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Stability Provided by the Sternum and Rib Cage In the Thoracic Spine

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Study Design. Multidirectional flexibility tests were conducted on 10 human thoracic spines with intact rib cage.

Objectives. To determine the amount of stability the rib cage imparts to the thoracic spine and to show the amount of stability lost by a sternal fracture.

Summary of Background Data. There is no published study of biomechanical testing of human cadaveric specimens with the rib cage intact.

Methods. In this study, 10 human cadaveric thoracic spines with the rib cage intact were tested using a biaxial material testing machine and an opto-electronic three-dimensional motion measuring device (Opto-trak 3020). The specimens were tested in axial compression, axial rotation, lateral bending, and flexion/extension. First, the specimens were tested through all four loading types with the sternum and rib cage intact. Next, the sternum was fractured at the sternomanubrial junction displacing the proximal fragment posteriorly. Lastly, the entire rib cage was removed.

Results. The rib cage increased the stability of the thoracic spine by 40% in flexion/extension (P = 0.012), 35% in lateral bending (P = 0.008), and 31% in axial rotation (P = 0.008). An indirect flexion-compression type of sternal fracture decreased the stability of the thoracic spine by 42% in flexion/extension (P = 0.036), 22% in lateral bending (P = 0.038), and 15% in axial rotation (P = 0.011).

Conclusion. The rib cage significantly increases the stability of the thoracic spine in flexion/extension, lateral bending, and axial rotation. A sternal fracture significantly decreases the stability of the thorax.

Key words: rib cage, sternum, stability, fracture, thoracic spine. **Spine 2005;30:1283–1286**

The thoracic spine differs from other regions because of the stability provided by the rib cage. Therefore, a disruption of the rib cage may decrease the stability of the thoracic spine. The amount of stability provided by the rib cage and the amount of stability lost by a sternal fracture has not been defined.

Several authors have documented fractures of the sternum in combination with thoracic spine injuries. Fowler found that 43% of sternal fractures were associated with a spinal injury in a 50-year review of the literature.[1] A study of blunt trauma by Hills reported that out of 27 patients with thoracic spine fractures, five had associated sternal fractures.[2] Brookes showed 4.8% incidence of thoracic spine fractures in patients with sternal fractures.[3] In a retrospective study between 1981 and 1987, Jones discovered eight patients with indirect sternal fractures and concomitant spinal fractures (5 thoracic and 3 lumbar).[4]

There have been many case reports, retrospective reviews, and biomechanical studies illustrating that the rib cage provides stability to the thoracic spine.[5–9] However, no human cadaveric study has shown the amount of stability the rib cage provides to the thoracic spine. Furthermore, the degree of instability caused by a sternal fracture has not been biomechanically studied.

The present study uses human cadaveric thoracic spines with intact rib cage. The objective was to quantify the amount of stability the rib cage imparts to the thoracic spine. Furthermore, this study investigates the amount of stability lost by a sternal fracture.

Materials and Methods

Ten human fresh frozen cadaveric specimens were tested. The average age of the specimens was 72 years old (range 55–91). There were six female and four male specimens. None of the specimens had evidence of thoracic spine or sternal fractures. The spines were appropriately degenerate for the age of the specimens. There were no levels with significant osteophytes or fused segments and no levels were collapsed. Four out of the ten specimens had rib fractures. Three specimens had two broken ribs and the other had three broken ribs. The rib fractures were repaired with 1/3 tubular stainless steel plates with two screws on both sides of the fracture.

The cadavers were thawed at room temperature. The specimens were harvested from C7 to L1 with the rib cage and sternum intact. All skin, fat, muscle, and organs were removed. The supraspinous and interspinous ligaments, ligamentum flavum, facet joints, anterior and posterior longitudinal ligaments, spinal cord, vertebral discs, costovertebral joints, intercostal muscles, ribs and sternum were preserved.

The specimens were fixed at both ends with polyurethane. The potting was done at C7 and T1 proximally and T12 and L1 distally. The process was completed using a jig to align the potting with a line connecting the midvertebral bodies of T1 and T12.

Multidirectional flexibility testing was performed on a bi-

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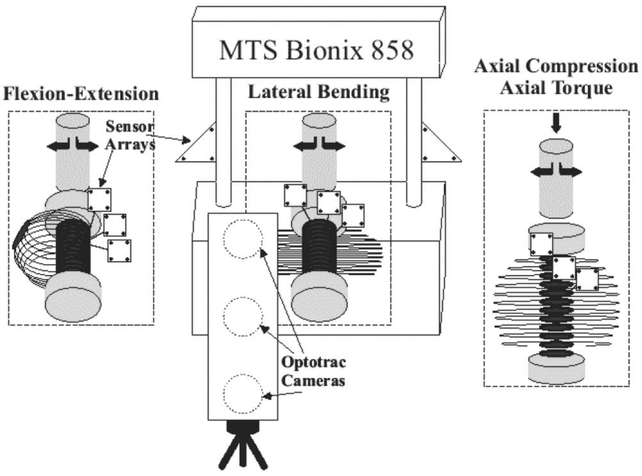

Figure 1. The orientation of the specimen determined which motion was tested. The cephalad sensor (placed in the pedicle of T1) represented motion of the entire thoracic spine.

axial material testing machine (MTS 858 Bionix) in a nondestructive manner. To minimize the viscoelastic effects, each test was repeated for five cycles, consisting of a 10-second ramp per cycle. Thus, the first four cycles served as preconditioning cycles with the fifth cycle used for analysis. The types of loading included axial compression (50–500 N), axial rotation (5 Nm with an axial compression preload of 50 N), lateral bending (2 Nm), and flexion/extension (2 Nm).

Motion was measured using the Optotrak 3020, an optoelectronic three-dimensional motion measuring device (Northern Digital, Inc., Waterloo, Ontario, Canada). This machine uses three cameras to detect movement of multiplexed arrays of light emitting diodes. An array attached to the MTS machine established the fixed coordinate axes. One array was attached to T1 by way of a rigid pin placed in the pedicle. With T12 rigidly fixed to the base of the MTS system, motion of the T1 array represented motion of the entire thoracic spine specimen.

The upper vertebra was attached to the moving ram of the MTS system by way of a custom universal cradle and x-y table fixture that allowed freedom of rotation and displacement about 2 orthogonal axes. The motion about the third orthogonal axis (vertical) was controlled by the MTS machine. Zero torque or force resistance could be provided by the MTS system to facilitate application of pure moments or axial forces to the T1 vertebra. The spinal segment could be positioned horizontally on custom fixtures to facilitate application of flexion-extension (rib cage projecting to the side) or lateral bending moments (rib cage facing downward; Figure 1).

First, the specimens were tested through all four loading types with the sternum and rib cage intact. The “intact” group included the repaired ribs for the subset that had rib fractures. Next, the sternum was fractured at the sternomanubrial junction, disrupting the intercostals muscles between the second and third ribs and displacing the proximal fragment posteriorly. The lower segment overlapped the upper segment allowing movement to occur between the two. Lastly, the entire rib cage was removed by severing the ribs 3-cm lateral to the costovertebral articulations.

Data were collected with the Optotrak machine. Only data sets that had data for all three conditions were used for analysis. With each intact specimen serving as its own control, ratios of fractured sternum flexibility over intact flexibility and no ribs flexibility over intact were calculated. A Wilcoxon nonparametric paired analysis was used to evaluate mean differences between intact, fractured sternum, and no rib conditions for each of the 4 types of loading. Mean differences were considered significant for $P < 0.05$.

■ Results

The four specimens with rib fractures were tested pre- and post-rib fracture fixation. The amount of flexibility did not significantly differ between the two states. The post fixation state was taken as the “intact” specimen.

In axial compression, the average amount of movement was 4.72 mm (range 1.56–12.23 mm) for the intact specimen, 5.31 mm (1.45–14.32 mm) with the sternal fracture, and 5.95 mm (1.53–17.06 mm) with the rib cage removed. The percentage of increase of axial compression, as compared with the intact specimen, was 12.6% with the sternal fracture ($P = 0.386$) and 26% with the rib cage removed ($P = 0.093$). This means that the rib cage and sternum provide 20.7% of the stiffness (inverse of the flexibility) of the thoracic spine in axial compression. The sternum alone provides 11.2% of compressive stiffness.

In axial rotation, the average amount of movement was 23.03° (6.17°-51.44°) for the intact specimen, 26.59° (8.66°-56.59°) with the sternal fracture, and 33.60° (11.95°-67.55°) with the rib cage removed. The percentage of increase of flexibility was 15.4% with the sternal fracture ($P = 0.011$) and 45.9% with the rib cage removed ($P = 0.008$). This means that the rib cage and sternum provide 31.4% of the stiffness of the thoracic spine in axial rotation. The sternum alone provides 13.4% of rotational stiffness.

In lateral bending, the average amount of movement was 10.36° (1.92°-26.81°) for the intact specimen, 12.61° (3.47°-26.30°) with the sternal fracture, and 16.04° (3.71°-27.96°) with the rib cage removed. The percentage of increase of flexibility was 21.7% with the sternal fracture ($P = 0.038$) and 54.8% with the rib cage removed ($P = 0.008$). This means that the rib cage and sternum provide 35.4% of the stiffness of the thoracic spine in lateral bending. The sternum alone provides 17.8% of the lateral bending stiffness.

In flexion-extension, the average amount of movement was 7.93° (2.64°-15.64°) in the intact specimen, 11.24° (2.84°-25.64°) with the sternal fracture and 13.17° (3.11°-29.29°) with the rib cage removed. The percentage of increase of flexibility was 41.7% with the sternal fracture ($P = 0.036$) and 66% with the rib cage removed ($P = 0.012$). This means that the rib cage and sternum provide 39.8% of the stiffness of the thoracic spine in flexion-extension. The sternum alone provides 29.4% of flexion-extension stiffness (Table 1).

■ Discussion

The sternum and rib cage impart stability to the thoracic spine. Fractures of the sternum cause partial loss of sta-

Table 1. Results of Biomechanical Tests

	Axial Compression (%)	Axial Torque (%)	Lateral Bending (%)	Flexion/Extension (%)
Increase in flexibility attributable to sternal fracture	12.6	15.4 *	21.7 *	41.7 *
Increase in flexibility attributable to rib cage removal	26	45.9 *	54.8 *	66 *
Contribution of intact sternum to overall stiffness	11.2	13.4	17.8	29.4
Contribution of sternum and rib cage to overall stiffness	20.7	31.4	35.4	39.8

Note. The inverse of the increase in flexibility equals the contribution to overall stiffness.
* $P < 0.05$.

bility. Different mechanisms of injury cause different patterns of sternal fracture.

Fowler[1] was among the first to describe injury patterns of the sternum. A direct blow will drive either the proximal or distal fragment posterior, according to the fragment struck. An indirect flexion-compression force causes forward buckling, which tends to displace the proximal fragment behind the lower. This second mechanism is associated with thoracic spine injuries.

The indirect sternal fracture pattern usually involves the upper segments of the sternum. Fowler[1] showed that the ribs played the primary role in transmitting the force from the spine to the sternum. He noted that when the sternum was removed in a cadaver, flexion of the neck and thoracic spine caused the upper two ribs to move downward and backward. With extreme flexion of the lumbar and thoracolumbar spine, the body of the sternum was forced upward and forward by the lower ribs. It was therefore postulated that the sternum failed with some combination of these two forces. The indirect pattern results in a fracture between ribs two and three at the sternomanubrial junction, with the proximal fragment displaced posteriorly.

In our study, we chose to reproduce the indirect sternal fracture because this pattern is commonly associated with thoracic spine injuries.

Helal[10] supported Fowler's theory of the indirect pattern of fracture. He presented two cases of sternal injuries at the sternomanubrial joint with posterior displacement of the proximal fragment. Both cases had associated thoracic spine fractures.

Berg[11] classified the indirect force causing sternal fractures with a proximal fragment posteriorly displaced to the distal piece as a flexion-distraction injury. This mechanism refers to the moment of force in relation to the spinal column. He presented two cases where this type of sternal fracture was associated with thoracic spine fractures. Furthermore, Berg emphasized the importance of the sternal-rib complex as a possible fourth column of stability in thoracic spine fractures.

Recently, Lund[12] supported the idea that the rib cage provides stability to the thoracic spine. He reported a case of multiple thoracic wedge fractures with an associated sternal fracture of the indirect mechanism type. The unstable spine progressively fell into kyphosis. Lund warned that a sternal injury associated with fractured thoracic spine may be an unstable combination.

The connection between the rib cage and the thoracic spine, and the stability that each imparts to the other, has been illustrated by case reports, as well as biomechanical studies.

Andriacchi *et al*, [13] performed a computer-simulated mathematical analysis showing that the rib cage enhances stability of the normal thoracic spine in flexion, rotation, lateral bending, and especially extension. They showed an increase in stiffness of 27% in flexion and of 132% in extension with the addition of the rib cage.

Comparison of our experimental results with the analytical results of Andriacchi is difficult because in our study flexion and extension moments were not isolated, and a neutral point was not identified. Instead, we measured overall flexion-extension flexibility. We found an increase of 39.8% of stiffness with the rib cage in the sagittal plane. This corresponds to 13.2° of rotation with no ribs and 7.9° with intact ribcage. For the sake of comparison, if the 13.2° of measured rotation comprised of 6.2° of flexion and 7° of extension, increases of stiffness equal to those found by Andriacchi would produce 5° of flexion and 3° of extension. This 8° of overall rotation agrees very well with our measured mean of 7.9° with intact ribcage. Therefore Andriacchi's data are not inconsistent with the present study.

Panjabi and White established criteria assessing stability in the thoracic spine.[14] From their studies they determined thresholds of mechanical stability: 2.5 mm of horizontal translatory displacement on lateral radiographs and 5° of rotatory displacement. They also performed studies supporting the stabilizing role of the costovertebral joints.[15] However, these experiments underestimated the role of the rib cage because the ribs were removed 3-cm lateral to the costovertebral joints.

Oda *et al*,[16] and Takeuchi *et al*,[17] showed significant increases in the neutral zone in lateral bending and axial rotation, but not in flexion-extension, after resection of the costovertebral joints and destruction of the rib cage. The limitation to these studies was the use of dog specimens rather than human. The discrepancy in our results is probably attributable to the following factors: anatomic differences between quadrupedal dog and bipedal human specimens and the difference between the sequence of resection of anatomic structures.

Recently, Oda *et al*,[18] showed that under flexion-extension, lateral bending, and axial rotation loading, right rib head resection after discectomy further increased the range of motion by 81%, 84%, and 72%, respectively. However, the ribs were cut 5 cm from the costovertebral articulation, thereby not accounting for the true effect of the rib cage.

Our study used human thoracic spines with the rib cage intact to model the passive thoracic region of the spine. One limitation to this passive, in vitro model was that intra-abdominal pressure (IAP) was not simulated. Hodges[19] found that IAP produced an extensor moment proportional to the pressure generated. Consequently, it is expected that IAP would affect flexion-extension stability to a greater extent than the other motions tested. It is unknown to what extent IAP, if it had been included in this study, would reduce the percentage of overall stability provided by the sternum and rib cage. Likewise, the effect of active moments, produced directly and indirectly (through fascial tension and increased IAP) by abdominal muscle contraction, was not taken into account in this study.

Our study had four specimens with fractured ribs. The fractures occurred near the sternocostal junction, presumably attributable to resuscitation attempts. We first tested the specimens with the fractured ribs. Then, the fractured ribs were repaired with internal fixation, and we repeated the testing. We did not find a significant difference in stability between the two conditions. This may be because of a lack of statistical power secondary to small sample size. We were not able to draw any conclusions about rib fractures and the stability of the spine in this present study. Furthermore, this is a possible source of error because not every specimen had an intact native rib cage.

Another possible limitation to our study was the use of elderly specimens with an average age of 72 years. Radiographs and bone density studies were not performed. It is unknown whether the rib cage provides a different amount of stability based on the age of the person. Future studies should investigate the relationship between bone density measurements and stabilizing effects of an intact ribcage.

We found that the rib cage and sternum provide 40% of the stability of the thoracic spine in flexion-extension, 35% of the stability in lateral bending, and 31% in axial rotation. An indirect flexion-compression type of sternal fracture decreases the stability of the thoracic spine by 42% in flexion/extension, 22% in lateral bending, and 15% in axial rotation. Previous investigations involving the biomechanics of the thoracic spine, including evaluations of thoracic instrumentation constructs, used human and animal thoracic spinal columns without intact rib cages. Some estimated the stabilizing contributions of the sternum and rib cage. Yet, the results presented here may have widespread implications regarding the conclusions of these previous investigations.

■ Conclusion

The rib cage substantially increases the stability of the thoracic spine. A sternal fracture decreases the stabilizing effect of the rib cage. A sternal fracture associated with a thoracic spine injury may be an unstable combination.

■ Key Points

- The rib cage significantly increases the stability of the thoracic spine in flexion/extension, lateral bending, and axial rotation.
- A sternal fracture significantly decreases the stability of the thorax.

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