Review Article

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Cardiac Surgery Through Median Sternotomy: Preserving and Refining Mastery of the Gold Standard Approach

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Abstract

Background

Median sternotomy remains the gold standard surgical approach for most cardiac procedures because of its excellent exposure, rapid access to mediastinal structures, and reproducibility. Despite its widespread use, sternotomy is associated with substantial postoperative morbidity, including pain, sternal instability, wound infection, mediastinitis, and delayed functional recovery. Increasing surgical complexity and the growing prevalence of comorbidities such as diabetes, obesity, and osteoporosis have intensified the need for improved sternotomy management strategies. Recent developments in rigid fixation systems, minimally invasive techniques, enhanced recovery protocols, infection prevention measures, and perioperative pain management have significantly improved patient outcomes. This review summarizes current evidence regarding optimization of sternotomy, examines emerging technologies and biomaterials, and discusses future directions for improving safety, stability, and recovery following cardiac surgery.

Keywords: Median sternotomy; cardiac surgery

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Introduction

In the mid 1950s, the median sternotomy approach to thoracic cavity revolutionized cardiac surgery by providing unparalleled direct access to the heart and great vessels [1]. It rapidly became the Gold Standard approach for congenital heart surgery, coronary artery bypass grafting (CABG), valve surgeries, aortic surgery, and heart transplantation. Although technically reliable and versatile, sternotomy remains associated with important postoperative complications that contribute to extended ICU stay, prolonged hospitalization, increased morbidity, mortality, and overall healthcare cost. The occurrence of these postoperative complications has driven the evolution of alternative surgical strategies, such as minimally invasive cardiac surgery, mini-sternotomy, totally endoscopic cardiac surgery, and robotic cardiac surgery [2-6]. Nonetheless, many complex multi valve surgeries, combined surgeries like CABG with valve surgeries/ aortic surgery, valve surgeries with aortic surgery, LA ablation, implantation of LVADs and heart-lung transplantation can be performed exclusively through median sternotomy. Therefore, it's imperative to refine and mastery this access to the thoracic cavity by addressing factors contributing to the complications. Although uncommon, the incidence of sternal wound complications ranges from 0.5% to 5%, while deep sternal wound infection, sternal dehiscence and mediastinitis carry mortality rates approaching 10-40% in general population [7]. Furthermore, postoperative pain and impaired chest wall mechanics significantly affect respiratory function, mobility, and quality of life [8]. Over the past two decades, significant attention has given to sternotomy outcomes by advances in surgical technique, closure technology, perioperative optimization, and minimal manipulation of the tissues. This review aims to evaluate modern strategies implemented at reducing complications and improving postoperative recovery following median sternotomy.

Biomechanics of Sternotomy

The sternum serves as a central structural component of the thoracic case connecting ribs anteriorly. It plays a critical role in respiratory mechanics and upper body stability. Median sternotomy divided the sternum longitudinally, disrupting both cortical and cancellous bone integrity of the sternum. The sternum consists of low vascularized tissue and is prone to damage, especially when internal thoracic arteries are harvested for the coronary artery bypass grafting [8].

In a biomedical study by *Pai et al*, it demonstrates that lateral distraction forces are particularly significant during coughing episodes, emphasizing the importance of stable sternal fixation during the closure [9]. During respiration and other upper extremities movements, excessive micromotion of the sternum impairs osteogenesis and increases the risk of sternal nonunion, dehiscence, chronic pain and deep sternal wound infection [10].

Common Complications Associated with Median Sternotomy are:

A. Sternal Wound Infection

Sternal wound infection remains one of the most serious complications following cardiac surgery [6] (Figure 1).

Figure 1. Deep sternal wound infection.

Infections are classified as:

1. Superficial sternal wound infection
2. Deep sternal wound infection
3. Mediastinitis

Deep infections are associated with sepsis, reoperation, prolonged intensive care stay, and

increased morbidity and mortality [6]. Major risk factors for deep infections are diabetes mellitus, obesity, smoking, osteoporosis, COPD, bilateral internal mammary artery harvesting, excessive use of bone wax, and prolonged operative time [9,10].

B. Sternal Instability and Dehiscence

Sternal instability results from inadequate fixation or impaired bone healing due to above mentioned risk factors. Sternal dehiscence can lead to severe pain, respiratory compromise, prolonged mechanical ventilation, and increased infection risk [10]. Patients with poor nutritional status or osteoporosis are particularly susceptible to sternal instability [11] (Figure 2).

C. Chronic Post-Sternotomy Pain

Persistent postoperative pain after median sternotomy affects approximately 20-30% of patients. Chronic pain significantly impairs quality of life and functional recovery of a patient. Mechanisms of chronic post-operative pain could be due to intercostal nerve injury, inadequate fixation, sternal instability, scar tissue formation, and chronic inflammation due to foreign body reaction to the sternal wires and bone wax [12]. It is crucial to avoid complications of median sternotomy to minimize morbidity and mortality associated with median sternotomy. Understanding the key factors that contribute to sternotomy and sternal closure complications is essential for optimizing surgical

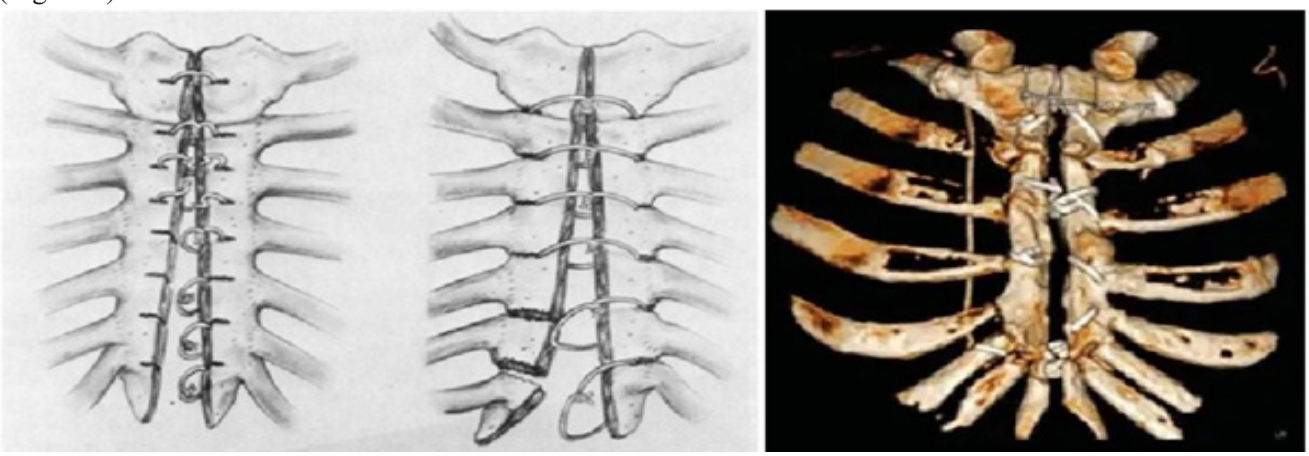

Figure 2. Unstable sternum

outcomes and improving patient safety.

Meticulous operative technique remains a backbone of reducing surgical wound complications. Basic, but important principles include careful tissue handling, preservation of blood supply, adequate hemostasis, and minimization of thermal injury. Justified use of cautery and bone wax for targeted hemostasis should be practiced.

One of the most important aspects of performing a sternotomy is to stay midline. Sternotomy should span systemic tissue dissection, controlled osteotomy to avoid zigzag, uneven left or right-side osteotomy. Proper placement of the sternal blades is essential not to damage the sternal plates during sternal spreading [13]. In the case of coronary artery bypass grafting, skeletonized internal mammary artery harvesting may preserve sternal vascularity and reduce infection risk compared with pedicled harvesting. Sternal closure techniques play a significant role in the development of complications in patients undergoing median sternotomy. It is fundamental to master traditional method of closure and learn novel techniques.

Conventional Wire Cerclage

Traditional wire cerclage remains the most commonly used closure technique worldwide because of surgeon's familiarity, simplicity and low cost [14]. Different sizes, single wire and double wires are used to close the sternum. According to the

manufacturer's product manual, two wires provide increased surface area and strength compared to that of a single wire suture of the same gauge and material. In addition, The Double Wire Twister allows for a one-handed technique that simultaneously applies tension and twists the suture for final approximation of the sternum.

Many modifications to sternal wire cerclage closure are adopted. Most common configurations include interrupted wires, figure-of-eight wiring, overlapping figure-of-eight, and Robicsek weave technique for weaker sternum [15,16] (Figure 3). Although effective in many patients, wire closure may provide insufficient stability in high-risk

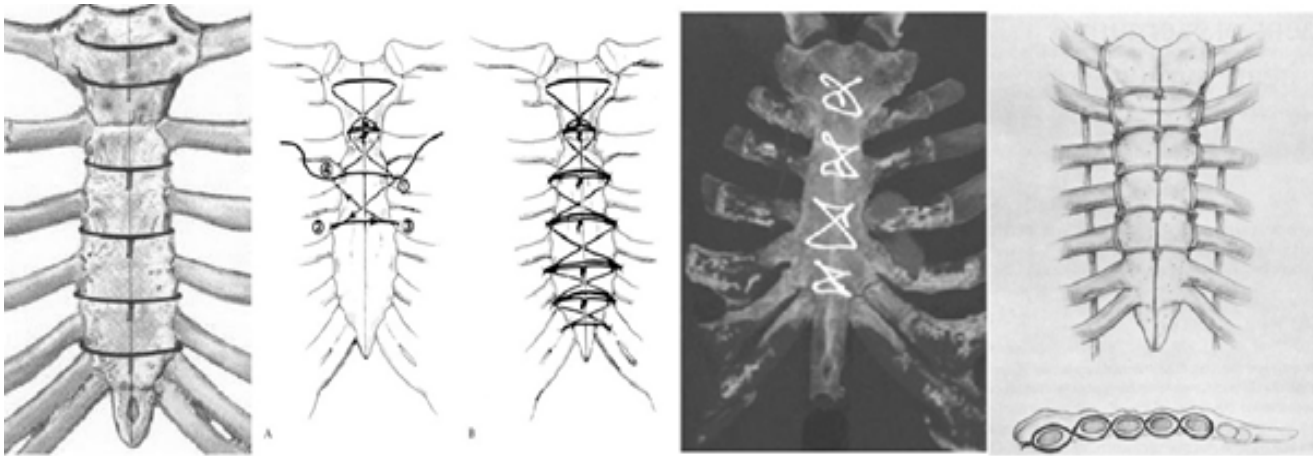

Figure 3. Different types of sternum closure using sternal wire cerclage.

patients and when closed inappropriately [17]. Wire cut through the sternum is one of the most common causes of sternal instability and dehiscence. To avoid such complications, force applied to twist the wires should be calculated not to be too tight or left untightened. Advanced techniques and materials are introduced for sternal closure to minimize sternal instability and dehiscence. Newly available techniques and materials should be evaluated and used according to their availability, practicality, and reproducibility.

Rigid Plate Fixation (RPF)

It has emerge pain, and earlier mobilization. It has emerged as a major advancement in sternotomy closure (Figure 4).

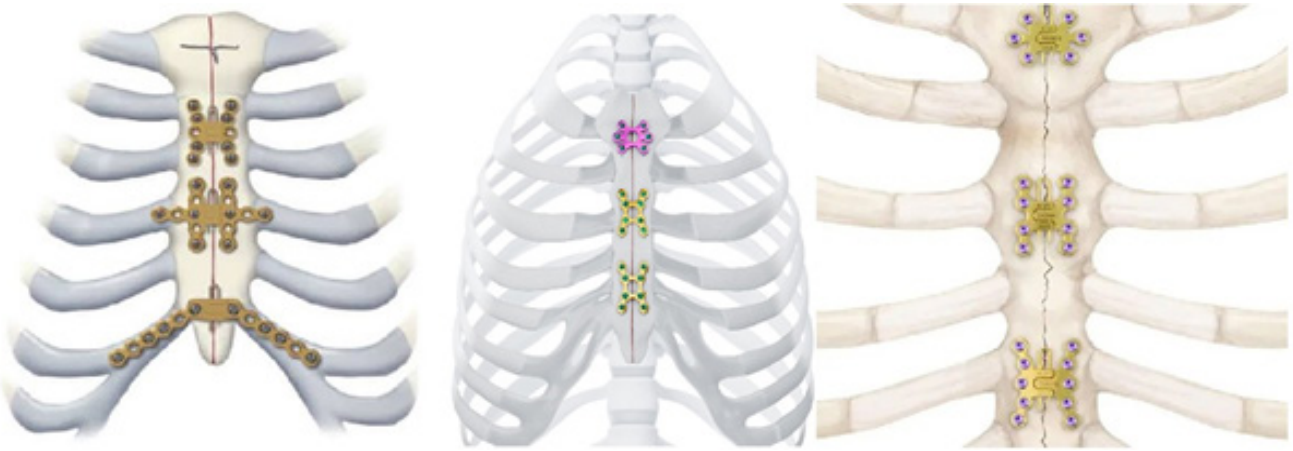

Figure 4. Different rigid plate fixation (RPF)

Titanium places and screws provide superior mechanical stabilization compared with wire cerclage [17]. Several studies have demonstrated the advantage of using RPF by reducing sternal micromotion, improved bone healing, lower rates of dehiscence, reduced postoperative pain, and earlier

mobilization. Rigid fixation appears particularly beneficial in obese patients, diabetic patients, reoperative sternotomy, and osteoporotic sternum

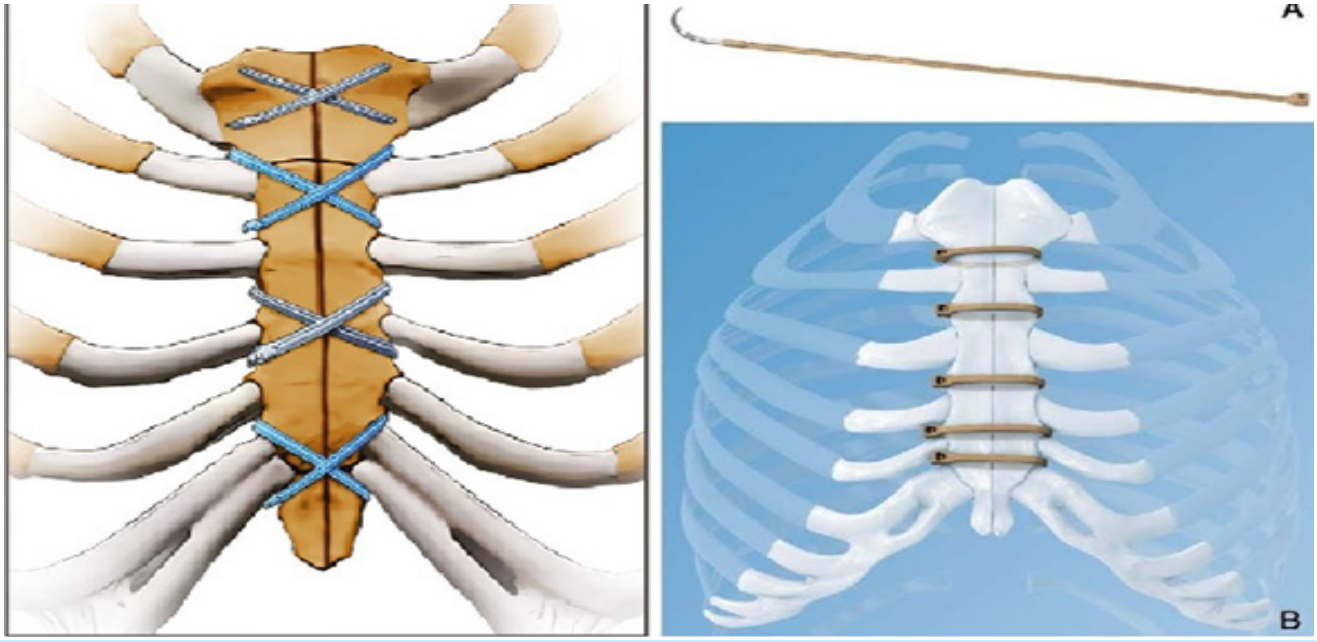

Figure 5. Suture tape and cable-tie closure of the sternum.

[18] (Figure 5).

Despite promising outcomes, higher cost, need for specialized training and increased operative time could be limitations in using these methods to close the sternum.

Suture Tapes and Cable-tie

In a study by *Kumar BA U et al* [19], authors have proposed a novel sternal closure system involving suture tapes, aiming to reduce sternal complications. In their case series, suture tape sternal closure was effective, reproducible, and safe. It showed significant advantages over steel wires, including lower rates of sternal infection, dehiscence, and post-operative pain, as well as decreased opioid usage, and shorter hospital admission and closure times (Figure 5). In a fisrt clinical study of cable-tie based sternal closure system, Grapow et al have shown that the sternal ZipFixTM can be used safely and effectively [20].

Several other innovative methods, hybrid systems for sternum closure with different novel materials, are emerging, which could improve the result of median sternotomy by decreasing the associated complications. For instance, the use of aseptically processed non-terminally irradiated amnion-chorion placental allografts to complement wound closure in high-risk patients has shown no wound infection, dehiscence or significant pain at one month follow-up due to better cell proliferation, angiogenesis and tissue remodeling [21]. In a recent study, Vasanthan et al have used a moldable, settable, and resorbable hemostatic putty (Montage bone putty) in addition to the wire cerclage closure of the sternum. This novel putty material hardens after application to adjunctively support fixation of the reapproximated sternum. In their study, there were no cases of sternal instability or separation and enhanced sternal closure using such putty demonstrated accelerated postoperative recovery in low-risk patients receiving elective cardiac surgery [22].

Infection Control

In addition to the novel methods and materials used, the basic infection control strategy is vital to evade deep wound infection and further sternal instability

leading to sternal dehiscence. Perioperative antibiotic administration remains fundamntal in preventing surgical site infection [23]. The society of thoracic surgeons practice guidelines emphasize administration of antibiotics within 60 minutes before incision and re-dosing during prolonged surgery. Weight adjusted dosing and appropriate gram-positive bacteria coverage is advocated. Vancomycin may be considered in institutions with high methicillin-resistant Staphylococcus aureus prevalence [24].

Glycemia control plays an important role in infection control. Hyperglycemia impairs immune function and wound healing. Tight perioperative glycemia control significantly reduces infection risk, particularly in diabetic patients. Most guidelines recommend maintaining glycemia below 180 mg/dl during the perioperative period [25]. In high-risk sternotomy patients and patients developing surgical site infection, use of closed-incision negative pressure wound therapy has gained increasing attention. Important benefits of this method are reduced edema, improved tissue perfusion, lower bacterial burden and enhanced wound stabilization [26].

Implementation of Enhanced Recovery After Surgery (ERAS) protocols is increasing in cardiac surgery. It has demonstrated reduced ICU length of stay, lower complication rates, faster recovey, reduced opioid consumption, improved patient satisfaction and patient quality of life. Key ERAS principles are preoperative patient education, preoperative and postoperative nutritional optimization, fast-track or early extubation, multimodal analgesia, early mobilization, active physiotherapy and opioid-sparing pain management [27].

Advances in Pain Management

Postoperative pain in patients undergoing cardiac surgery via median sternotomy significantly affects pulmonary function and rehabilitation. Contemporary pain management emphasizes multimodal strategies combining Acetaminophen, Nonsteroidal anti-inflammatory drugs, Gabapentin, Regional anesthesia like bilateral erector spinae plane block (ESPB), parasternal block, paravertebral blocks and cryoanalgesia [28,29].

Emerging Technologies and Future Directions

Personalized Surgical Planning using three-dimensional imaging and patient-specific modelling allow tailored surgical approached and individualized surgical strategies in patients undergoing cardiac surgery [30]. Preoperatively, a surgeon can print, physically hold and study a patients' exact anatomy, which will help to avoid future complications. Moreover, with use of the evolving AI technology, smart implants and biomechanical simulation involving future fixation systems may incorporate embedded sensors, real-time monitoring, infection detection, and stability assessment [31].

Despite major advances, several challenges and limitations remain. Foremost limitation remains higher cost associated with rigid fixation plates and other novel materials. Lack of standardization and limited long-term randomized data poses another significant obstacle in the use of novel materials and methods. Resource disparities between institutions and regions of the world impose restricted implementation of available technologies.

Conclusions

Median sternotomy remains an essential and gold standard approach in cardiac surgery despite ongoing evolution toward minimally invasive cardiac surgery. Recent advances in rigid fixation systems, novel materials, infection prevention, enhanced recovery protocols, and perioperative pain management have significantly improved patient outcomes. Sticking to the basic principle of surgical practice, multidisciplinary, patient-specific approach and implementation of emerging technologies including smart implants, regenerative medicine, and personalized biomedical modelling may further transform sternotomy care in future by

minimizing complications and optimizing recovery. Continued innovation and hight-quality, multicentre clinical research will remain critical for improving sternotomy outcomes in modern cardiac surgery.

Innovation is reshaping the future of modern cardiac surgery through minimally invasive and robotic cardiac surgery techniques. We should embrace these innovations with enthusiasm, as they expand our surgical horizon. Yet, true innovation is built upon a strong foundation. Refining and Mastery of the Gold Standard conventional median sternotomy remains the cornerstone of the surgical excellence and the hallmark of a well-trained cardiac surgeon.

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