Improvement of Sternal Closure Stability With Reinforced Steel Wires

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Background. **Sternal dehiscence occurs when steel wires pull through sternal bone. This study tests the hypothesis that closure stability can be improved by jacketing sternal wires with stainless steel coils, which distribute the force exerted on the bone over a larger area.**

Methods. **Midline sternotomies were performed in 6 human cadavers (4 male). Two sternal closure techniques were tested: (1) approximation with six interrupted wires, and (2) the same closure technique reinforced with 3.0-mm-diameter stainless steel coils that jacket wires at the lateral and posterior aspects of the sternum. Intrathoracic pressure was increased with an inflatable rubber bladder placed beneath the anterior chest wall, and sternal separation was measured by means of sonomicrometry crystals. In each trial, intrathoracic pressure was increased until 2.0 mm of motion was detected. Differences in displacement pressures between groups were examined at 0.25-mm intervals using the paired Student's t test.**

Results. **The use of coil-reinforced closures produced significant improvement in sternal stability at all eight displacement levels examined ($p < 0.03$). Mean pressure required to cause displacement increased 140% (15.5 to 37.3 mm Hg) at 0.25 mm of separation, 103% (34.3 to 69.8 mm Hg) at 1.0 mm of separation, and 122% (46.8 to 103.8 mm Hg) at 2.0 mm of separation.**

Conclusions. **Reinforcement of sternal wires with stainless steel coils substantially improves stability of sternotomy closure in a human cadaver model.**

(Ann Thorac Surg 2003;76:1631–4)

Less invasive surgical incisions are widely used in many surgical disciplines. However, cardiac surgeons remain less enthusiastic about their use in open heart surgery. The median sternotomy incision remains appealing because it offers advantages paramount to cardiac surgery. It can be performed quickly, provides excellent exposure of vital chest structures, affords the safety of central cannulation for cardiopulmonary bypass, and is well tolerated by most patients. But sternotomy incisions can be burdened by technical complications that contribute to postoperative pain, pulmonary morbidity, and mediastinitis. In the United States, approximately 500,000 coronary artery bypass graft operations using a sternotomy are performed each year [1, 2]. The expected mortality is approximately 2%, but increases to 25% if mediastinitis develops [3], resulting in significant excess mortality that can be attributed to sternal complications.

In an attempt to clarify mechanical weaknesses of median sternotomy closure, we previously performed a comprehensive analysis of routine sternal closure stability in a cadaver model [4]. Our data showed that under physiologic loads, sternal separation occurs mostly at the xiphoid when steel wires cut into the sternal bone. To prevent wires from cutting into the bone, we now evaluate the use of a stainless steel coil that jackets sternal wires and distributes the force exerted on the bone over a larger area. The goal of this study is to determine whether jacketed sternal wires improve the mechanical stability of sternotomy closure.

Material and Methods

Midline sternotomies were performed in 6 adult human cadavers (4 male). All cadavers were subjected to two sternal closure techniques: (1) approximation with simple interrupted wires, and (2) the same closure reinforced with 3.0-mm-diameter stainless steel coils positioned where wires pass through or around sternal bone (Fig 1). These coils were not custom-designed for sternal closure and were purchased at a local Pep Boys automotive store and manufactured by Perfect Circle (McHenry, IL). Intrathoracic pressure was then increased, and separation between the two halves of the sternum was measured. The amount of pressure needed to induce sternal distraction was then compared for both closure methods. Details of this cadaver model have been previously published [4], but techniques used for cadaver preparation and measurement of sternal distraction are summarized below.

Cadaver Preparation

Median sternotomy was performed with an oscillating saw. An inflatable rubber bladder was placed inside the thorax. A pair of fluid-filled sensors was placed in the

Accepted for publication April 29, 2003.

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Published by Elsevier Inc

0003-4975/03/$30.00
doi:10.1016/S0003-4975(03)00760-4

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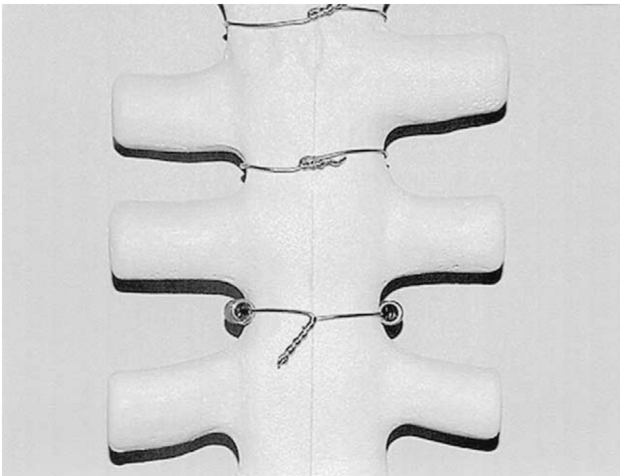

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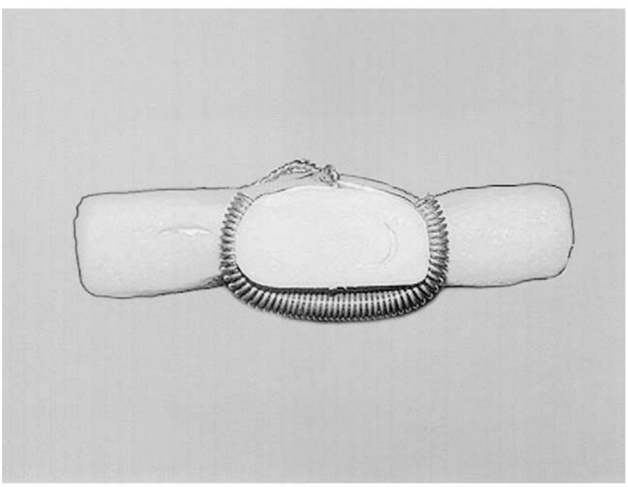

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Fig 1. Anteroposterior (A) and coronal (B) views of 3.0-mm-diameter coil-reinforced sternal wire placement. Their low-profile nature facilitates application. For clarity these figures are shown on sternal models. However, experiments were performed on human cadavers.

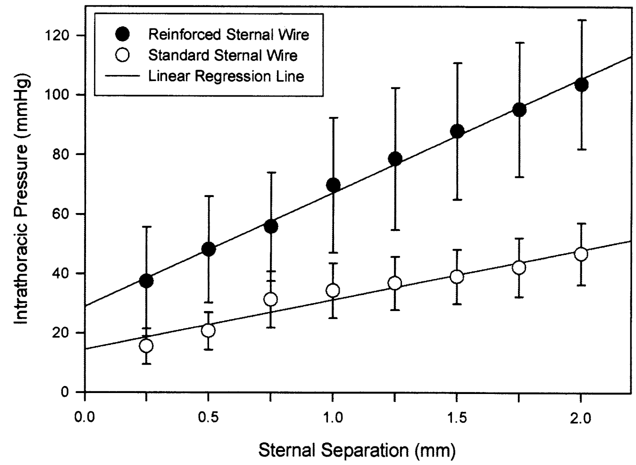

Fig 2. Plot of sternal separation versus intrathoracic pressure for sternotomies closed with standard wire and wire reinforced with stainless steel coils. Data are mean ± standard error of the mean.

right and left pleural cavities, and attached to a pressure transducer (model 52-966; Harvard Apparatus, Inc, South Natick, MA). The transducer was used to measure intrathoracic pressure. Sterna were approximated first using number 5 steel wire placed in a simple interrupted fashion. Six wires were placed: two through the manubrium and four around the sternum at intercostal spaces 2 to 5. The wires were symmetrically tightened by twisting with a large needle driver. After this closure was tested, the sterna were next approximated using sternal wires reinforced with 3.0-mm-diameter stainless steel coils that jacket the portion of the wire passing through or around the sternal bone. A hand-held drill was used to facilitate coil placement through the bone. This second wire configuration was the same as the first, but wires were placed through different holes with the addition of the coil jackets.

Measurement of Sternal Distraction

Piezoelectric crystals were used to measure distraction of the sternal closure site (sonomicrometer model 120; Triton Technology, Inc, San Diego, CA). Our previous work showed that the xiphoid portion of sternal closure is the least stable, with most motion occurring in a transverse plane. Therefore, crystals were placed on the anterior surface of the sternoxiphoid junction, and oriented to detect distraction in a transverse plane. Ultrasonic gel was placed between the two crystals to facilitate sound wave conduction. Intrathoracic pressure was increased by inflating the rubber bladder with a Topeak JB-2G pump (Foxborough, MA), until 2.0 mm of distraction was noted between the ultrasonic crystals. This end point was chosen as an amount of motion that would be clinically important and as a means to prevent complete dehiscence. In all cases, closure using simple interrupted wires was tested first, followed by closure using reinforced wires.

Data Collection and Statistical Analysis

Crystal separation was measured by continuously recording sonomicrometry waveforms while intrathoracic pressure was increased. Data were digitized at a rate of 25 samples/s and stored in an IBM 300PL personal computer (data acquisition package: WinDAQ; Dataq Instruments, Akron, OH). Statistical differences between closure techniques were examined at 0.25-mm intervals using the paired Student's *t* test (True Epistat; Epistat Services, Richardson, TX). Summary data are expressed as mean ± standard error of the mean.

Results

Sternal separation increased linearly with both closure techniques as intrathoracic pressure was increased. However, higher intrathoracic pressures were required to cause separation in sterna closed with reinforced wires

Table 1. Intrathoracic Pressure Needed to Cause Sternal Separation[a]

Distraction (mm)	Standard Closure (mm Hg)	Reinforced Closure (mm Hg)	p Value
0.25	15.5 ± 6.0	37.3 ± 18.0	0.03
0.50	20.7 ± 6.3	48.2 ± 17.9	0.007
0.75	31.3 ± 9.5	55.8 ± 18.3	0.002
1.00	34.3 ± 9.3	69.8 ± 22.7	0.002
1.25	36.8 ± 9.0	78.7 ± 23.9	0.002
1.50	39.0 ± 9.2	88.0 ± 22.9	0.001
1.75	42.2 ± 9.9	95.3 ± 22.6	0.001
2.00	46.8 ± 10.4	103.8 ± 21.8	0.001

[a] Data are mean ± standard error of the mean.

(Fig 2). Furthermore, the slope of their respective regression lines demonstrates that for any given increase in intrathoracic pressure, sterna closed with reinforced wires had less separation. Overall, sterna closed with reinforced wires withstood approximately twice as much intrathoracic pressure as those closed with regular wire. This was true at each 0.25-mm interval at which the data were examined ($p < 0.03$; Table 1). Wires reinforced with coil jackets had less migration into the sternum than regular wires.

Comment

Sternotomy wound complications occur in a small but consistent percentage of patients. These problems can be catastrophic, such as sternal dehiscence with resulting right ventricular rupture or mediastinitis, or they can be minor, such as prolonged incisional pain or sternal nonunion. Minor wound problems are less alarming, but cannot be overlooked. They discourage patients and often limit their motivation to resume a normal lifestyle. The common mechanism leading to both major and minor sternal complications is the inability to maintain stabilization of the sternotomy closure site. This happens when sternal stresses are concentrated at the steel wires, causing them to cut into the bone, and allowing variable degrees of motion to occur at the closure site.

This study uses stainless steel coils to reinforce sternal wires and distribute the force of wires over a wider surface. This resulted in less wire migration into sternal bone, and a 118% increase in the mean intrathoracic pressure needed to induce sternal separation, when compared with standard closure. The improvement in closure stability was consistent at each 0.25-mm measurement interval (Table 1). This indicates that over the range of intrathoracic pressure seen in this study, sternal stresses were consistently dampened by stainless steel coils.

Most previous investigations of sternotomy sequelae focus on steel wire limitations [5, 6] or patient-related risk factors [7, 8]. Relatively few studies evaluate closure techniques that are specifically designed to prevent closure material from cutting into sternal bone. Such techniques include the basketweave formation popularized by Robicsek and colleagues [9] and the use of parasternal steel bands [10] or Mersilene (Ethicon, Inc, Somerville, NJ) ribbon [11], which attempt to achieve wider force distribution at the lateral edge of the sternum. Using a different approach, a modified sternal plating technique was developed by Ozaki and associates [12] that more effectively distributes force across the sternum, and was found to be more secure than standard plate or wire configurations. Despite apparent advantages of these techniques [13, 14], none has been widely adopted by the surgical community for routine sternal closure. Instead, surgeons prefer simple wire configurations because they are inexpensive and efficient, and offer familiar handling characteristics. Most importantly, steel wires do not impede emergent chest reentry, when needed.

Recent work by Cohen and Griffin [15] expanded on our previous findings by evaluating a parasternal stainless steel plate (DSF system; Pectofix Inc, South Plainfield, NJ). They placed this device in the intercostal space at the lateral edge of the sternum to distribute the force of sternal wire. Using synthetic sterna, they demonstrated a 25% improvement in yield strength and less wire migration with the Pectofix plates, as compared with a wire closure technique. This important biomechanical evaluation achieved improved results by combining the advantages of steel wire with a device designed to limit wire migration into sternal bone.

Using a similar concept, our study also demonstrates an improvement in the mechanical stability of sternal closure. However, several features of our study are unique. First, the low-profile (3.0 mm diameter) nature of coil jackets expands on the size limitations of previous devices by allowing application along the entire length of the sternum. At the manubrium, the small diameter allows them to be placed through the bone. Along the remainder of the sternum, they are easily placed in all intercostal spaces without traumatizing intercostal muscle or internal mammary vessels. Larger devices such as parasternal bands or Pectofix plates cannot be placed through the manubrium, and placement around the rest of the sternum can result in trauma to surrounding tissues. Second, the small size of coil jackets allows consistent placement at the xiphoid. The large size of other devices limits placement at lower interspaces, especially at the xiphoid where the interspaces become increasingly narrow from the common articulation of lower ribs on the sternum. This is an important difference, as the xiphoid is the area of the sternum most prone to wire migration [4]. Third, this intact human thorax model likely reproduces real-life sternal stress distributions more accurately than other laboratory constructs. The natural supportive geometry of the chest (small diameter of upper thorax, more horizontal position of upper ribs, insertion of clavicles on the manubrium) is maintained, and sterna are stressed by increasing intrathoracic pressure. This simulates the complex force vectors experienced by the living human thorax more accurately than inducing separate unidirectional forces. Inducing these forces on human cadaver bone rather than synthetic bone may also be more indicative of living sternal failure modes because variation in human sternal density and geometry is inherently considered [16, 17]. Of course, this model cannot account for influential patient factors such as diabetes mellitus, obesity, or chronic obstructive pulmonary disease.

The limitations of this study relate to repeated instrumentation of the same cadavers. In each case, simple interrupted closures were performed before reinforced wire closures. This may have weakened the sternal bone before reinforced wire testing. To limit the impact of this possibility, sterna were only stressed until 2.0 mm of motion was detected, and reinforced wires were placed at sites different from simple interrupted wires. If the first round of testing had significantly altered the integrity of sternal bone, the results would have likely been biased against reinforced wire closure, when, in fact, reinforced closure still proved to be the more stable closure method. We therefore think it is unlikely that any appreciable differences in closure techniques resulted from repeated testing on the same cadavers.

Results from this study show that the technique of reinforcing sternal wires with stainless steel coils improves sternal closure stability and limits wire migration into the sternum in an intact human cadaver model. The use of these coils permits continued use of steel wire, which is familiar to all surgeons. Their low-profile nature allows easy application at the xiphoid, which is known to be the most unstable area of sternotomy closure. Further refinement of this technology would allow living human application that may improve sternal complication rates.

This work was supported by the Allegheny Heart Institute, Pittsburgh, PA.

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