Right Anterolateral Thoracotomy Compared with Median Sternotomy in Atrial Septal Defect Closure: Surgical Outcomes

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Received: 28 October 2024, **Accepted:** 17 November 2024, **Published:** 20 November 2024

Abstract

Background: Atrial septal defect (ASD) is one of the most common congenital heart diseases requiring surgical intervention when transcatheter closure is not feasible. Median sternotomy has traditionally been the standard surgical approach, offering excellent exposure and reliable outcomes. However, advances in cardiothoracic surgical techniques have led to the development of minimally invasive approaches, particularly right anterolateral thoracotomy, which aim to reduce surgical trauma while preserving the safety and efficacy of conventional methods.

This review aims to compare minimally invasive right anterolateral thoracotomy with standard median sternotomy for ASD closure, with a focus on surgical outcomes, safety, and cosmetic considerations. Key intraoperative parameters such as cardiopulmonary bypass time and aortic cross-clamp duration are evaluated alongside postoperative outcomes including pain, duration of mechanical ventilation, intensive care unit stay, and overall hospital stay. Additionally, patient-centered factors such as cosmetic satisfaction and quality of life are examined, reflecting their growing importance in surgical decision-making.

Available evidence indicates that minimally invasive right anterolateral thoracotomy achieves comparable success rates in ASD closure and maintains a similar safety profile to median sternotomy when applied to appropriately selected patients. Although this approach may be associated with slightly longer operative times, these differences do not appear to negatively impact overall clinical outcomes. Furthermore, the minimally invasive technique is often associated with reduced postoperative pain, faster recovery, and improved cosmetic results.

In conclusion, minimally invasive right anterolateral thoracotomy is a safe and effective alternative to median sternotomy for ASD closure in selected patients. While median sternotomy remains essential in more complex cases, the minimally invasive approach offers clear advantages in terms of recovery and patient satisfaction. Further research is needed to refine patient selection and strengthen the evidence supporting its broader adoption.

Keywords: *Right Anterolateral Thoracotomy, Median Sternotomy, Atrial Septal Defect Closure*

Introduction

Atrial septal defect (ASD) is a common congenital cardiac anomaly characterized by a persistent communication between the left and right atria, resulting in left-to-right shunting, right heart volume overload, and, if untreated, long-term complications such as pulmonary hypertension, atrial arrhythmias, and right heart failure. Surgical closure remains a definitive treatment, particularly in patients who are not suitable for transcatheter device closure due to anatomical limitations such as large defects, inadequate septal rims, or associated intracardiac anomalies. Over time, surgical strategies have evolved to improve outcomes while reducing procedural morbidity. [1]

Median sternotomy has historically been regarded as the gold standard approach for ASD closure, offering excellent exposure of cardiac structures, facilitating safe cannulation for cardiopulmonary bypass, and enabling reliable defect repair with high success rates. Its widespread use is largely attributed to its technical simplicity and reproducibility. However, this approach is associated with certain limitations, including a relatively large incision, increased postoperative pain, risk of sternal wound complications, and a visible scar, which may be particularly concerning in younger patients and females. [2]

In recent decades, minimally invasive cardiac surgical techniques have emerged as attractive alternatives, with right anterolateral thoracotomy becoming one of the most commonly utilized approaches for ASD closure. This technique typically involves a limited incision in the right chest, avoiding sternotomy while still providing sufficient access for intracardiac repair under cardiopulmonary bypass. The primary objective of this approach is to reduce surgical trauma, enhance postoperative recovery, and improve cosmetic outcomes without compromising the safety and efficacy of the procedure. [3]

Despite the increasing adoption of minimally invasive approaches, there remains ongoing debate regarding their comparative benefits and potential drawbacks relative to median sternotomy. Several studies have reported favorable outcomes with right anterolateral thoracotomy, including reduced postoperative pain, shorter hospital stay, and improved cosmetic satisfaction. However, concerns persist regarding increased technical complexity, longer cardiopulmonary bypass and cross-clamp times, and the potential for increased perioperative risk, particularly in centers with limited experience in minimally invasive cardiac surgery. [4]

The aim of this review is to provide a comprehensive comparative analysis of minimally invasive right anterolateral thoracotomy and standard median sternotomy for ASD closure, focusing on surgical outcomes, safety, and cosmetic considerations. A significant research gap exists due to the limited availability of large-scale randomized controlled trials directly comparing these approaches. Most of the current evidence is derived from retrospective studies and single-center experiences, with variability in patient selection and outcome reporting. Addressing these limitations is essential for establishing evidence-based guidelines and optimizing patient-centered surgical decision-making in ASD management. [5]

Surgical Anatomy and Clinical Background of Atrial Septal Defect Relevant to Operative Repair

Atrial septal defect (ASD) encompasses a group of congenital abnormalities characterized by defects in the interatrial septum, allowing communication between the left and right atria. The most common subtype is ostium secundum ASD, which occurs at the region of the fossa ovalis and accounts for approximately 70–80% of cases. Other subtypes include ostium primum ASD, sinus venosus defects (superior and inferior), and coronary sinus defects. Each subtype has distinct anatomical relationships that are critically important for surgical planning, particularly when considering minimally invasive approaches that may limit exposure compared to median sternotomy. [6]

From a surgical perspective, a detailed understanding of the interatrial septum and its surrounding structures is essential. The septum lies in close proximity to vital anatomical landmarks, including the superior and inferior vena cava, the atrioventricular valves, and the conduction system. In sinus venosus

defects, for example, anomalous pulmonary venous return is frequently present, requiring more complex repair techniques such as patch redirection. These anatomical variations can significantly influence the choice of surgical approach, as complex lesions may favor median sternotomy due to the need for wider exposure and enhanced operative control. [7]

Hemodynamically, ASDs result in a left-to-right shunt driven by pressure differences between the atria, leading to chronic right atrial and right ventricular volume overload. Over time, this can cause dilation of the right heart chambers, increased pulmonary blood flow, and eventual pulmonary vascular remodeling. If left untreated, patients may develop complications such as pulmonary hypertension, atrial arrhythmias (particularly atrial fibrillation), and right-sided heart failure. The timing of surgical intervention is therefore crucial, typically recommended when there is evidence of significant shunting with right heart enlargement, even in asymptomatic patients. [8]

The clinical presentation of ASD varies widely depending on defect size and patient age. Many patients remain asymptomatic during childhood and are diagnosed incidentally, while others may present later in life with exercise intolerance, dyspnea, or arrhythmias. Advances in imaging, particularly transthoracic and transesophageal echocardiography, have greatly improved the ability to accurately define defect size, location, and associated anomalies. These imaging modalities are essential not only for diagnosis but also for preoperative planning, especially when selecting candidates for minimally invasive approaches such as right anterolateral thoracotomy. [9]

The anatomical suitability of ASD for minimally invasive repair is influenced by several factors, including defect type, size, and the presence of associated anomalies. Isolated secundum ASDs with favorable anatomy are ideal candidates for minimally invasive approaches, as they typically require straightforward patch or primary closure. In contrast, more complex defects—such as primum ASDs or those associated with partial anomalous pulmonary venous return—may necessitate broader exposure, making median sternotomy a more appropriate and safer option. Therefore, careful patient selection based on detailed anatomical assessment is a cornerstone for achieving optimal surgical outcomes. [10]

Indications for Surgical Closure and Patient Selection

The decision to proceed with surgical closure of an atrial septal defect (ASD) is primarily guided by hemodynamic significance, symptomatology, and anatomical suitability for intervention. Current clinical practice supports closure in patients with evidence of a significant left-to-right shunt resulting in right atrial and right ventricular enlargement, regardless of symptom presence. A commonly accepted threshold includes a pulmonary-to-systemic flow ratio (Qp/Qs) greater than 1.5:1, which indicates substantial volume overload and justifies intervention to prevent long-term complications such as pulmonary hypertension and right heart failure. [11]

Symptomatic patients, particularly those presenting with exertional dyspnea, reduced exercise tolerance, or atrial arrhythmias, are clear candidates for ASD closure. However, even asymptomatic individuals may benefit from early intervention if imaging demonstrates right-sided chamber dilation or progressive changes in cardiac function. Early repair has been shown to reduce the risk of late complications, including atrial fibrillation and paradoxical embolism. Conversely, closure is generally contraindicated in patients with severe, irreversible pulmonary vascular disease and Eisenmenger physiology, where right-to-left shunting predominates and surgical intervention may worsen clinical outcomes. [12]

Patient selection for surgical versus transcatheter closure depends largely on anatomical considerations. Percutaneous device closure is preferred for suitable secundum ASDs with adequate septal rims and appropriate defect size. However, surgical closure remains the treatment of choice in cases with large defects, deficient rims, multiple defects, or associated anomalies such as partial anomalous pulmonary venous return or atrioventricular valve abnormalities. In such scenarios, surgery offers definitive repair with excellent long-term outcomes. [13]

When surgical intervention is indicated, the choice between median sternotomy and minimally invasive right anterolateral thoracotomy depends on multiple patient-related and anatomical factors. Ideal candidates for minimally invasive approaches include patients with isolated secundum ASDs, favorable body habitus, and no history of prior thoracic surgery or significant pleural adhesions. Additionally,

patients who place a high value on cosmetic outcomes—particularly young adults and female patients—may preferentially benefit from thoracotomy due to the less visible incision. [14]

Conversely, median sternotomy remains the preferred approach in complex cases, including large or multiple defects, associated intracardiac anomalies, redo surgeries, or when extensive exposure is required. It is also favored in situations where rapid access to the heart is necessary or when institutional experience with minimally invasive techniques is limited. Ultimately, the choice of surgical approach should be individualized, taking into account patient anatomy, comorbidities, surgeon expertise, and available institutional resources to ensure optimal safety and outcomes. [15]

Operative Principles of Median Sternotomy

Median sternotomy remains the standard and most widely utilized surgical approach for atrial septal defect (ASD) closure, offering unparalleled exposure of the القلب and great vessels. The procedure begins with a midline skin incision extending from the sternal notch to the xiphoid process, followed by division of the sternum using a surgical saw. This approach provides direct and symmetrical access to all cardiac chambers, facilitating safe and efficient conduct of intracardiac procedures. Its versatility and familiarity make it the preferred approach in both simple and complex congenital cardiac repairs. [16]

After achieving adequate exposure, systemic heparinization is administered, and cardiopulmonary bypass (CPB) is established through standard cannulation of the ascending aorta and both vena cavae (bicaval cannulation). This allows for complete diversion of systemic venous return and optimal decompression of the right atrium. The use of CPB ensures a bloodless and motionless operative field, which is essential for precise intracardiac repair. Aortic cross-clamping is then performed, followed by administration of cardioplegia to achieve myocardial protection during the arrest period. [17]

The right atrium is subsequently opened, providing direct visualization of the interatrial septum and the defect. Depending on the size and type of ASD, closure is performed either by primary suturing for small defects or by patch repair using autologous pericardium or synthetic materials such as Dacron or polytetrafluoroethylene (PTFE). The wide exposure afforded by sternotomy allows the surgeon to handle complex anatomical variations, including multiple defects or associated anomalies, with high precision and safety. [18]

Following successful closure of the defect, the right atriotomy is closed, and the patient is gradually weaned off cardiopulmonary bypass after ensuring hemodynamic stability and adequate cardiac function. Hemostasis is carefully secured, and chest drains are placed to prevent postoperative accumulation of blood or fluid. The sternum is then reapproximated using stainless steel wires, and the soft tissues are closed in layers. Despite its effectiveness, sternal closure requires meticulous technique to minimize the risk of complications such as sternal instability or infection. [19]

Although median sternotomy provides excellent operative conditions and remains the benchmark for safety and reproducibility, it is associated with certain disadvantages. These include increased postoperative pain, longer recovery time due to sternal healing, risk of wound infection or dehiscence, and a prominent anterior chest scar. These limitations have driven the development and adoption of minimally invasive approaches, particularly in patients with isolated ASD, where less invasive access may achieve comparable outcomes with improved patient satisfaction. [20]

Operative Principles of Minimally Invasive Right Anterolateral Thoracotomy

Minimally invasive right anterolateral thoracotomy has emerged as a well-established alternative to median sternotomy for atrial septal defect (ASD) closure, particularly in selected patients with favorable anatomy. This approach typically involves a small incision, usually 4–6 cm, placed in the right submammary or inframammary region, often through the fourth or fifth intercostal space. The incision location allows for improved cosmetic outcomes, especially in female patients, as the scar can be concealed beneath the breast or along natural skin creases. Importantly, this approach avoids sternal division, thereby reducing skeletal trauma and facilitating faster postoperative recovery. [21]

Following incision and entry into the thoracic cavity, the pericardium is opened anterior to the phrenic nerve and suspended to optimize exposure of the right atrium. Unlike median sternotomy, cardiopulmonary bypass (CPB) is commonly established via peripheral cannulation, most frequently

through the femoral artery and femoral vein, with or without additional cannulation of the superior vena cava via the internal jugular vein. This technique allows adequate venous drainage and arterial perfusion while maintaining a relatively unobstructed operative field within the limited thoracic access. [22]

Myocardial protection is achieved through aortic cross-clamping, which may be performed using a transthoracic clamp or, in some setups, an endoaortic balloon occlusion device. Cardioplegia is administered to induce cardiac arrest, similar to conventional techniques. The right atrium is then opened, and the ASD is visualized directly. Closure is performed using either primary suturing or patch repair, depending on the size and morphology of the defect. Despite the smaller incision, advances in instrumentation and surgical technique allow for precise intracardiac repair comparable to that achieved through sternotomy. [23]

At the completion of the repair, the right atriotomy is closed, and the patient is weaned from cardiopulmonary bypass following standard protocols. De-airing maneuvers are particularly important in minimally invasive approaches due to the limited exposure and altered patient positioning. Chest drainage is established through small intercostal tubes, and the thoracotomy incision is closed in layers, often resulting in minimal visible scarring. Avoidance of sternal disruption contributes to reduced postoperative pain and earlier mobilization. [24]

While minimally invasive right anterolateral thoracotomy offers several advantages, including superior cosmetic outcomes and faster recovery, it is technically more demanding and requires a learning curve. Limitations include restricted operative field, dependence on peripheral cannulation, and potential challenges in managing intraoperative complications. Therefore, careful patient selection and adequate surgical expertise are essential to ensure safety and achieve outcomes comparable to those of median sternotomy. [25]

Intraoperative Outcomes: Exposure, Cannulation, Cardiopulmonary Bypass Time, and Cross-Clamp Time

Intraoperative parameters are critical in evaluating the comparative effectiveness of minimally invasive right anterolateral thoracotomy and median sternotomy for atrial septal defect (ASD) closure. One of the most notable differences between the two approaches lies in surgical exposure. Median sternotomy provides wide, direct visualization of the heart and great vessels, allowing optimal maneuverability and ease of access to all intracardiac structures. In contrast, right anterolateral thoracotomy offers a more limited operative field, which may challenge visualization, particularly in complex anatomical variants. However, with advances in surgical instruments and video-assisted techniques, adequate exposure can still be achieved in appropriately selected cases. [26]

Cannulation strategies also differ significantly between the two approaches. In median sternotomy, central cannulation of the ascending aorta and both vena cavae is standard, providing reliable and efficient cardiopulmonary bypass (CPB). Conversely, minimally invasive thoracotomy typically relies on peripheral cannulation, most commonly via the femoral artery and vein, sometimes supplemented by internal jugular venous access. While peripheral cannulation is generally safe, it introduces additional considerations such as the risk of vascular complications, limb ischemia, and the need for careful patient selection, particularly in individuals with peripheral vascular disease. [27]

Cardiopulmonary bypass time and aortic cross-clamp duration are frequently reported as slightly longer in minimally invasive approaches compared to median sternotomy. This is largely attributed to the technical complexity of working through a smaller incision, the need for peripheral cannulation, and the learning curve associated with these techniques. Despite these differences, multiple studies have demonstrated that the modest increase in operative times does not significantly impact overall clinical outcomes, including morbidity and mortality, when procedures are performed by experienced surgical teams. [28]

Another important intraoperative consideration is myocardial protection. Both approaches utilize similar cardioplegic strategies; however, the method of aortic occlusion may differ. In thoracotomy, specialized instruments such as transthoracic clamps or endoaortic balloon devices are often required, which can add to procedural complexity. Nevertheless, when properly executed, myocardial protection is comparable

between the two techniques, and no significant differences in postoperative cardiac function have been consistently reported. [29]

Overall, while median sternotomy offers superior exposure and shorter operative times, minimally invasive right anterolateral thoracotomy provides acceptable intraoperative conditions with comparable safety in selected patients. The differences in CPB and cross-clamp times are generally offset by the benefits observed in postoperative recovery and patient satisfaction, reinforcing the importance of surgical expertise and appropriate case selection in achieving optimal outcomes. [30]

Early Postoperative Outcomes: Pain, Ventilation, ICU Stay, and Hospital Stay

Early postoperative outcomes represent a major determinant in evaluating the clinical benefit of minimally invasive right anterolateral thoracotomy compared with median sternotomy for atrial septal defect (ASD) closure. One of the most consistently reported advantages of the minimally invasive approach is reduced postoperative pain. Avoidance of sternal division significantly decreases musculoskeletal trauma, allowing patients to experience less discomfort, require lower doses of analgesics, and achieve earlier mobilization. In contrast, sternotomy is associated with considerable postoperative pain due to sternal splitting and retraction, which may delay recovery and rehabilitation. [31]

Duration of mechanical ventilation is another important parameter reflecting early recovery. Patients undergoing minimally invasive thoracotomy often demonstrate shorter ventilation times, attributed to reduced surgical trauma, improved postoperative respiratory mechanics, and less impairment of chest wall stability. Conversely, patients undergoing median sternotomy may require longer ventilatory support due to pain-related splinting, decreased pulmonary compliance, and higher risk of atelectasis. However, it is important to note that differences in ventilation time may also be influenced by institutional protocols and perioperative management strategies. [32]

Intensive care unit (ICU) stay is frequently reported to be shorter in patients undergoing minimally invasive ASD closure. Earlier extubation, reduced pain, and faster hemodynamic stabilization contribute to more rapid transfer from ICU to the general ward. In comparison, sternotomy patients may require prolonged monitoring due to higher postoperative discomfort and potential complications related to sternal healing. Nevertheless, in experienced centers, the difference in ICU stay may be modest, particularly when enhanced recovery protocols are applied uniformly across both groups. [33]

Hospital length of stay is another key indicator of recovery and healthcare resource utilization. Numerous studies have demonstrated that minimally invasive thoracotomy is associated with a shorter overall hospital stay, reflecting faster mobilization, fewer wound-related issues, and earlier return to normal activities. In contrast, patients undergoing median sternotomy often require longer hospitalization due to the need for sternal precautions, pain management, and monitoring for potential complications such as wound infection or dehiscence. [34]

Overall, minimally invasive right anterolateral thoracotomy offers clear advantages in early postoperative recovery compared to median sternotomy. Reduced pain, shorter ventilation time, decreased ICU stay, and shorter hospitalization collectively contribute to improved patient experience and reduced healthcare burden. However, these benefits are closely linked to appropriate patient selection and surgical expertise, emphasizing the need for well-established minimally invasive programs to achieve consistent and optimal outcomes. [35]

Safety Profile and Complications

The safety profile of both median sternotomy and minimally invasive right anterolateral thoracotomy for atrial septal defect (ASD) closure has been extensively evaluated, with most studies demonstrating comparable overall morbidity and mortality between the two approaches when performed in appropriately selected patients. Surgical ASD closure is generally associated with very low operative mortality, particularly in isolated defects, and both techniques achieve high success rates with complete defect closure and minimal residual shunting. [36]

Wound-related complications represent a key point of distinction between the two approaches. Median sternotomy carries a risk of sternal wound infection, dehiscence, and mediastinitis, which, although relatively uncommon, can result in significant morbidity. In contrast, right anterolateral thoracotomy

avoids sternal division and is associated with a lower incidence of deep wound complications. However, thoracotomy incisions may still be associated with localized issues such as seroma formation, minor infection, or intercostal neuralgia, although these are generally less severe and easier to manage. [37]

Cardiopulmonary bypass-related complications, including bleeding, air embolism, and systemic inflammatory response, are possible in both approaches, with no consistent evidence suggesting a significant difference in incidence. However, minimally invasive techniques introduce specific considerations related to peripheral cannulation, such as femoral vessel injury, limb ischemia, hematoma, or pseudoaneurysm formation. Careful preoperative assessment of vascular status and meticulous cannulation technique are essential to minimize these risks. [38]

Arrhythmias, particularly atrial fibrillation, are among the most common postoperative complications following ASD repair. The incidence appears to be similar between the two approaches, as it is more closely related to atrial manipulation and patient factors rather than the surgical access itself. Other potential complications include pleural effusion, pericardial effusion, and transient right ventricular dysfunction, all of which are generally manageable with appropriate postoperative care. [39]

Neurological complications and systemic embolic events are rare but important considerations in both techniques. In minimally invasive surgery, particular attention must be paid to de-airing procedures due to altered operative angles and limited exposure. Despite these concerns, current evidence indicates that with proper technique and experience, the risk of neurological events remains low and comparable to that observed with median sternotomy. [40]

Cosmetic Outcomes and Patient Satisfaction

Cosmetic outcome has become an increasingly important endpoint in modern cardiothoracic surgery, particularly for procedures such as atrial septal defect (ASD) closure that are frequently performed in young, otherwise healthy patients. Median sternotomy results in a long, midline scar over the anterior chest, which is often highly visible and may be associated with psychological distress, especially in adolescents and female patients. Concerns related to body image, self-esteem, and social confidence have been increasingly recognized as relevant factors influencing patient satisfaction and overall quality of life after surgery. [41]

Minimally invasive right anterolateral thoracotomy offers a clear cosmetic advantage by utilizing a smaller incision that can be strategically placed in the inframammary or submammary region. This allows the scar to be concealed beneath the breast or along natural skin folds, making it significantly less noticeable. In many cases, the cosmetic outcome is one of the primary reasons patients and families opt for the minimally invasive approach when clinically appropriate. The reduced incision size and avoidance of sternal disruption further contribute to a more aesthetically favorable result. [42]

Patient satisfaction is closely linked to cosmetic outcomes but also encompasses broader aspects of recovery, including pain, return to normal activity, and overall surgical experience. Studies have consistently shown higher satisfaction scores among patients undergoing minimally invasive ASD closure compared to those treated via median sternotomy. These findings reflect not only improved cosmetic appearance but also the perception of a less invasive procedure and faster recovery. Such factors are particularly relevant in elective cardiac surgery, where multiple treatment options may be available. [43]

In addition to aesthetic considerations, the psychological impact of surgical scars should not be underestimated. Prominent scars from sternotomy may serve as a constant reminder of the surgical experience, potentially affecting long-term emotional well-being. In contrast, less visible scars from thoracotomy are associated with improved body image and reduced psychological burden. This is especially important in pediatric and adolescent populations, where long-term quality of life is a key consideration in treatment planning. [44]

Despite these advantages, it is important to balance cosmetic benefits with clinical safety and surgical feasibility. While minimally invasive approaches provide superior aesthetic outcomes, they should not be prioritized at the expense of procedural safety or completeness of repair. Therefore, careful patient selection and thorough preoperative counseling are essential to ensure that expectations regarding both cosmetic and clinical outcomes are appropriately aligned. [45]

Conclusion

Minimally invasive right anterolateral thoracotomy has emerged as a safe and effective alternative to median sternotomy for the surgical closure of atrial septal defects, offering comparable clinical outcomes in appropriately selected patients. While median sternotomy continues to provide unmatched exposure and remains essential for complex cases, the minimally invasive approach demonstrates clear advantages in terms of reduced postoperative pain, faster recovery, shorter hospital stay, and superior cosmetic results. These benefits are particularly relevant in younger and female patients, where aesthetic considerations and quality of life play a significant role in decision-making. Despite slightly longer operative times and increased technical demands, advancements in surgical expertise and technology have minimized these limitations. Ultimately, the choice of surgical approach should be individualized, taking into account patient anatomy, clinical condition, and institutional experience, to ensure optimal safety, efficacy, and patient satisfaction.

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