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BRIEF ARTICLE

Comparison of straight median sternotomy and interlocking sternotomy with respect to biomechanical stability

Fatih Küçükdurmaz, İsmail Ağır, Murat Bezer

Fatih Küçükdurmaz, Clinic of Orthopaedics and Traumatology, Bezmialem Vakif University, School of Medicine, Istanbul 34093, Turkey
İsmail Ağır, Departments of Orthopaedics and Traumatology, Adiyaman University School of Medicine, Adiyaman 02040, Turkey
Murat Bezer, Departments of Orthopaedics and Traumatology, Marmara University School of Medicine, Pendik 34899, Istanbul, Turkey
Author contributions: All authors contributed to conception and design, acquisition of data, or analysis and interpretation of data; drafting the article or revising it critically for important intellectual content and final approval of the version to be published.
Correspondence to: Dr. Fatih Küçükdurmaz, Clinic of Orthopaedics and Traumatology, Bezmialem Vakif University, School of Medicine, Adnan Menderes Blv, Istanbul 34093, Turkey. fatihmfk@hotmail.com
Telephone: +90-212-4531700 Fax: +90-212-6217580
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Abstract

AIM: To increase the stability of sternotomy and so decrease the complications because of instability.

METHODS: Tests were performed on 20 fresh sheep sterna which were isolated from the sterno-costal joints of the ribs. Median straight and interlocking sternotomies were performed on 10 sterna each, set as groups 1 and 2, respectively. Both sternotomies were performed with an oscillating saw and closed at three points with a No. 5 straight stainless-steel wiring. Fatigue testing was performed in cranio-caudal, anterio-posterior (AP) and lateral directions by a computerized materials-testing machine cycling between loads of 0 to 400 N per 5 s (0.2 Hz). The amount of displacement in AP, lateral and cranio-caudal directions were measured and also the opposing bone surface at the osteotomy areas were calculated at the two halves of sternum.

RESULTS: The mean displacement in cranio-caudal direction was 9.66 ± 3.34 mm for median sternotomy and was 1.26 ± 0.97 mm for interlocking sternotomy, $P < 0.001$. The mean displacement in AP direction was 9.12 ± 2.74 mm for median sternotomy and was 1.20 ± 0.55 mm for interlocking sternotomy, $P < 0.001$. The mean displacement in lateral direction was 8.95 ± 3.86 mm for median sternotomy and was 7.24 ± 2.43 mm for interlocking sternotomy, $P > 0.001$. The mean surface area was 10.40 ± 0.49 cm^2 for median sternotomy and was 16.8 ± 0.78 cm^2 for interlocking sternotomy, $P < 0.001$. The displacement in AP and cranio-caudal directions is less in group 2 and it is statistically significant. Displacement in lateral direction in group 2 is less but it is statistically not significant. Surface area in group 2 is significantly wider than group 1.

CONCLUSION: Our test results demonstrated improved primary stability and wider opposing bone surfaces in interlocking sternotomy compared to median sternotomy. This method may provide better healing and less complication rates in clinical setting, further studies are necessary for its clinical implications.

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Key words: Median sternotomy; Interlocking stenotomy; Stability; Osseos healing; Biomechanics

Core tip: Sternal healing after median sternotomy can be compromised by an unstable closure. In this *in vitro* study, we found that the biomechanical characteristics of the median interlocking sternotomy were superior to those of the straight median sternotomy. The zigzag cuts made the sternotomy line significantly more stable and provided more surface area

for bony healing. These improved features are highly associated with improved bony healing. We believe that the interlocking sternotomy will decrease the complications associated with sternotomy in clinical basis by providing a better bony healing.

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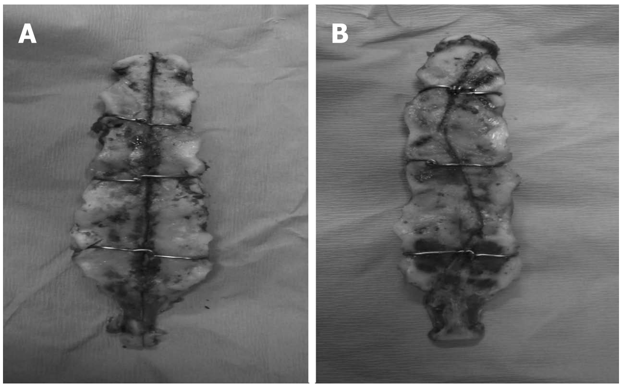

Figure 1 Sternotomy. A: Fixated median straight sternotomy, anterior view; B: Fixated interlocking sternotomy, anterior view.

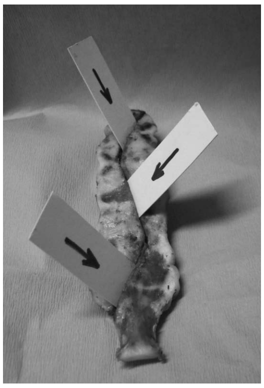

Figure 2 Sternotomy planes of interlocking sternotomy. Each zigzag osteotomy line was perpendicular to the previous line in the axial plane, which are showed with arrows.

INTRODUCTION

Median sternotomies are the most commonly performed osteotomy in the world[1]. Sternotomy is the best transsternal approach for accessing lesions localized to the vertebral bodies of the upper thoracic spine[2,3], and it is a standard incision for thoracic and cardiac surgery.

Despite the popularity of median sternotomy, complications such as nonunion, persistent pain, and infection occur in 0.3% to 5% of cases and are associated with a 14% to 47% mortality rate if mediastinitis supervenes[4]. The morbidity, mortality, and expenses associated with these complications continue to make their prevention and treatment of great importance.

The continuous motion between the halves of the divided sternum resulting from the lack of immobilization causes postoperative sternal instability[5], which is the most important factor in postoperative morbidity and mortality. Providing greater stability[3,4,6] and promoting primary osseous healing is crucial for preventing these complications[7-11].

More than 40 different techniques have been described for closing median sternotomy[12-16]. The biomechanical characteristics of different sternal closures may substantially improve sternotomy reduction and stability[17-19]. In particular, interlocking sternotomy appears to offer better stability and greater surface area for bone healing than other techniques. However, the biomechanical characteristics of this technique have not been assessed. Accordingly, in this experimental study, we compared the biomechanical characteristics of interlocking sternal closure with those of straight sternal closure in a study of sheep sterna.

MATERIALS AND METHODS

We obtained sterna freshly isolated from the sterno-costal joints of the ribs of 20 sheep (Ovis ammon aries) in same age and weight from slaughterhouse. We had institutional ecthical approval from Marmara University ethical committee. Median straight (Figure 1A) and interlocking (Figure 1B) sternotomies were performed on 10 sterna each.

Sternotomy procedure

Interlocking sternotomy was created with 3 zigzag osteotomy lines approximately 150 degrees to each other in the coronal plane. Each osteotomy line was perpendicular to the previous line in the axial plane (Figure 2). Median sternotomy was performed as a straight osteotomy line in the cranio-caudal (CC) direction. We measured the dimension of the cut surface and simply calculated the area of surface for interlocking sternotomy and median sternotomy.

Both sternotomies were performed with an oscillating saw and closed at three points with No. 5 straight stainless-steel wiring (Figure 1). The wire tension during closure is done by free hand, with 5 times twisting the wire for each suture.

The sterna were attached to custom fixtures designed to produce displacement in one of three directions: (1) CC shear; (2) anterio-posterior (AP) shear; and (3) lateral (distraction) shear. The test was done in CC, AP and distraction directions sequentially. The fixtures designed to have 3 grasping jigs in 3 directions like the *x*, *y* and *z* dimensions.

Biomechanical testing

Fatigue testing was performed by a computerized materials-testing machine (High Capacity 8802, Instro, Norwood, MA, United States). The sterna were attached (Figure 3) to custom fixtures designed to produce dis-

Table 1 Biomechanical characteristics of median sternotomies in fresh sheep sterna 4 d after surgery

Characteristic	Median straight sternotomy (n = 8), mean (range)	Median interlocking sternotomy (n = 8), mean (range)	Difference (95%CI)
CC displacement, mm	9.66 ± 3.34 (5.24 to 15.35)	1.26 ± 0.97 (0.3 to 2.8)	6.08 to 10.71 P < 0.001
AP displacement, mm	9.12 ± 2.74 (5.48 to 14.78)	1.20 ± 0.55 (0.3 to 2.5)	6.06 to 9.77 P < 0.001
Lateral displacement, mm	8.95 ± 3.86 (5.1 to 17.1)	7.24 ± 2.43 (3.26 to 11.11)	-1.32 to 4.74 P > 0.001
Surface area, cm²	10.40 ± 0.49 (9.6 to 10.9)	16.8 ± 0.78 (15.3 to 18.3)	-7.01 to 5.78 P < 0.001

CC: Cranio-caudal; AP: Anterio-posterior.

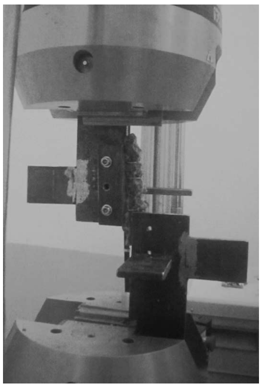

Figure 3 The sterna were attached to custom fixtures designed to produce displacement in one of three directions.

placement in one of three directions: (1) CC shear; (2) AP shear; and (3) lateral (distraction) shear. The displacement between the halves of the sternum was measured and recorded automatically by the testing device.

Fatigue testing was performed by cycling between loads of 1 and 400 N per 5 s (0.2 Hz) for 60 cycles of distraction and release. One sterna in each group was distracted for 180 cycles. The test was ended if the wires were torn from the bone or if the bone broke.

Statistical analysis

Mean displacement was measured after completion of distraction in all three directions and was compared between the two groups with Student's t test for independent groups. The data conformed to the assumptions of the t test, and all tests were two-tailed. Alpha was set at 0.05. The "SPSS 16.0" statistical software program was used in the analyses was used.

RESULTS

Two sterna in each group broke during the calibration of the testing machine so they were excluded from analyses. Fractures were related to fixation apparatus not related to test, and after the fractures it was revised and test began from the beginning. Displacement in all directions was smaller in the interlocking sternotomies (Table 1).

The mean displacement in CC direction was 9.66 ± 3.34 mm for median sternotomy and was 1.26 ± 0.97 mm for interlocking sternotomy, P < 0.001. The mean displacement in AP direction was 9.12 ± 2.74 mm for median sternotomy and was 1.20 ± 0.55 mm for interlocking sternotomy, P < 0.001. The mean displacement in lateral direction was 8.95 ± 3.86 mm for median sternotomy and was 7.24 ± 2.43 mm for interlocking sternotomy, P > 0.001. The mean surface area was 10.40 ± 0.49 cm² for median sternotomy and was 16.80 ± 0.78 cm² for interlocking sternotomy, P < 0.001. The displacement in AP and cranio-caudal directions is less in group 2 and it is statistically significant. Displacement in lateral direction in group 2 is less but it is statistically not significant. Surface area in group 2 is significantly wider than group 1.

DISCUSSION

Normal breathing, coughing, and movement apply pressure to the sternum, creating a combination of lateral displacement forces and anterior-posterior shear and cranial-caudal shear[20]. After sternotomy, these forces can interfere with bony healing and cause serious complications[21-23]. An unstable sternotomy can increase postoperative sternal pain, which can lead to atelectasis and pneumonia, secondary to a decreased inspiratory effort[9]. Other serious complications related to instability include sternal dehiscence, deep sternal infection, fulminant medistinitis, osteomylelitis, and chronic sternal instability[4,24-26]. These complications are associated with a 14% to 47% mortality rate[4]. Providing a more stable osteotomy and improving sternal osteosynthesis is the best way to prevent these complications[3,4,27,28].

More than 40 different techniques with various materials have been described for sternal closure[12-16]. Most techniques revolve around a different pattern of wire cerclage, rigid plate fixation, or various non-rigid methods of closure[29-36]. The techniques those provide more rigid fixation are associated with relatively fewer wound infection and even mortality[3]. However, one has to consider the movements of sternal halves at AP and CC directions. Current methods provide sufficient lateral stability, but does not provide adequate AP and CC stability[20]. Due to this three dimensional movement of sternum during physiological activities, providing stability in AP and CC directions is important as well as stability in lateral direction.

The sternal fixation with using plate and screw provides relatively more stability in AP and CC directions. However, this method has some serious disadvantages[3]. Drilling into the sternum increases the obvious risks to the heart and bypass conduits[3], and the costs of plate fixation are about 10 times higher than those of wire fixation[6]. In addition, the screw holes closest to the midline tend to break through the adjacent bone[6]. That is why the plate and screw fixation does not gain popularity. Also, in an *in vitro* study, Saito *et al*[35] compared wire fixation with wire fixation plus an intrasternal pin. The intrasternal pin was presented, as a technical modification required increasing stiffness in the AP and CC directions. Intrasternal pin fixation did provide significantly more stability than did wire fixation alone. However, the clinical application of this technique is not reported yet.

Current methods aiming to increase the stability of sternotomy are focused on different implants and configuration of suturing with wire. On the other hand, it is well known that, improving the stability of an osteotomy line can be increased by selecting the correct osteotomy technique[37,38]. In our study, we focused on decreasing AP and CC interfragmentary motion at the same time by changing the configuration of the osteotomy line itself. In our literature search we determined, two clinical studies have shown that the stability of the sterna can be increased by the sternotomy configuration itself. Joshi *et al*[36] performed a lazy-S-shaped sternotomy, which minimized post-operative pain, was also associated with better respiratory function, and reduced rates of sternal dehiscence and mediastinitis. Lee *et al*[39] performed curvilinear paramedian sternotomy and found this technique ensuring precise open reduction and internal fixation. These results may indicate that the changing the sternotomy technique prevents CC motion, on the other hand, these sternotomy techniques still does not prevent the AP motion.

In our study, we focused on decreasing AP and CC interfragmentary motion at the same time by changing the configuration of the osteotomy line itself. The interlocking osteotomy created an inherently more stable closure that was less affected by displacement and shear forces and that provided a greater mean surface area than that provided by straight sternotomies. Although the interlocking sternotomy indirectly reduced lateral displacement, the amount of displacement was not statistically significant.

Increasing the opposing surface areas of an osteotomy is important for primary bone healing[36]. The interlocking sternotomy maximizes the opposing surfaces of the sternal halves. By preventing the slippage of sternal ends in the AP and CC directions, the interlocking sternotomy ensures appropriate approximation during closing and should substantially improve the osseous healing.

In this *in vitro* study, we found that the biomechanical characteristics of the median interlocking sternotomy were superior to those of the straight median sternotomy. The zigzag cuts made the sternotomy line significantly more stable and provided more surface area for bony healing. Our method does not require any extra equipments or implants. The wires are used as fixation material, already employed and the surgeons are familiar with. Also this technique does not require surgeons to make great changes in their routine practice. It is possible to make this sternum incision with sternotomy saws in routine use. We believe that the interlocking sternotomy provide a significantly more stable sternotomy without extra costs. Although no clinical or animal experiment study has been performed with interlocking sternotomy, our biomechanical study may be evidence of superiority in primary osseos healing if interlocking sternotomy is performed in clinical practice.

COMMENTS

Background

The continuous motion between the halves of the divided sternum resulting from the lack of immobilization causes postoperative sternal instability, which is the most important factor in postoperative morbidity and mortality. Providing greater stability and more surface area promoting primary osseous healing is crucial for preventing these complications.

Research frontiers

Interlocking sternotomy appears to offer better stability and greater surface area for bone healing than other techniques. However, the biomechanical characteristics of this technique have not been assessed. In this study, authors compared the biomechanical characteristics of interlocking sternal closure with those of straight sternal closure in a study of sheep sterna and compared the surface area of two osteotomies.

Innovations and breakthroughs

More than 40 different techniques with various materials have been described for sternal closure. The techniques those provide more rigid fixation are associated with relatively fewer wound infection and even mortality. Current methods provide sufficient lateral stability, but do not provide adequate anterio-posterior (AP) and cranio-caudal (CC) stability. Interlocking sternal closure provide stability in AP, CC and in lateral direction and more surface area.

Applications

Authors believe that the interlocking sternotomy provide a significantly more stable sternotomy and more surface area for bony healing so decreasing the complications without extra costs.

Terminology

The interlocking sternotomy is a zigzag cut in three dimension. CC movement is a movement of one half of sternum superior while the other half inferior.

Peer review

The sterna were attached to custom fixtures designed to produce displacement in one of three directions: (1) CC shear, (2) AP shear, and (3) lateral (distraction) shear. The displacement between the halves of the sternum was measured and recorded automatically by the testing device. The zigzag cuts made the sternotomy line significantly more stable and provided more surface area for bony healing.

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