuit, and the heart is collapsed. When cardiac contraction resume, the heart is allowed to fill while suction is maintained on the aortic root. When the patient is fully warmed and cardiac function restored, cardiopulmonary bypass is discontinued. Removal of air continues even after the heart resumes its function. Initially, this is performed with direct suction via the aortic root vent. After bypass is discontinued, this can be accomplished by allowing the aorta to bleed through the puncture site in the aortic root until the surgeon believes that adequate removal of air has been accomplished **(Sellke et al., 2009).**

Closure of the Sternum:

After decannulation and hemostasis has been obtained,, one or more large chest tubes are placed and led out through stab wounds at the lower end of the incision. The sternum is approximated with five to eight heavy stainless-steel wires passed through the sternum or, if one prefers or when the sternum is friable, around the sternum. If the wires are placed around the sternum, care must be taken to avoid injury to the internal mammary arteries. Traction is placed on these wires, and they are carefully tightened to achieve uniform approximation of the sternum. Care must be taken to avoid twisting the wires too tightly or they may cut through the sternum. Stainless-steel wire has been found to provide the most stable sternal closure when compared with other methods of closure including mersilene tape, stainless-steel bands, and plastic bands **(Molina, 2018)**. The twisted wires must be carefully turned down into the sternum so that they do not protrude externally and are not palpable, particularly in elderly thin patients or children.

At the time of closure, care must be taken to avoid entrapment of pacing wires, and chest tubes. The linea Alba is approximated with non absorbable sutures, as is the pectoralis fascia. Subcutaneous tissue may be closed with either continuous or interrupted absorbable sutures. For skin closure, either staples or standard suture is satisfactory, but subcuticular skin closure with a continuous absorbable suture provides a superior cosmetic result and avoids the necessity of removing sutures **(Molina, 2018)**

References:

1. Austen, W. G., & Wooler, G. H. (1960). Surgical treatment of mitral stenosis by the transventricular approach with a mechanical dilator. New England Journal of Medicine, 263(14), 661-665.
2. Bailey, C. P. (1949). The surgical treatment of mitral stenosis (mitral commissurotomy). Diseases of the Chest, 15(4), 377-393.

3. Balasubramanyam, U., & Kapoor, P. M. (2020). Anesthetic challenges in minimally invasive cardiac surgery. Journal of Cardiac Critical Care TSS Vol, 3(1).
4. Barac, Y. D., & Glower, D. D. (2020). Port-Access mitral valve surgery—an evolution of technique. Paper presented at the Seminars in thoracic and cardiovascular surgery.
5. Bates, M. J., & Chitwood, W. R. (2021). Minimally invasive and robotic approaches to mitral valve surgery: transthoracic aortic crossclamping is optimal. JTCVS techniques, 10, 84-88.
6. Campbell, T. S., Johnson, J. A., & Zernicke, K. A. (2020). McGill Pain Questionnaire. In Encyclopedia of Behavioral Medicine (pp. 1348-1349): Springer.
7. Carpentier, A., Loulmet, D., Aupecle, B., Kieffer, J., Tournay, D., Guibourt, P., . . . Cardon, C. (1998). Computer assisted open heart surgery. First case operated on with success. Comptes rendus de l'Academie des sciences. Serie III, Sciences de la vie, 321(5), 437-442.
8. Cetinkaya, A., Geier, A., Bramlage, K., Hein, S., Bramlage, P., Schönburg, M., . . . Richter, M. (2021). Long-term results after mitral valve surgery using minimally invasive versus sternotomy approach: a propensity matched comparison of a large single-center series. BMC Cardiovascular Disorders, 21(1), 314.
9. Chapman, C. R., Casey, K., Dubner, R., Foley, K., Gracely, R., & Reading, A. (1985). Pain measurement: an overview. Pain, 22(1), 1-31.
10. Chen, S.-W., Chen, C.-Y., Wu, V. C.-C., Chou, A.-H., Cheng, Y.-T., Chang, S.-H., & Chu, P.-H. (2022). Mitral valve repair versus replacement in patients with rheumatic heart disease. The Journal of Thoracic Cardiovascular Surgery, 164(1), 57-67. e11.
11. Chitwood, W., & Rodriguez, E. (2008). Minimally invasive and robotic mitral valve surgery. Cardiac Surgery in the Adult. 3rd edition. New York, NY: McGraw-Hill, 1079-1100.
12. Choudhary, S. K., & Reddy, P. R. (2022). Cannulation strategies in aortic surgery: techniques and decision making. Indian Journal of Thoracic Cardiovascular Surgery, 38(Suppl 1), 132-145.
13. Cohn, L. H. (1998). Parasternal approach for minimally invasive aortic valve surgery. Operative Techniques in Cardiac Thoracic Surgery, 3(1), 54-61.
14. Cosgrove III, D. M., Sabik, J. F., & Navia, J. L. (1998). Minimally invasive valve operations. The Annals of thoracic surgery, 65(6), 1535-1539.
15. Cuartas, M. M., & Davierwala, P. M. (2020). Minimally invasive mitral valve repair. Indian journal of thoracic cardiovascular surgery, 36, 44-52.
16. Cutler, E. C., & Levine, S. A. (1923). Cardiotomy and valvulotomy for mitral stenosis; experimental observations and clinical notes concerning an operated case with recovery. The Boston Medical Surgical Journal, 188(26), 1023-1027.
17. Echeverria-Villalobos, M., Munlemvo, D. M., Fiorda-Diaz, J., & Essandoh, M. K. (2019). Mechanical ventilation and cardiopulmonary bypass: a narrative review of the mechanistic lung protective measures. Vessel Plus, 3, 33.
18. Elshihy, E. M. A., Fouad, A. S. E., Mohamed, A. Y., Abd Raboh, A. M., & Eldin, M. M. (2022). Minimal Invasive Mitral Valve Surgery Versus Conventional Median Sternotomy Approach Regarding Postoperative Pulmonary Complications. NeuroQuantology, 20(5), 5420.
19. Eltonsy, A. M., Elborae, W. S., Elkay, H. M., & Ali, H. F. (2023). Early Outcome of Minimally Invasive Versus Conventional Mitral Valve Replacement Surgery. The Egyptian Journal of Hospital Medicine, 90(1), 186-193.

20. Eqbal, A. J., Gupta, S., Basha, A., Qiu, Y., Wu, N., Rega, F., . . . Whitlock, R. P. (2022). Minimally invasive mitral valve surgery versus conventional sternotomy mitral valve surgery: a systematic review and meta-analysis of 119 studies. Journal of cardiac surgery, 37(5), 1319-1327.
21. Felger, J. E., Chitwood Jr, W. R., Nifong, L. W., & Holbert, D. (2001). Evolution of mitral valve surgery: toward a totally endoscopic approach. The Annals of thoracic surgery, 72(4), 1203-1209.
22. Fuller, A. M., Bharde, S., & Sikandar, S. (2023). The mechanisms and management of persistent postsurgical pain. Frontiers in Pain Research, 4, 1154597.
23. Gerosa, G., Tessari, C., & Fabozzo, A. (2023). Cannulations for cardiopulmonary bypass. In Cardiopulmonary Bypass (pp. 223-235): Elsevier.
24. Ghamrawy, A., Ibrahim, N. N., & Abd El-Wahab, E. W. (2020). How accurate is the diagnosis of rheumatic fever in Egypt? Data from the national rheumatic heart disease prevention and control program (2006-2018). PLOS Neglected Tropical Diseases, 14(8), e0008558.
25. Giamberti, A., Mazzera, E., Di Chiara, L., Ferretti, E., Pasquini, L., & Di Donato, R. (2000). Right submammary minithoractomy for repair of congenital heart defects. European journal of cardio-thoracic surgery, 18(6), 678-682.
26. Goldstein, D. J., & Oz, M. C. (2003). Minimally invasive cardiac surgery: Springer Science & Business Media.
27. Gumus, F., Hasde, A. I., Bermede, O., Kilickap, M., & Durdu, M. S. (2020). Multiple valve implantation through a minimally invasive approach: comparison of standard median sternotomy and right anterior thoracotomy. Heart, Lung Circulation, 29(9), 1418-1423.
28. Hage, A., Hage, F., Al-Amodi, H., Gupta, S., Papatheodorou, S. I., Hawkins, R., . . . Chu, M. W. (2021). Minimally invasive versus sternotomy for mitral surgery in the elderly: a systematic review and meta-analysis. Innovations, 16(4), 310-316.
29. Harlan, B. J., Starr, A., & Harwin, F. M. (2012). Manual of cardiac surgery: Springer Science & Business Media.
30. Holman, E., & Willett, F. (1949). The surgical correction of constructive pericarditis. Surgery, gynecology obstetrics, 89(2), 129-144.
31. Hussein, A. E. A., AbdelBary, K. H., & Abdel, M. (2021). Minimally invasive mitral valve surgery (MIMVS) Evolution.
32. Iyengar, A., Goel, N., Kelly, J. J., Han, J., Brown, C. R., Khurshan, F., . . . Desai, N. (2020). Effects of frailty on outcomes and 30-day readmissions after surgical mitral valve replacement. The Annals of thoracic surgery, 109(4), 1120-1126.
33. Jahanian, S., Arghami, A., Wittwer, E. D., King, K. S., Daly, R. C., Dearani, J. A., . . . Schaff, H. V. (2023). Does minimally invasive mitral valve repair mean less postoperative pain? The Annals of thoracic surgery, 115(5), 1172-1178.
34. Kaneko, Y., Kohno, T., Ohtsuka, T., Ohbuchi, T., Furuse, A., & Konishi, T. (1996). Video-assisted observation in mitral valve surgery. The Journal of Thoracic Cardiovascular Surgery, 111(1), 279-280.
35. Kastengren, M., Svenarud, P., Ahlsson, A., & Dalén, M. (2019). Minimally invasive mitral valve surgery is associated with a low rate of complications. Journal of Internal Medicine, 286(6), 614-626.

36. Klersy, C., Collarini, L., Chiara Morellini, M., & Cellino, F. (1997). Heart surgery and quality of life: a prospective study on ischemic patients. European journal of cardio-thoracic surgery, 12(4), 602-609.
37. Kofidis, T. (2021). Minimally Invasive Cardiac Surgery: A Practical Guide: CRC Press.
38. Krishnamoorthy, B. (2020). Cardiothoracic Manual for Perioperative Practitioners: M&K Update Ltd.
39. Kubitz, J. C., Schulte-Uentrop, L., Zoellner, C., Lemke, M., Messner-Schmitt, A., Kalbacher, D., . . . Girdauskas, E. (2020). Establishment of an enhanced recovery after surgery protocol in minimally invasive heart valve surgery. PLoS One, 15(4), e0231378.
40. Kuinose, M., Watanabe, T., Tsujimoto, K., Kondo, K., Isoda, R., Tokunaga, N., . . . Yamatsuji, T. (2020). Minimally invasive cardiac surgery via a right mini-thoracotomy. Kawasaki medical journal, 46, 103-114.
41. Lender, O., Göbölös, L., Bajwa, G., & Bhatnagar, G. (2022). Sternal wound infections after sternotomy: risk factors, prevention and management. Journal of wound care, 31(Sup6), S22-S30.
42. Maron, B. A., Abman, S. H., Elliott, C. G., Frantz, R. P., Hopper, R. K., Horn, E. M., . . . Kovacs, G. (2021). Pulmonary arterial hypertension: diagnosis, treatment, and novel advances. American journal of respiratory Critical care medicine, 203(12), 1472-1487.
43. MILLER, W. F., JOHNSON JR, R. L., & WU, N. (1956). The half-second expiratory capacity test: a convenient means of evaluating the nature and extent of pulmonary ventilatory insufficiency. Diseases of the Chest, 30(1), 33-42.
44. Modi, P., Rodriguez, E., Hargrove III, W. C., Hassan, A., Szeto, W. Y., & Chitwood Jr, W. R. (2009). Minimally invasive video-assisted mitral valve surgery: a 12-year, 2-center experience in 1178 patients. The Journal of Thoracic Cardiovascular Surgery, 137(6), 1481-1487.
45. Mohamed, M. A., Cheng, C., & Wei, X. (2021). Incidence of postoperative pulmonary complications in patients undergoing minimally invasive versus median sternotomy valve surgery: propensity score matching. Journal of Cardiothoracic Surgery, 16, 1-8.
46. Molina, J. E. (2018). Cardiothoracic Surgical Procedures and Techniques: Springer.
47. Moorjani, N., Ohri, S. K., & Wechsler, A. (2013). Cardiac surgery: recent advances and techniques.
48. Navia, J. L., & Cosgrove, D. M. (1996). Minimally invasive mitral valve operations. The Annals of thoracic surgery, 62(5), 1542-1544.
49. Papadopoulos, N., Ntinopoulos, V., Dushaj, S., Häussler, A., Odavic, D., Biefer, H. R. C., & Dzemali, O. (2024). Navigating the challenges of minimally invasive mitral valve surgery: a risk analysis and learning curve evaluation. Journal of Cardiothoracic Surgery, 19(1), 24.
50. Parvathy, U. T., Rajan, R., Faybushevich, A., & Zhanna, K. D. (2020). Pulmonary dysfunction: a predictor of postoperative outcome in severe mitral stenosis. Annals of Clinical Cardiology, 2(2), 60-69.
51. Pradeep, A., Rangasamy, J., & Varma, P. K. (2021). Recent developments in controlling sternal wound infection after cardiac surgery and measures to enhance sternal healing. Medicinal research reviews, 41(2), 709-724.
52. Reichenspurner, H., Boehm, D. H., Gulbins, H., Schulze, C., Wildhirt, S., Welz, A., . . . Reichart, B. (2000). Three-dimensional video and robot-assisted port-access mitral valve operation. The Annals of thoracic surgery, 69(4), 1176-1181.

53. Revill, S., Robinson, J., Rosen, M., & Hogg, M. (1976). The reliability of a linear analogue for evaluating pain. Anaesthesia, 31(9), 1191-1198.
54. Sa, M. P. B., Van den Eynde, J., Cavalcanti, L. R. P., Kadyraliev, B., Enginoev, S., Zhigalov, K., . . . Dreyfus, G. (2020). Mitral valve repair with minimally invasive approaches vs sternotomy: A meta-analysis of early and late results in randomized and matched observational studies. Journal of cardiac surgery, 35(9), 2307-2323.
55. Sachdeva, U. M., Wright, C. D., & Mathisen, D. J. (2021). Approach to the mediastinum: transcervical, transsternal, and video-assisted. In Surgery of the thyroid and parathyroid glands (pp. 70-78. e71): Elsevier.
56. Sellke, F., Del Nido, P. J., & Swanson, S. J. (2009). Sabiston and Spencer's Surgery of the Chest E-Book: Elsevier Health Sciences.
57. Shumacker Jr, H. B., & Lurie, P. R. (1953). Pulmonary valvulotomy: Description of a new operative approach with comments about diagnostic characteristics of pulmonic valvular stenosis. Journal of Thoracic Surgery, 25(2), 173-186.
58. Souttar, H. S. (1925). The surgical treatment of mitral stenosis. British medical journal, 2(3379), 603.
59. Starr, A., & Edwards, M. L. (1961). Mitral replacement: clinical experience with a ball-valve prosthesis. Annals of surgery, 154(4), 726.
60. Tribble, C., Merrill, W., Derryberry, S., & Parrino, G. (2021). The median sternotomy: the unkindest cut of all? Pearls, pitfalls, aphorisms, & myths. Paper presented at the The Heart Surgery Forum.
61. Troosters, T., Gosselink, R., & Decramer, M. (2005). Respiratory muscle assessment. European respiratory monograph, 31, 57.
62. Van Praet, K. M., Kofler, M., Montagner, M., Heck, R., Eggert-Doktor, D., Stamm, C., . . . Kempfert, J. r. (2020). Minimally invasive mitral valve repair using external clamping—pearls and pitfalls. Journal of Visualized Surgery, 6.
63. Vanermen, H., Farhat, F., Wellens, F., de Geest, R., Degrieck, I., van Praet, F., & Vermeulon, Y. (2000). Minimally Invasive Video-Assisted Mitral Valve Surgery: From Port-Access Towards a Totally Endoscopic Procedure. Journal of Cardiac Surgery, 15(1), 51-60.
64. von Oppell, U., Szafranek, A., & Anderson, R. (2022). Cardiac surgery and percutaneous interventions in the elderly. Pathy's Principles Practice of Geriatric Medicine, 1, 455-481.
65. Walther, T., Falk, V., Metz, S., Diegeler, A., Battellini, R., Autschbach, R., & Mohr, F. W. (1999). Pain and quality of life after minimally invasive versus conventional cardiac surgery. The Annals of thoracic surgery, 67(6), 1643-1647.
66. Wells, F. C. (2023). Atlas of Cardiac Surgery: Springer.
67. Zapata, D., Halkos, M., Binongo, J., Puskas, J., Guyton, R., & Lattouf, O. (2020). Effects and outcomes of cardiac surgery in patients with cardiometabolic syndrome. Journal of Cardiac Surgery, 35(4), 794-800.
68. Zeitani, J. (2020). Sternal Wound Complications. Plastic Thoracic Surgery, Orthopedics Ophthalmology, 229-239.
69. Zhou, S., Egorova, N., Moskowitz, G., Giustino, G., Ailawadi, G., Acker, M. A., . . . Gelijns, A. (2021). Trends in MitraClip, mitral valve repair, and mitral valve replacement from 2000 to 2016. The Journal of Thoracic Cardiovascular Surgery, 162(2), 551-562. e554.
70. Zoghbi, W. A., Enriquez-Sarano, M., Foster, E., Grayburn, P. A., Kraft, C. D., Levine, R. A., . . . Rakowski, H. (2003). Recommendations for evaluation of the severity of native

valvular regurgitation with two-dimensional and Doppler echocardiography. Journal of the American Society of Echocardiography, 16(7), 777-802.