Late Complications of Chest Wall Reconstruction: Management of Painful Sternal Nonunion

Kyle J. Chepla, M.D.,¹ Christopher J. Salgado, M.D.,² Cathy J. Tang, M.D., M.S.,³ Samir Mardini, M.D.,⁴ and Karen K. Evans, M.D.⁵

ABSTRACT

Although rare, sternal nonunion after median sternotomy or traumatic injury is associated with a high rate of morbidity. Pain and sternal clicking are two of the most common complaints and reasons these patients seek evaluation and treatment. Diagnosis of sternal nonunion is based on a thorough history and physical examination and can be confirmed with subsequent radiographic imaging. The treatment for symptomatic sternal nonunion requires stable fixation of the bony fragments and chest wall after the debridement of all nonviable bony and soft tissue by the cardiothoracic or reconstructive surgery team. Multiple fixation techniques have been described and incorporate a wide variety of materials including combinations of wires, cables, pins, bands, staples, and plates. Most recently, several new commercially available plating systems have demonstrated low recurrence and complication rates and resolution of the patient's symptoms on follow-up evaluation. Included in this review are three cases demonstrating the management of symptomatic sternal nonunion using these new techniques and review the history, diagnosis, risk factor, and classification, as well as several of the previously described fixation methods.

KEYWORDS: Sternum, nonunion, treatment, management

First described in 1897 and then reintroduced and popularized in 1957, the median sternotomy remains the standard surgical approach to the heart and mediastinal structures for cardiothoracic surgeons.¹ Whereas the vast majority of patients will heal without complication after standard wire fixation, 0.5 to 3% of patients will develop sternal nonunion.^{2–6} Sternal nonunion, initially reported in 1928, was thought to be secondary to infection; however, in 1978 Stoney et al classified and described sterile sternal nonunion as a

separate entity.^{2,7} Currently, diagnosis of sternal nonunion requires subjective complaint of pain or clicking with objective clinical evidence of instability for greater than 3 months in the absence of infection or mediastinitis.^{2–6}

The traditional repair of the median sternotomy consists of five or more no. 5-caliber or no. 6-caliber stainless steel wires passed transversely through the sternum in either a simple interrupted or figure-of-eight fashion. Lateral tension, created by chest wall movement

¹Department of Plastic Surgery, University Hospitals Case Medical Center, Cleveland, Ohio; ²Division of Plastic Surgery, University of Miami Miller School of Medicine, Miami, Florida; ³Department of Surgery, University of California San Francisco, San Francisco, California; ⁴Division of Plastic Surgery, Mayo Clinic, Rochester, Minnesota; ⁵Georgetown University Medical Center, Washington, DC.

Address for correspondence and reprint requests: Christopher J. Salgado, M.D., Division of Plastic Surgery, University of Miami Miller

School of Medicine, 1611 NW 12th Avenue, ET 3019, Miami, FL 33136 (e-mail: salgado_plastics@hotmail.com).

Chest Wall Reconstruction; Guest Editors, Karen K. Evans, M.D., Samir Mardini, M.D., and Phillip G. Arnold, M.D.

Semin Plast Surg 2011;25:98–106. Copyright © 2011 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662.

DOI: <http://dx.doi.org/10.1055/s-0031-1275176>.

ISSN 1535-2188.

during physiologic respiration in the early postoperative period, parallels the axis of the wire and can cut or fracture the bone.^{8,9} When undiagnosed, this loss of fixation results in movement at the bone-bone interface and subsequent nonunion.⁶ Although cardiothoracic surgery accounts for the majority of cases, sternal nonunion can also occur after blunt chest trauma. Traumatic sternal fractures are usually the result of motor vehicle accidents where direct impact from the steering column causes posterior displacement of the distal sternal fragment.^{10,11}

Risk factors for sternal nonunion after median sternotomy are classified either as extrinsic or intrinsic although failure is likely multifactorial. Extrinsic factors include preexisting patient conditions and intraoperative and postoperative events.^{2,12} Contributing patient conditions include obesity,^{5,13–16} chronic obstructive pulmonary disease,^{4,17} osteoporosis,¹⁸ radiation to the chest wall,⁵ as well as malnutrition, diabetes, and steroid use, all of which inhibit healing.⁶ Intraoperatively, technical errors in sternal closure,^{16,19,20} paramedian (off-midline) sternotomy,²¹ and the harvest of bilateral internal mammary arteries for grafting result in bone deterioration and mechanical failure.^{22,23} Postoperatively, prolonged ventilatory support, decreased cardiac function, and the need for closed chest cardiac massage are all associated with increased sternal and wound complication rates.^{4,16,18} Intrinsic risk factors associated with nonunion relate to the characteristics of the bone and include fracture pattern (multiple longitudinal and transverse fragments), persistent fracture gap after reduction, and an unstable reduction.^{6,24,25} All risk factors need to be carefully considered and analyzed prior to any reconstructive procedures.

Sternal nonunion is broadly classified as partial or complete.⁶ Complete nonunion can be further divided into four categories based on the presence of transverse fractures or missing bone segments. Type I describes a midline nonunion without any associated transverse fractures. Type II is nonunion with a unilateral transverse fracture, and type III refers to nonunion with single or multiple bilateral transverse fractures. Type IV nonunions involve multiple fractures with a missing bone segment and subsequent free-floating bone fragments.⁶

On presentation to the plastic surgeon, these patients typically report pain, popping, or grinding with movement that impacts and limits activities of daily living. Anxiety and frequent hospitalizations are common as patients are unable to differentiate cardiac from musculoskeletal pain and worry about solid organ injury from sharp bone edges or loose wires. These patients present at various lengths of time from their initial surgery and are referred from a wide variety of specialists including pain management, cardiologists, cardiac surgeons, and even family physicians after long courses of narcotics, anxiolytics, or antidepressants fail to ameliorate

their symptoms. Although early mortality is not significantly increased, proper treatment of these patients is essential as sterile nonunion is associated with significant morbidity and is believed to be a precursor to osteomyelitis, mediastinitis, and deep sternal space infections, which have high associated mortality rates.^{26,27}

TREATMENT

Indications for operative repair include chronic pain or instability, limitations on activities of daily living, and an altered respiratory mechanism in an otherwise stable patient. Multiple methods of sternal repair or fixation exist; however, the key elements of the operative procedure including removal of the existing avascular scar or pseudoarthrosis, culture of any fluid collections, removal of preexisting plates and wires, debridement of the sternal edges to bleeding healthy bone, irrigation, and closure, often with interposed muscle flaps, are similar in any repair. Preoperative radiographs or computed tomography (CT) scans are often useful and can be particularly helpful in confirmation of the diagnosis, identification of the number and location of fracture fragments and wires, and surgical planning.²⁸

Ultimately, the goal of any sternal repair is long-lasting, rigid fixation and bony union. Many of these techniques described are anecdotal and based on small series of patients; there is currently no accepted “gold standard” for either primary or secondary sternal fixation. Prior to referral, in many cases, nonunion is simply treated by repeat circumferential peristernal rewiring. However, failure to address the underlying cause for failure and resulting fracture patterns result in unacceptably high recurrence rates.^{16,20,29,30}

To prevent recurrence, multiple other wiring techniques have been described and can be used. The addition of parasternal or pericostal wiring to peristernal orients the wire obliquely to tension, improves the lateral stability of the sternum, and incorporates healthy bone to better distribute the tension.^{6,31–35} Peristernal wiring in a figure-of-eight improves lateral stability,^{31,36,37} and parasternal wiring can be used to add lateral support. The Robicsek weave, a widely accepted method for primary and secondary repair, is a combination of a parasternal over-and-under weave at the sternocostal junction, coupled with circumferential peristernal wires.²⁹ Pericostal wiring involves figure-of-eight loops around the costochondral junctions outside the operative area and thus recruits stable, healthy bone. Pericostal wiring, like other techniques, can also be combined with peristernal or parasternal wiring.^{20,38,39} The management of sternal nonunion using these techniques remains popular and accepted as wire is cheap, readily available, and familiar to many cardiothoracic surgeons. However, the extensive parasternal and peristernal dissection required for wire placement in addition to the extreme

strangulation of an already compromised sternum with a tenuous blood supply during sternal fixation leads to further wound-healing problems.

Closure using other materials and techniques such as steel banding, polymer tapes, and absorbable sutures has been explored and reported. Steel banding, as described by Kalush and Bonchek,¹⁷ uses three Parham bands (Richards Manufacturing Co, Memphis, TN) in high-risk patients. The bands are thicker and less likely to break or become displaced and are associated with decreased postoperative pain and shorter hospitalizations⁴⁰; however, they are difficult to coapt due to their rigidity, lack a locking mechanism, and are difficult to remove if re-exploration is required. Other authors have coupled banding with peristernal wiring.⁴¹ LeVeen and Piccone described the use of nylon tapes for closure in an attempt to reduce sheering forces associated with wiring.⁴² Although the use of nylon tapes was discontinued due to high complication rates, they have been replaced by Mersilene tapes (Ethicon, Cincinnati, OH). Mersilene tapes act to reduce shearing and rates of nonunion, and complication rates are similar to alternative methods of fixation.¹⁸ Other adjuncts, such as staples, have also been used to bridge the median sternotomy or anchor transsternal wires, with acceptable results.^{43–45} The Dall-Miles crimped cable grip system (Howmedica, Inc., Rutherford, NJ), typically used for repair of femoral neck fractures, has also been used for primary and secondary sternal fixation.⁴⁶ In this technique, four 2.0-mm Dall-Miles cables are passed through subperiosteal tunnels around the sternum. The tensioner is then used to approximate the fragments, the cables are cut, and the overlying soft tissue is closed. Similar to Parham bands, the Dall-Miles cables are significantly thicker and less likely to cut through bone but are also flexible without sharp ends obviating the need for muscle flaps, and the tensionometer allows for precise, controlled tightening.

Most recently, rigid plate and screw fixation, adapted from craniofacial and orthopedic fracture fixation, is now routinely used for both primary and secondary sternal closure.^{6,24,47–49} Plate fixation, first described by Sherman et al, was used in conjunction with bone grafting for repair of a sternal defect after excision of a chondrosarcoma.⁵⁰ Early plate fixation of median sternotomy repair consisted of two longitudinal plates placed on each half of the sternum and coupled with peristernal and transsternal circumferential wiring. Good outcomes were reported in three high-risk patients, but concerns including cost and risk of injury to underlying organs, loosening, and fracture limited their use.^{6,34,35,48,51} This has changed over the past several decades as the development of new plating systems and biomechanical studies have demonstrated the superiority of rigid fixation.

Early studies of four fixation techniques, performed by Cheng et al, evaluated repair of cadaveric median sternotomy with no. 5 stainless steel wire, 5-mm plastic band, 5-mm Mersilene ribbon, and 5-mm steel band.⁵² Wire provided improved stability compared with Mersilene, but no other significant differences were noted. However, other studies demonstrate the limitations of wire repair. Mathematical models have shown stainless steel results in instability under physiologic conditions, and in a recent study of 41 patients who underwent secondary repair using a Robicsek weave, 20% noted persistent instability, 10% had persistent pain, and 14% required reoperation.^{33,53} Ozaki et al compared steel wire and “H”-shaped titanium plates and found decreased lateral displacement with rigid fixation over wire fixation.⁴⁸ Improved fixation and outcomes of plate fixation over other techniques has been supported by other studies.⁵⁴ Recently, new transverse plating systems were compared with various methods of wire fixation including wires, cables, and plates, wire, cable combinations in a cadaveric model.⁵⁵ Dehiscence, defined as separation of 2 mm, occurred at significantly lower pressures for the wire and cable closures compared with four-plate closure. Rigid fixation has also been proposed to eliminate paradoxical chest wall motion and improve pulmonary mechanics.⁵¹

Multiple plating approaches and systems exist. In the most simple, sternal plates are used in conjunction with wiring in an attempt to better distribute the reduction forces.^{35,56} The two sternal halves are plated longitudinally using 2.4-mm fixation plates placed laterally over good bone stock, and four no. 5 wires are placed beneath the plates prior to screw fixation. The wires are then used to approximate the sternum, and bilateral pectoralis major flaps are used for soft tissue coverage. Emergent access to the mediastinum can be accomplished by simply cutting the wires. However, in the presence of multiple transverse fractures or decreased bone density, wire tension can act to avulse the screws with subsequent loss of fixation.⁵⁷ Sternal plating using the tension band principle for stable approximation of the bony fragments eliminates the need for substernal dissection and wiring, decreasing the risk to underlying grafts, organs, and protecting the tenuous sternal blood supply.⁶ CT was used to evaluate sternal anatomy (size and location of bone fragments) in six patients to determine the appropriate plate location and size. No muscle flaps were used in closure due to the low profile of the plates. Subjectively, five patients were pain free, and all reported improvement in their feelings of depression postoperatively.⁶ However, Eich and Heinz believed that tension band plating required too much dissection at the lateral sternal margin and resulted in sacrifice of viable costal cartilage.⁴⁶ The Sternalock system (W. Lorenz Surgical, Inc., Jacksonville, FL) was used on six patients with sterile sternal nonunion after median

sternotomy or trauma. These low-profile plates require minimal periosteal stripping and can be used to span bone gaps thus eliminating the need for bone grafting. At 6 to 18 months, all patients were pain free without any complication. Bony healing was assessed and confirmed with plain radiographs.¹²

Cicilioni et al first described titanium locking reconstruction plates spanning the sternum with fixation into the adjacent ribs for 50 patients that failed primary or secondary wiring.⁵⁸ These plates were then modified to include a midline release pin for rapid access to the mediastinum and a star or "H"-shaped plate for manubrial fixation (Titanium Sternal Fixation System; Synthes USA, Paoli, PA). After sternal debridement, the pectoralis muscles are released and the ribs exposed bilaterally. Three locking 3.0-mm screws are placed on each half after the sternum has been reapproximated using clamps. The pectoralis muscles are then sutured together in the midline with postpectoral drains after plate coaptation. In two trials of 4 and 14 patients, all had stable union with immediate improvement in pain; complications included a tear in the parietal pleura by the rib approximator, seroma requiring operative drainage, plate failure requiring reoperation, and hardware infection necessitating removal.^{57,59} To date, no comparative studies exist that address the cost-effectiveness of these plating systems. In a recent study, the average cost of using the Synthes system was \$8508 per patient (range \$3900 to \$16,189).⁵⁹ Whether the decreased rate of failure with need to return to the operating room, chronic pain medication usage, and multiple emergency department visits due to chest pain offsets this cost remains to be determined.

There is also no consensus on how much of a bone gap is acceptable after sternal approximation. Although some authors report good outcomes with plates spanning bone defects,⁵⁹ other techniques have been described to repair bone gaps or persistent nonunion. Bertin et al describe iliac crest bone graft for the repair of transverse sternal nonunion after trauma and ministernotomy.⁴⁹ Parallel plates were placed on both sides of the sternal midline, the proximal fragment was fixed, and the distal segment was approximated. The resulting gap, which was 10 to 25 mm in size, was then filled with cancellous bone graft. Sternal healing was noted on plain radiographs 6 to 8 weeks after repair, and all patients were able to return to full activity without recurrence. Again, these were noninfected cases. Mayba, Coons et al, and Huh et al all have also reported plating or wiring sternal fractures in conjuncture with bone grafting from various sources, including adjacent ribs.^{24,25,59} Recently, bone morphogenetic protein has been used for a chronic, transverse nonunion resulting from chest wall trauma to prevent the need for autogenous bone grafting.⁶⁰ For this patient, primary sternal fixation was attempted using the Sternalock system; however, no evidence of callous formation or union was noted on postoperative radio-

graphs. At the time of reoperation, good bony apposition without loosening of the plates was noted. The bone was further debrided to allow placement of the collagen sponge; CT performed at 4 months demonstrated complete healing.

Fixation of the sternum may ultimately be unnecessary. In a recent study, 24 high-risk patients with symptomatic sternal instability underwent removal of remaining wires or plates, limited sternal debridement with preservation of the retrosternal scar tissue, and bilateral pectoralis muscle flap reconstruction and primary skin closure without sternal fixation. Patients in this study reported a decrease in pain from 7.7 (range 6 to 10) to 2.2 (range 0 to 4) postoperatively with clinically improved sternal stability (no data given).²³ Thus, this technique is recommended and should be considered for patients who are at high risk of failing secondary procedures.

Multiple methods exist for primary and secondary sternal fixation. Recent studies comparing closure techniques point to the superiority of rigid sternal fixation using plates and screws. Although more costly, we believe that this will be offset by reduced recurrence rates and patient morbidity. However, as with most other surgical procedures, each patient should be considered on a case by case basis after evaluation of all relevant risk factors, soft and bony tissue, and previous attempts at fixation.

CASE REPORTS

We present three patients with symptomatic sterile sternal nonunion after failure of primary peristernal wiring. All patients underwent sternal fixation with commercially available plating systems after debridement of the sternum and wound bed. While patients 1 and 2 were repaired with syntheses plates, patient 3 was fixed with the KLS Martin sternal Talon.

Patient 1

The patient is a 57-year-old man who underwent three-vessel coronary artery bypass grafting. Three months postoperatively, he began to experience pain, a sternal click, and palpable sternal instability with evidence of loose wires on examination. A preoperative CT scan demonstrated nonunion of the bone edges (Fig. 1). Because of the degree and debilitating effects of the patient's symptoms, the decision was made to return to the operating room where the cardiothoracic surgeons trimmed ~2 mm from each sternal edge until bleeding healthy tissue was seen (Fig. 2A). Cultures were taken, and after antibiotic irrigation, bilateral pectoralis muscles flaps were raised to expose the ribs. Although we were unable to place a plate on the manubrium due to the amount resected, three 12-hole plates were coapted to fit over ribs 4 to 6 and fixed in place with 14- and 16-mm

Figure 1 CT scan demonstrating sternal nonunion without evidence of fluid collection or osteomyelitis.

screws (Fig. 2B, C). The pectoralis muscles were advanced, sutured together in the midline, and drains were placed (Fig. 2D). Postoperatively, the patient's symptoms resolved. On an early CT taken approximately 2 weeks after the time of surgery, good bone approximation was noted without evidence of hardware infection (Fig. 3). The patient's wound went on to heal without complication (Fig. 4).

Patient 2

The patient is a 71-year-old man with chronic obstructive pulmonary disease who underwent three-vessel coronary artery bypass grafting. Approximately 3 weeks postoperatively, he began to experience a sternal click and pain. Physical exam demonstrated sternal instability, which was confirmed by preoperative CT scan (Fig. 5). Upon opening the chest, it was noted that the sternal

Figure 2 Intraoperative photographs. (A) Sternal defect after debridement of bone and soft tissue. (B) Sternal edges approximated with bone forceps. (C) Three plates approximating the sternal defect with two drains placed in the retrosternal space. (D) Midline approximation of bilateral pectoralis major muscle flaps. Additional drains placed in the submuscular and subcutaneous spaces.

Figure 3 Two-week postoperative CT scan demonstrating close approximation of sternal edges without evidence of bridging callous formation.

wires were intact but had cut through the left hemisternum. The sternum was debrided to bleeding bone. Cultures taken at the time of surgery were negative for bacterial or fungal growth. Pectoralis major flaps were raised, and three 12-hole plates were coapted to ribs 3 to

Figure 4 Postoperative photograph at 5 months.

Figure 5 CT scan of chest demonstrating sternal wire pull-through and fracture.

Figure 6 Postoperative photograph at 6 months.

5 and secured with 14- and 16-mm screws. A postoperative chest radiograph demonstrated appropriate plate positioning, and although the patient developed a small draining sinus tract from the inferior aspect of his wound, this was believed to represent a superficial fluid collection, and the presence of the underlying muscle flaps over the hardware allowed us to attempt conservative management with local wound care. The patient went on to heal his wound fully without complication or need for further intervention (Fig. 6).

Patient 3

The patient is a 56-year-old man who is status post coronary revascularization followed by a sternal wound infection that required partial sternectomy. After heal-

Figure 7 Exposure of sternum and debridement of the area of nonunion at the manubrium.

Figure 8 Rib grafts were harvested from lower lateral chest and split. The first layer of bone graft fixation can be seen in this photograph.

Figure 9 The second layer of rib graft placement can be seen.

ing, he continued to have symptoms of chronic low-grade pain and severe pain with motion. His symptoms were consistent with an unstable sternum. He underwent physical therapy for 2 years with no improvement. He came to us seeking options. After long discussions between the cardiac surgeon, our team, and the patient,

Figure 10 Two types of fixation were used. First, a device that provides compression was placed vertically, then vertically oriented rigid fixation plates were applied.

Figure 11 Bilateral pectoralis muscle flaps were advanced to cover the hardware.

Figure 12 Postoperative photograph at 5-month follow-up. The patient has healed and is free of pain and discomfort at rest and during strenuous activities.

the patient elected to proceed with surgical reconstruction (Fig. 7). After debridement of the area of nonunion, rib grafts were harvested from the lower lateral chest wall and split. The area was reconstructed with two layers of bone grafts (Fig. 8 and Fig. 9). Two types of fixation were used. First, a device that provides compression was placed in a vertical direction, providing compression to the rib grafts. Then, vertically oriented plates were used to provide rigid fixation to the sternum (Fig. 10). Bilateral pectoralis major muscle flaps were advanced to cover the plates and the area of nonunion (Fig. 11). The patient had no adverse complications, and his pain and discomfort has been alleviated (Fig. 12).

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