Biomechanical evaluation of a simulated T-9 burst fracture of the thoracic spine with an intact rib cage

Laboratory investigation

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Objective. Classic biomechanical models have used thoracic spines disarticulated from the rib cage, but the biomechanical influence of the rib cage on fracture biomechanics has not been investigated. The well-accepted construct for stabilizing midthoracic fractures is posterior instrumentation 3 levels above and 2 levels below the injury. Short-segment fixation failure in thoracolumbar burst fractures has led to kyphosis and implant failure when anterior column support is lacking. Whether shorter constructs are viable in the midthoracic spine is a point of controversy. The objective of this study was the biomechanical evaluation of a burst fracture at T-9 with an intact rib cage using different fixation constructs for stabilizing the spine.

Methods. A total of 8 human cadaveric spines (C7–L1) with intact rib cages were used in this study. The range of motion (ROM) between T-8 and T-10 was the outcome measure. A robotic spine testing system was programmed to apply pure moment loads (± 5 Nm) in lateral bending, flexion-extension, and axial rotation to whole thoracic specimens. Intersegmental rotations were measured using an optoelectronic system. Flexibility tests were conducted on intact specimens, then sequentially after surgically induced fracture at T-9, and after each of 4 fixation construct patterns. The 4 construct patterns were sequentially tested in a nondestructive protocol, as follows: 1) 3 above/2 below (3A/2B); 2) 1 above/1 below (1A/1B); 3) 1 above/1 below with vertebral body augmentation (1A/1B w/VA); and 4) vertebral body augmentation with no posterior instrumentation (VA). A repeated-measures ANOVA was used to compare the segmental motion between T-8 and T-10 vertebrae.

Results. Mean ROM increased by 86%, 151%, and 31% after fracture in lateral bending, flexion-extension, and axial rotation, respectively. In lateral bending, there was significant reduction compared with intact controls for all 3 instrumented constructs: 3A/2B (−92%, p = 0.0004), 1A/1B (−63%, p = 0.0132), and 1A/1B w/VA (−66%, p = 0.0150). In flexion-extension, only the 3A/2B pattern showed a significant reduction (−90%, p = 0.011). In axial rotation, motion was significantly reduced for the 3 instrumented constructs: 3A/2B (−66%, p = 0.0001), 1A/1B (−53%, p = 0.0001), and 1A/1B w/VA (−51%, p = 0.0002). Between the 4 construct patterns, the 3 instrumented constructs (3A/2B, 1A/1B, and 1A/1B w/VA) showed comparable stability in all 3 motion planes.

Conclusions. This study showed no significant difference in the stability of the 3 instrumented constructs tested when the rib cage is intact. Fractures that might appear more grossly unstable when tested in the disarticulated spine may be bolstered by the ribs. This may affect the extent of segmental spinal instrumentation needed to restore stability in some spine injuries. While these initial findings suggest that shorter constructs may adequately stabilize the spine in this fracture model, further study is needed before these results can be extrapolated to clinical application.

Key Words • spine biomechanics • burst fracture • spinal fusion • thoracic stability

The thoracic spine is unique, in part due to the sternocostovertebral articulations and musculature that provide additional strength and stability to the region.¹⁷,²² Biomechanical studies have shown that a complete rib cage with sternum increased thoracic spine stability by 40%, 35%, and 31% in flexion-extension, lateral bending, and axial rotation, respectively.²² Burst fractures in the midthoracic region tend to lead to structural instability, possibly resulting in neurological deficit, pain, and/or deformity. Treatment of these fractures involves stabilization of the unstable site. Typically, a well-accepted construct for such unstable injuries is posterior instrumentation 3 vertebral levels above and 2 vertebral levels below the injury.¹⁴,¹⁹ These long constructs are desired because...
of their increased structural stability.\textsuperscript{4} Short-segment fixations in the treatment of thoracolumbar burst fractures with no anterior column support have been shown to lead to kyphosis and implant failure.\textsuperscript{15,16} However, the use of short-segment constructs for midthoracic fractures in a preparation that preserves the natural ligamentous support structures has been proposed as a more minimally invasive option. Thoracic fracture in the presence of an intact rib cage has not been studied biomechanically. The additional stability provided by the rib cage might negate or at least moderate the biomechanical performance advantage of a longer construct over short-segment constructs. The more extensive approaches for burst fracture treatment involving long-segment fixation, although they may provide increased stability and strength when tested in the disarticulated spine, may not be necessary in treating all fractures that occur in the midthoracic levels in the presence of an intact rib cage.

A majority of the classic biomechanical studies in the literature have evaluated the stability of thoracic constructs in the absence of the rib cage. The few studies that have evaluated the effect of the entire rib cage on the thoracic spine have shown that it contributes to approximately 78\% of the stability of the thoracic spine.\textsuperscript{5} To date, no biomechanical studies have assessed the contribution of the rib cage and sternum in the context of the treatment of thoracic fractures. This study aims to evaluate the biomechanical characteristics of short and long constructs in burst fractures using spines with intact rib cages. We tested the hypothesis that burst fractures occurring in the midthoracic spine may gain additional support from the intact rib cage and thus gain comparable stability from short-segment constructs compared with traditional long-segment constructs.

Methods

Specimen Preparation

Eight fresh-frozen cadaveric adult human torsos, including spinal levels C-7 to L-1 with intact rib cages, were used in this study. The cadavers were from 6 men and 2 women, with a mean age of 63 years (range 52–70 years). The following exclusion criteria were implemented during specimen selection: history of prior spine surgery, cancer, poor bone quality, spinal deformities, fractures, or defects. Additionally, the selected specimens were further assessed for any significant structural defects or anatomical abnormalities through visual inspection and CT. Although dual energy x-ray absorptiometry scanning was not performed, a patient’s medical history excluded the most common causes of bone mineral deficiency, and CT established normal trabecular structure and ruled out any evidence of compression or insufficiency fracture. Prior to testing, the specimens were thawed overnight and prepared at room temperature. Each specimen was dissected to remove all nonligamentous soft tissues while preserving all the structural elements. The sternum, sternocostal articulations, intercostal musculature, posterior ligamentous complex (PLC), facets, and costovertebral articulations were preserved during dissection.

Custom-designed spinal fixtures were used to secure the cranial and caudal ends of the spine onto custom fabricated jigs designed to attach directly to the control arm and baseplate of the spine testing system. This process has been described in previously published studies.\textsuperscript{11,12,20} Before mounting onto the custom fixtures, the vertebrae of C-7 and T-1 were firmly secured together using wood screws inserted through the vertebral body of C-7 into the vertebral body of T-1. The wood screws were then embedded in Cereband, a liquid metal alloy (HiTech Alloys), for additional stability. A similar approach was performed on the caudal vertebrae consisting of T-12 and L-1, where wood screws were inserted through the vertebral body of L-1 into T-12. Once the spine had been firmly secured onto the custom fixtures (cranial and caudal ends), it was frozen at −20°C until the evening prior to the day of testing. On the day of testing the thawed specimen with the custom spinal fixtures was mounted onto the industrial robot through a positive lock interface.

Experimental Testing

A previously validated industrial robotic system (KR-16, KUKA Robotics), using a custom software and programming algorithm and capable of motion in 6 axes, was used as the spine testing system (Fig. 1). A 6-axis, force-moment sensor (Gamma, ATI Industrial Automation) was used to measure the applied load and provide feedback to the robot. The sensor also measured the off-axis forces and moments to provide feedback to ensure that a pure moment was being applied along the primary axis of motion of the spine. The robot was programmed using custom force-torque software to apply 3 continuous loading and unloading cycles of pure moment in torque control along each of the primary axes of the spine to simulate lateral bending, flexion-extension, and axial rotation. The program was developed in Labview (National Instruments), a graphical programming platform used to interface with the robotic controller, and was set to minimize loads in all other axes. Applying this biomechanical feedback algorithm to identify and minimize off-axis strains throughout the range of motion (ROM), the robotic unit was programmed to simulate full range of lateral bending, flexion-extension, and axial rotation in an uninterrupted series of load-controlled tests.

The spine and rib cage specimen was thawed to room temperature overnight prior to the test day. On the day of testing, the specimen was mounted onto the industrial robot via the custom spinal fixtures as described in previous studies.\textsuperscript{5,12,20} The spine’s posture was adjusted until it reflected a neutral posture, and this position was recorded by the test system. The spine was returned to its precise initial neutral position following each test sequence. The specimens were then tested to establish intact control values for displacement in the uninjured specimen; after a series of conditioning cycles to overcome initial viscoelastic rigidity, each spine/torso unit was subjected to 3 cycles each of flexion-extension, lateral bending, and axial rotation at an applied pure moment of ± 5 Nm, all with a 50-N preload applied coaxial to the vertical axis of T-1. Tests were conducted in series, without removing the specimen from the testing frame. Each individual spine was then sequentially instrumented and retested with each of the
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fixation constructs. As separate constructs were applied, the implants were placed with the spine held in its original neutral position, again without removing the specimen from the testing array.

To eliminate any viscoelastic effects, the specimens were preconditioned in all planes of motion. To avoid dehydration and tissue changes that might affect kinematics, the spine was kept moist during testing by lightly spraying exposed tissues with saline solution.

The relative vertebral motion between T-8 and T-10 was measured using infrared markers placed on the spinous processes of the 2 vertebrae. The relative motion was captured using an optoelectronic camera system (Optotak, Northern Digital Inc.). The robotic testing system and the motion capture system were synchronized to begin at the same time to obtain matching loading and motion data. Specimens were subjected to nondestructive testing, allowing direct comparison of changes within each individual specimen (normalized to control) and eliminating a vast number of uncontrollable variables introduced by destructive testing methods. Load/displacement data, measured as ROM, was determined from the final loading cycle for each specimen.

Test Conditions

Each specimen was subjected to nondestructive multidirectional flexibility testing under the following conditions.

**Intact Control.** Intact specimens were subjected to pure moments of ± 5 Nm to simulate flexion-extension, lateral bending, and axial rotation. Intervertebral ROM was measured between T-8 and T-10.

**Fracture Creation at T-9.** Following intact testing, an osteotome and a high-speed drill (Stryker Instruments) were used to surgically induce an unstable anterior- and middle-column fracture at T-9. The anterior longitudinal ligament was disrupted, and the anterior and posterior cortical walls of the vertebral body were fractured, including the cancellous bone in between. The osteotome cuts were reproduced precisely in each specimen. The pedicles, PLC, and posterior column were not violated. The rib cage and intercostal muscles were not disrupted or incised. Flexibility tests were repeated again in all 3 planes of motion to determine the postinjury control for each specimen.

**Fixation Constructs.** After the completion of postinjury flexibility tests, 4 different fixation construct patterns were applied in sequence to stabilize the fracture segment. Each construct pattern was sequentially tested in a nondestructive protocol as follows.

- **Long Construct: 3 Above/2 Below (3A/2B).** A long construct is considered the gold standard for fracture stabilization of the thoracic and thoracolumbar spine. The fracture site was stabilized using pedicle screws and rods placed 3 vertebral levels above and 2 below the fracture (Fig. 2 left). Flexibility tests were then repeated in all 3 planes of motion.

- **Short-Segment Pedicle Instrumentation: 1 Above/1 Below (1A/1B).** Short-segment pedicle instrumentation was fracture site stabilization involving the placement of pedicle screws and rods 1 vertebral level above and below the injury site only (Fig. 2 right). All prior screws remained in place, but longer rods were replaced with shorter rods, forming a construct from T-8 to T-10. Following the placement of instrumentation, flexibility tests were repeated.

- **Short-Segment Pedicle Instrumentation With Vertebral Augmentation (1A/1B w/VA).** Additional stabilization was performed through vertebral augmentation of the T-9 fracture by injecting 3 ml of polymethylmethacrylate via a unilateral left transpedicular approach. The cement was allowed to harden in place, and flexibility tests were repeated in all 3 planes of motion.

- **Vertebral Augmentation Only (VA).** For the vertebral augmentation only construct, the posterior fixation rods were removed from the previous construct (1A/1B w/VA), leaving only the augmented vertebra. Flexibility tests were repeated once again in all 3 planes of motion.

All implants were placed by an experienced spine surgeon (T.G.P. or R.F.M.) using traditional anatomical landmarks to initiate pedicle screw placement. Prior to placing the screw, each tapped pilot hole was palpated with a ball-probe to establish integrity of the pedicle. After placement, visual inspection of the vertebral body and pedicle confirmed that there were no misplaced screws or cortical penetrations.

**Data and Statistical Analysis**

Range of motion was measured in this study as the
angular motion between the T-8 and T-10 segments at ± 5 Nm and was determined from the final loading cycle for each specimen. Statistical analysis was performed using Minitab 15 (Minitab Inc.). A repeated-measures ANOVA was used with post hoc Tukey-Kramer analysis (p < 0.05 was considered statistically significant) for multiple comparisons (group to group) of intact control and the 4 fixation constructs.

Results

Table 1 shows the mean ROM and standard deviations between T-8 and T-10 for the intact control group, fracture group, and the 4 treatment conditions. Intact mean ROM was measured to be 4.68° ± 2.42°, 4.17° ± 2.03°, and 7.76° ± 3.30° for lateral bending, flexion-extension, and axial rotation, respectively. A graphic representation of the effects on ROM after fracture and subsequent stabilization using the 4 construct patterns is shown in Fig. 3. Our results showed that the fracture simulation used in this study caused instability, with a statistically significant increase in motion in all 3 planes of motion. We found that in lateral bending, there was a significant increase in motion of 86% (p = 0.0001) compared with intact control. Flexion-extension motion after fracture showed the largest significant increase of 151% (p = 0.0001), and 31% (p = 0.036) compared with intact controls. While there is no established biomechanical threshold beyond which surgery is known to be necessary, the changes observed under these physiological loads consistently exceeded displacements noted in any intact segment and were believed to be consistent with an unstable, 2-column spinal fracture.

In comparisons between the 4 construct patterns, we found that the long-rod construct was the most rigid in all planes of motion, but that the 3 instrumented construct patterns (3A/2B, 1A/1B, and 1A/1B w/VA) showed no statistical difference in stabilization of the fracture in any of the 3 motion planes.

In lateral bending, we found that the instrumented construct patterns 3A/2B, 1A/1B, and 1A/1B w/VA were all significantly stiffer than the intact controls and significantly reduced motion by −92% (p = 0.0004), −63% (p = 0.0132), and −66% (p = 0.0150), respectively. The improvements observed with the 3 construct patterns did not differ significantly from each other. When final lateral bending stiffness was compared with the fractured control values, there was a significant reduction in motion of −96% (p = 0.0001) for the 3A/2B construct, −80% (p = 0.0001) for the 1A/1B construct, and −82% (p = 0.0001) for the 1A/1B w/VA construct. The 3 instrumentation constructs did not differ significantly with respect to each other. Fracture segments stabilized by vertebral augmentation alone (VA only) showed an increase in lateral bending, but the change in motion was not significant (p = 0.18) compared with intact controls.

In flexion-extension, the long-rod instrumented construct (3A/2B) provided a significant reduction in motion (−90%, p = 0.011) compared with intact controls and −96% reduction compared with fractured controls. The other 2 instrumented constructs, 1A/1B (−65%, p = 0.119) and 1A/1B w/VA (−69%, p = 0.086), showed trends toward significance, but their motion reduction was not statistically significant compared with the intact spine. When final flexion-extension stiffness was compared with the fracture control values, there was a significant reduction in motion of −96% (p = 0.0001) for the 3A/2B construct,
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TABLE 1: Mean ROM and standard deviations between T-8 and T-10 for all conditions

<table>
<thead>
<tr>
<th>Test Conditions</th>
<th>Lateral Bending (°)</th>
<th>Flexion-Extension (°)</th>
<th>Axial Rotation (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>intact</td>
<td>4.68 ± 2.42</td>
<td>4.17 ± 2.03</td>
<td>7.76 ± 3.30</td>
</tr>
<tr>
<td>fracture</td>
<td>8.72 ± 3.82</td>
<td>10.49 ± 4.50</td>
<td>10.19 ± 3.92</td>
</tr>
<tr>
<td>3A/2B</td>
<td>0.38 ± 0.39</td>
<td>0.42 ± 0.25</td>
<td>2.67 ± 1.08</td>
</tr>
<tr>
<td>1A/1B</td>
<td>1.75 ± 0.83</td>
<td>1.45 ± 0.74</td>
<td>3.69 ± 1.95</td>
</tr>
<tr>
<td>1A/1B w/VA</td>
<td>1.58 ± 0.76</td>
<td>1.29 ± 0.81</td>
<td>3.79 ± 1.12</td>
</tr>
<tr>
<td>VA</td>
<td>6.58 ± 3.37</td>
<td>6.37 ± 2.42</td>
<td>8.37 ± 2.24</td>
</tr>
</tbody>
</table>

Discussion

In this study, we evaluated 4 fixation constructs used in the stabilization of a thoracic burst fracture, applied in a unique fracture model with an intact rib cage and sternum. Watkins et al., using a passive in vitro model, showed that an intact rib cage with sternum increased thoracic spine stiffness.\(^2\) They analyzed their intact specimens (mean age 72 years) against a post-sternal fracture condition. They did not study fixation constructs of any kind, but their raw values for ROM were very similar to our intact control values. In their study, the intact rib cage increased thoracic stiffness by 40%, 35%, and 31% in flexion-extension, lateral bending, and axial rotation, respectively. Our findings demonstrate that with preservation of the sternocostovertebral joints in the setting of a thoracic fracture (T-9 in this study), a shorter construct (1A/1B) can achieve the same stability as the historically favored longer construct (3A/2B) even without vertebral augmentation. To our knowledge, there are no biomechanical studies in the literature that have evaluated midthoracic fracture and its stabilization in the presence of intact sternocostovertebral joints.

There are several biomechanical studies in the literature that have evaluated the use of short constructs and long constructs in the stabilization of thoracolumbar fractures, but very few that have investigated the thoracic spine specifically.\(^3\) An et al. conducted a biomechanical study on L-2 burst fracture and found no significant difference in construct stiffness between short constructs and long constructs (2 above and 2 below).\(^3\) Baaj et al. in their study compared the biomechanical characteristics of short constructs (1 above and 1 below, with additional screws placed at fracture level) to long extended constructs (2 above and 2 below with index-level screws) for an L-1 burst fracture model. They found that the ex-
tended construct showed higher stiffness than the short construct.4 Wahba et al. in their biomechanical study on T-12 burst fracture showed that short-segment posterior instrumentation with cross-links significantly improved construct stiffness.23 Mahar et al. in their study compared short segmental fixation (additional short screws placed at fracture level) with traditional nonsegmental fixation for an L-2 burst fracture cadaveric model. These investigators found that stability significantly increased with segmental fixation.13 These studies all focused on the thoracolumbar junction, mechanically a very different region than the thoracic spine, and essentially unprotected by the ribs and sternum above. Inclusion of the rib cage in the biomechanical model tested would not be expected to greatly affect the outcome obtained in these studies.

The choice of long-fixation constructs over short-segment constructs in thoracic spine fractures is subject to numerous assumptions and is not clearly supported by any existing biomechanical studies. Extended constructs are often recommended as a means of ensuring sagittal correction when the anterior column is compromised, particularly after the posterior column has been treated by laminectomy. Long segmental instrumentation constructs can be placed in a variety of ways, depending on the fracture level and pattern. Successful constructs observe 3 primary biomechanical principles: 1) 3-point bending forces, applied through the proximal and distal fixation points and the contact of the longitudinal rod with the midthoracic laminae, resist axial and sagittal bending moments trying to create kyphosis; 2) multiple fixation points distribute corrective forces over a greater number of segments, minimizing risk of pullout failure; and 3) passive or active correction of deformity places the spine in satisfactory sagittal and coronal balance prior to instrumentation. The thoracic spine is relatively immobile and tolerant of fusion, and extending the construct into these segments has little mechanical cost while providing more extensive fixation. Is this added security needed in a thoracic fracture?

Our current study design has several strengths. We used a well-validated robotic spine testing system to conduct the nondestructive biomechanical tests in a protocol that did not require removing and remounting specimens at any point during analysis. This ensured that the array returned to the precise, same starting point at the end and beginning of each series of tests, ensuring consistency in the analysis. This robotic system precisely controlled the applied loads and boundary conditions. Loads were applied along the primary motion axis in each maneuver, while feedback from in-system strain gauges provided input that allowed the system to constantly recognize, compensate for, and minimize all off-axis loads, thus ensuring that the entire spine was subjected to a pure-moment load. The multiple axes of the robotic system enable unconstrained motion of the spine, thus simulating realistic in vivo spinal motion.

Surgical intervention for an unstable fracture of the thoracic spine may vary depending on many factors. The involvement of the PLC, number of columns violated, patient body habitus, other confounding injuries, comminution of the fracture, postfracture kyphotic angulation, patient comorbidities, osteoporosis, and neurological deficits are just a few of the variables to consider when contemplating surgery for a thoracic fracture. This study could not accommodate many of those variables and still provide a rationale biomechanical analysis. Hence, the model selected was nondestructive by design, to allow intraindividual comparisons that would minimize confounding variables inherent in destructive tests. Cyclic testing and load-to-failure testing require large numbers of separate specimens randomized to different treatment groups, not feasible in this preparation. The hypothesis tested also assumes that the decision for surgical intervention in this simulated fracture has been accepted, and the study does not attempt to establish a biomechanical threshold that might correlate with a clinical indication for surgical or nonoperative care. This acute, nondestructive model assessed the deformation of the uninjured and injured spine, along with selected fixation constructs, under physiologically loading, and strived to compare 4 basic constructs with respect to their relative stabilization of this fracture in the circumstance of an intact rib cage.

The morbidity of longer constructs is not necessarily limited to the overall decreased ROM involved in fusing 4 levels; the morbidity encompasses the longer incision, muscle dissection, longer surgery time, increased length of stay, estimated blood loss, and postsurgical transfusion. Also, with each additional screw placement there is a small, but measurable, potential for added complications. These biomechanical principles observed in this study can be applied to both open and percutaneous surgical stabilization. Our results also show that even when the PLC, sternum, and rib cage are preserved, an unstable fracture
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will increase the relative displacement in lateral bending ($p = 0.001$), flexion-extension ($p = 0.0001$), and axial rotation ($p = 0.036$).

There are a number of potential limitations to this study that should be recognized. First, this is a biomechanical study of cadaveric tissue, and caution must be exercised when considering the clinical applications of this analysis. This study looked at a very specific fracture configuration, simulated in the in vivo spine, which maintained an intact PLC, rib cage, sternum, and sternocostovertebral articulations. Whether this injury would consistently cause enough clinical instability to require surgical treatment in an isolated thoracic spine fracture is unknown. Certainly, the need for surgical treatment has been argued by clinicians for almost every condition save the most extreme, and this study cannot provide a quantitative guide to surgical indications. The probability that other bones, ligaments, and muscles would be compromised is high in such a high-energy injury. To provide a testable, consistent model, our study preserved all of these structures, and the individual contributions of these structures have yet to be established.

Second, we cannot say that the biomechanics observed in this study can be extrapolated to the other thoracic levels. The only fracture level studied here was T-9, which is usually the last rib that has attachment to the sternum. The application of the biomechanics of this level to the other levels above should be similar, although the role of the rib cage may be even more substantial at those levels. However, it must be emphasized that T-11 and T-12, junctional vertebrae with floating ribs, may be expected to demonstrate different contributions of the rib cage and sternum to the overall stability of the fractured level. The common observation of short-segment failure at those levels clearly argues against extrapolating our results to injuries at those levels.

Third, there are no clear guidelines as to what defines a clinically significant change in the ROM after fracture or treatment. This concept is difficult to quantify. The biomechanics of our study indicate that lateral bending, flexion-extension, and axial rotation ROM increased by 86%, 151%, and 31%, respectively, from intact controls to fractured controls. Most of the increased motion occurs in the flexion-extension plane (151% increase compared with intact control), as would be expected. Again, the purpose of this study was not to try to establish clinical guidelines or threshold parameters for clinical application, but to assess the relative treatment benefit of different fixation constructs applied in the lifelike biomechanical scenario of a fracture associated with an intact torso. There have been no similar studies attempted, and the results here support the proposition offered by some in the clinical literature that short-segment constructs may play a reasonable role in selected thoracic fractures. More analysis is needed before that conclusion can be supported with suitable evidence.

Finally, this testing algorithm focused on nondestructive loading and sampling of torque-controlled displacement at modest physiological loads. Other testing methodologies can be recommended, including repetitive cyclic testing, or load to failure testing, that would examine a different aspect of the construct stiffness and failure behavior. We selected the nondestructive testing plan both for the nature of the data we sought—displacement under low loads, as would be observed in an injured patient during treatment and recovery after surgery—and because the need to control variables in human cadaver specimens is most reliably met when each specimen is preserved to serve as its own control. Test-retest strategies have previously shown that repeated testing of cadaver specimens does not lead to deterioration of the specimen or drift of the mechanical properties of the bone or soft tissue. Conversely, it is known that any extended cyclic loading study progressively disrupts bone and loosens hardware, rendering each specimen suitable for only a single examination. With the variables noted in cadaver tissues, the need for additional specimens rises exponentially as each test and each construct are added to consideration. This cost and availability of the very large number of specimens needed to conduct even a portion of this initial study was not believed to be reasonable.

Conclusions

Using this unique preparation and testing system, our results showed that when the thoracic rib cage is intact there is no statistically significant difference in the stability provided by any of the 3 instrumented constructs tested (3A/2B, 1A/1B, and 1A/1B w/VA). Thoracic fractures, which may appear more grossly unstable when tested in the disarticulated spine, are significantly bolstered by the ribs and sternum, and testing that includes those structures is likely to better reflect real-life circumstances. This reinforcement may affect the relative importance of segmental spinal instrumentation in restoring stability to the spine in clinical practice. While this study could not assess repetitive motion over an extended interval, or load to failure characteristics of the separate implants, there is sufficient evidence here to support the study of focal, less-extensive fixation constructs for use with isolated thoracic burst fractures. Further study of the impact of rib and sternal fractures are warranted and ongoing.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: McLain, Perry, Mageswaran, Francis. Acquisition of data: Mageswaran, Colbrunn. Analysis and interpretation of data: Mageswaran, Colbrunn, Bonner. Drafting the article: McLain, Perry, Mageswaran, Francis. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: McLain. Statistical analysis: Mageswaran, Colbrunn, Bonner. Administrative/technical/material support: McLain, Francis. Study supervision: McLain.

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