The effect of spinal instrumentation on kinematics at the cervicothoracic junction: emphasis on soft-tissue response in an in vitro human cadaveric model

Laboratory investigation

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Object. Thoracic pedicle screw instrumentation is often indicated in the treatment of trauma, deformity, degenerative disease, and oncological processes. Although classic teaching for cervical spine constructs is to bridge the cervicothoracic junction (CTJ) when instrumenting in the lower cervical region, the indications for extending thoracic constructs into the cervical spine remain unclear. The goal of this study was to determine the role of ligamentous and facet capsule (FC) structures at the CTJ as they relate to stability above thoracic pedicle screw constructs.

Methods. A 6-degree-of-freedom spine simulator was used to test multidirectional range of motion (ROM) in 8 human cadaveric specimens at the C7–T1 segment. Flexion-extension, lateral bending, and axial rotation at the CTJ were tested in the intact condition, followed by T1–6 pedicle screw fixation to create a long lever arm inferior to the C7–T1 level. Multidirectional flexibility testing of the T1–6 pedicle screw construct was then sequentially performed after sectioning the C7–T1 supraspinous ligament/interspinous ligament (SSL/ISL) complex, followed by unilateral and bilateral FC disruption at C7–T1. Finally, each specimen was reconstructed using C5–T6 instrumented fixation and ROM testing at the CTJ performed as previously described.

Results. Whereas the application of a long-segment thoracic construct stopping at T-1 did not significantly increase flexion-extension peak total ROM at the supra-adjacent level, sectioning the SSL/ISL significantly increased flexibility at C7–T1, producing 35% more motion than in the intact condition (p < 0.05). Subsequent FC sectioning had little additional effect on ROM in flexion-extension. Surprisingly, the application of thoracic instrumentation had a stabilizing effect on the supra-adjacent C7–T1 segment in axial rotation, leading to a decrease in peak total ROM to 83% of the intact condition (p < 0.05). This is presumably due to interaction between the T-1 screw heads and titanium rods with the C7–T1 facet joints, thereby limiting axial rotation. Incremental destabilization served only to restore peak total ROM near the intact condition for this loading mode. In lateral bending, the application of thoracic instrumentation stopping at T-1, as well as SSL/ISL and FC disruption, demonstrated trends toward increased supra-adjacent ROM; however, these trends did not reach statistical significance (p > 0.05).

Conclusions. When stopping thoracic constructs at T-1, care should be taken to preserve the SSL/ISL complex to avoid destabilization of the supra-adjacent CTJ, which may manifest clinically as proximal-junction kyphosis. In an analogous fashion, if a T-1 laminectomy is required for neural decompression or surgical access, consideration should be given to extending instrumentation into the cervical spine. Facet capsule disruption, as might be encountered during T-1 pedicle screw placement, may not be an acutely destabilizing event, due to the interaction of the C7–T1 facet joints with T-1 instrumentation. (DOI: 10.3171/2010.4.SPINE09995)

Key Words • cervicothoracic junction • biomechanical study • pedicle screw • scoliosis • adjacent-segment degeneration

Thoracic pedicle screw instrumentation has gained prominence over traditional hook/wire techniques in recent years due to the superior biomechanical properties provided by 3-column fixation. Although these biomechanical advantages have improved construct stability over the operative spinal segment, the same factors that contribute to motion reduction have also been implicated in the progression of adjacent-segment degeneration. In the case of scoliosis or kyphosis.

This article contains some figures that are displayed in color online but in black and white in the print edition.
reduction, this typically manifests as PJK, with a reported prevalence in adolescent idiopathic scoliosis of 9.2%–46%, and in adult spinal deformity ranging from 26% to 39%.1,5,6,9,11,14,19,23,24 Biomechanical factors that have been implicated in adjacent-segment disease in the thoracic spine include soft-tissue integrity at the supra-adjacent level, construct stiffness, and sagittal-plane alignment in both the pre- and postoperative setting.2

When pedicle screw instrumentation is extended into the upper thoracic spine, the complex biomechanics of the CTJ must also be taken into account. The CTJ represents an important spinal transition zone from the flexible, lordotic cervical spine to the rigid, kyphotic thoracic region.1,5,6,9,11,14,19,23,24 In addition, despite the stabilizing effect of the sternum, costovertebral joints, and rib cage, the upper thoracic spinal levels have been shown to provide measurable amounts of motion in all loading modes (flexion-extension, axial rotation, and lateral bending), which must factor into surgical reconstruction in this region.10,20 The propensity for construct failure at the CTJ has led authors to propose bridging the junction into the thoracic spine when placing long-segment cervical constructs, especially when bone or soft-tissue decompression is required at C7–T1.17,25

To understand better the effect of soft tissues, as well as length of construct moment arm, on supra-adjacent motion at the CTJ, a cadaveric biomechanical study was performed. After multidirectional ROM testing of the intact spine condition, multilevel thoracic pedicle screw instrumentation ending at T-1 was placed in each specimen. Sequential ligamentous and facet capsule disruption was then performed at the CTJ to determine the factors that warrant extension of thoracic pedicle screw constructs into the cervical spine.

**Methods**

**Specimen Preparation**

Eight fresh-frozen human cadaveric spines (C1–T8) were harvested en bloc and stored at −20°C in double-thickness plastic bags. All specimens were inspected using anteroposterior and lateral radiographs and were found to be devoid of fracture, disc space ankylosis, deformity, or oncological disease at the treatment level (C7–T1). Prior to flexibility testing, specimens were thawed to room temperature and then dissected free of all paraspinal musculature. Ligamentous structures and joint capsules were left intact.

**Multidirectional Flexibility Testing**

Specimens were fixed at the rostral (C-4) and caudal (T-7) levels by using rectangular metal tubing containers fitted with 8 four-point compression screws. Two Plexiglas motion detection markers were secured to the anterior aspect of the C-7 and T-1 vertebral bodies, with a third marker affixed to the caudal tubing container. Each marker was equipped with 3 noncolinear light-emitting diodes, which allow motion detection by an optoelectronic motion measurement system (OptoTrak 3020; Northern Digital, Inc.).

Multidirectional flexibility testing was performed using a custom-designed 6-degree-of-freedom spine simulator. This device’s gimbal apparatus contains 3 independent stepper motors, harmonic drives, and electromagnetic clutches, which are capable of applying pure, unconstrained rotational moments in the positive and negative directions (designated by ± in this context) about 3 axes—X, Y, and Z. Likewise, unconstrained translations in the positive and negative directions (±) are permitted using linear bearing guide rails (X and Z) and a pneumatic-controlled linear actuator (Y axis). The caudal portion of each vertically oriented specimen was fixed to the testing platform, and nondestructive pure-moment loads [flexion-extension (± X axis), axial rotation (± Y axis), and lateral bending (± Z axis)] were sequentially applied to the superior potted portion of each spine. A maximum applied moment of ± 3 Nm was used for each loading mode and applied at a stepper motor rate of 3°/second. A total of 3 load/unload cycles were performed for each motion, with data analysis based on the final cycle. For the 6 main
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motions—corresponding to the moments applied—the C7–T1 level vertebral rotations (in degrees) were quantified in terms of peak ROM and NZ, with ROM defined as the maximal displacement from neutral position. Computational data were acquired using LabView software, and analyzed with Microsoft Office Excel.

Sequential Destabilization at C7–T1 and Placement of Instrumentation

The ROM for each specimen was first tested in the intact condition at the C7–T1 level. Posterior instrumentation (Expedium System; DePuy Spine, Inc.) was then used to create a long-segment thoracic pedicle screw construct below the CTJ. For each construct, 4.35 × 25–mm pedicle screws were placed bilaterally at T1–2, and 4.35 × 30–mm pedicle screws at T3–6 by using the “straight forward” technique, and connected by 5.5-mm-diameter titanium rods (Fig. 1 left). To avoid disruption of the C7–T1 FCs during T-1 screw placement, anteroposterior fluoroscopy was used to mark ideal pedicle screw starting points that were inferior to the facet joints in each case. With the inferior potting container fixing the T6–7 facet joints and extending caudally to the T8–9 level, this further lengthened the thoracic construct in each case to magnify any effects of instrumentation at the supraadjacent level. The ROM testing was then performed at the C7–T1 level in each specimen. The SSL/ISL complex at C7–T1 was subsequently sectioned to simulate ligamentous injury in trauma, inadvertent surgical dissection, or disruption following a laminectomy procedure at T-1 (Fig. 2). The ROM testing was repeated in the destabilized condition. Unilateral FC sectioning was then performed at the C7–T1 level to simulate violation during T-1 pedicle screw placement, and flexibility testing was repeated as previously described. This was then followed by bilateral C7–T1 FC sectioning for further destabilization of the CTJ. Finally, each pedicle screw construct was extended into the cervical spine by using 3.5 × 14–mm lateral mass screws (Mountaineer System; DePuy Spine, Inc.) placed bilaterally at C-5 and C-6, and connected using tapered (3.5- to 5.5-mm) titanium thoracic transition rods (Fig. 1 right).

Anteroposterior and lateral fluoroscopic images were taken of each construct (T1–6 and C5–T6) to verify proper screw position (Fig. 3). The specimens were copiously moistened using 0.9% NaCl irrigation solution throughout each testing procedure.

Calculation of ROM, NZ, and Statistical Analysis

The segmental ROM at the C7–T1 spinal level was calculated as the sum of the neutral and elastic zones (NZ + EZ = ROM) for the 6 main motions corresponding to the applied moments, and represents the peak total ROM (Euler angles rotation and percentage of intact condition) at the third loading cycle. The expressed degrees of rotation (flexion-extension ± X axis, axial rotation ± Y axis, and lateral bending ± Z axis) for multidirectional flexibility analyses were computed according to the 3D framework of Panjabi.

Multidirectional ROM and NZ data at C7–T1 are presented as the mean ± 1 SD. Repeated-measures ANOVA and post hoc Student-Newman-Keuls testing were used for multiple comparisons between treatment groups and the intact control. The threshold for statistical significance was defined as p < 0.05.

Results

The mean specimen age was 88 ± 6 years (range 78–95 years; 5 male and 3 female) and causes of death included cardiovascular dysfunction, cancer, and Parkinson disease. One specimen was removed from the flexion-extension and axial rotation data analysis because it had an ROM that was an order of magnitude higher in the intact condition and in all subsequent destabilized or reconstructed states. For lateral bending, 2 specimens had no ROM in the intact condition, and were therefore removed from the data analysis for this loading mode only.

The ROM and the NZ

Flexion-Extension (± X Axis). Following placement of a long-segment thoracic pedicle screw construct ending at the T-1 level, there was a 12% increase in flexion-
extension ROM at the C7–T1 motion segment relative to the intact condition (Fig. 4, Table 1). Although this change did not reach statistical significance \( p > 0.05 \), the trend is presumably due to the increased lever arm below the CTJ created by long-segment fixation in the thoracic spine. A significant increase in flexion-extension ROM was subsequently caused at C7–T1, however, by sectioning the SSL/ISL complex at this level. After SSL/ISL disruption, flexion-extension ROM increased by 35% relative to the intact condition \( p < 0.05 \). Subsequent unilateral and bilateral FC disruption at C7–T1 produced only a minor additional effect on ROM in flexion-extension at the CTJ \( p > 0.05 \). Following bridging of the CTJ by cervical lateral mass screw placement at the C5–6 level, ROM decreased to 16% of intact, which was statistically significant compared with all other treatment groups \( p < 0.05 \).

Neutral zone motion was also assessed in flexion-extension at C7–T1, demonstrating similar trends to that of the peak total ROM (Table 2). Although C5–T6 fixation produced significantly less NZ motion compared with all other treatment conditions \( p < 0.05 \), smaller differences between groups precluded any further determination of statistical significance for this parameter.

**Axial Rotation (± Y Axis).** In axial rotation, the placement of a long-segment thoracic pedicle screw construct significantly decreased ROM at the supra-adjacent C7–T1 level to 83% of intact \( p < 0.05 \); see Fig. 5 and Table 1). This decrease in peak total ROM is hypothesized to be due to interaction of the T-1 screw heads and superior portion of the titanium rods with the C7–T1 facet joints, thereby limiting axial rotation. Subsequent sectioning of the SSL/ISL and each FC served only to normalize ROM to near the intact condition. Although bilateral FC sectioning (101% of intact) produced significantly greater ROM compared with the T1–6 construct without destabilization (83% of intact; \( p < 0.05 \)), there was no difference between bilateral FC disruption and the intact condition \( p > 0.05 \). As expected, bridging the CTJ to C-5 with lateral mass screws produced a significant decrease in ROM compared with all other groups, stabilizing this level to 22% of the intact spine condition \( p < 0.05 \).

As in the case of flexion-extension, NZ motion for the C5–T6 construct significantly decreased compared with all other conditions \( p < 0.05 \); Table 2). Overall, NZ motion once again mirrored peak total ROM, but did not provide further statistical significance between treatments, due to the smaller magnitude of motion and larger relative SDs.

**Lateral Bending (± Z Axis).** Following placement of thoracic pedicle screw instrumentation to the T-1 level, a trend toward increased peak total ROM in lateral bending was noted at the CTJ, resulting in a 26% increase relative to the intact condition (Fig. 6, Table 1). With each incremental destabilization, this trend continued—SSL/ISL, unilateral FC, and bilateral FC sectioning at C7–T1 led to 35%, 41%, and 45% increases, respectively, compared with the intact spine. This trend did not reach statistical significance, however, due to relative variation between specimens, causing higher SDs than were noted in either flexion-extension or axial rotation ROM testing \( p > 0.05 \). Following extension of the instrumentation construct into the cervical spine, lateral bending ROM significantly decreased compared with all other treatment groups, stabilizing the CTJ to 11% of intact \( p < 0.05 \).

Neutral zone data were once again limited by the small magnitude and high SDs, thereby not allowing a
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**Discussion**

Adjacent-segment degeneration is gaining attention with the increased use of spinal instrumentation.⁴,¹⁰,¹⁵ Although long-segment constructs may be required to achieve spinal balance and to fix complex deformities or other pathological processes, the mechanical stress at the supra- and infra-adjacent levels remains poorly understood.¹⁵ The incidence of delayed failure above and below spinal instrumentation is probably multifactorial, including such factors as patient age, bone health, spinal alignment, and the region of the spine that was treated.⁴,¹⁵

The integrity of posterior soft-tissue structures, including the ISL/SSL complex and capsular ligaments, has also been reported to affect adjacent-segment stability following spinal fixation.¹⁴,¹⁵ For instance, in 2004 Lai et al.¹⁵ retrospectively reviewed 101 patients with a minimum 6-year follow-up who underwent instrumented posterolateral lumbar fusion. These authors reported that 24.3% of patients who had disruption of the posterior complex between the rostral fused level and the supra-adjacent motion segment developed instability, compared with only 6.5% of patients with intact posterior elements. Biomechanically, the effects of facet joint and posterior element integrity at the supra-adjacent level have also been studied in the lumbar spine. In a cadaveric experiment performed by Cardoso et al.,⁴ motion at the supra-adjacent segment was studied sequentially after L5–S1 pedicle screw fixation, unilateral facet joint breach at L4–5, bilateral facet joint breach at L4–5, and after L-5 laminectomy. This sequence of testing was then repeated after extending instrumentation to the L-4 and L-3 levels, respectively. As expected, the results of this study showed significant increases in flexion-extension ROM after violation of the posterior tension band via superior-segment laminectomy, while bilateral facet disruption had a significant destabilizing effect on supra-adjacent ROM in axial rotation. Interestingly, increasing the construct length alone was also found to increase superior-segment ROM significantly in all loading modes.

Length of construct and posterior ligamentous/FC integrity seem to play a role in adjacent-segment stability.

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### TABLE 1: Range of motion data at C7–T1*

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Flexion-Extension (º)</th>
<th>Axial Rotation (º)</th>
<th>Lateral Bending (º)</th>
</tr>
</thead>
<tbody>
<tr>
<td>intact</td>
<td>4.3 ± 2.0</td>
<td>6.2 ± 3.0</td>
<td>4.5 ± 3.2</td>
</tr>
<tr>
<td>T1–6 fixation</td>
<td>4.6 ± 1.9</td>
<td>5.1 ± 2.5</td>
<td>5.3 ± 3.7</td>
</tr>
<tr>
<td>+ C7–T1 SSL/ISL section</td>
<td>5.5 ± 2.5</td>
<td>5.5 ± 2.4</td>
<td>5.8 ± 4.6</td>
</tr>
<tr>
<td>+ C7–T1 unilt FC section</td>
<td>5.5 ± 2.5</td>
<td>5.8 ± 2.6</td>
<td>6.2 ± 5.3</td>
</tr>
<tr>
<td>+ C7–T1 bilat FC section</td>
<td>5.7 ± 2.7</td>
<td>6.2 ± 2.7</td>
<td>6.3 ± 5.3</td>
</tr>
<tr>
<td>C5–T6 fixation</td>
<td>0.5 ± 0.1</td>
<td>1.4 ± 1.1</td>
<td>0.4 ± 0.2</td>
</tr>
</tbody>
</table>

* Data are represented as degrees ± 1 SD. Entries in the left-hand column are sequential (they are subentries of the treatment immediately preceding them).

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### TABLE 2: Neutral zone data at C7–T1*

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Flexion-Extension (º)</th>
<th>Axial Rotation (º)</th>
<th>Lateral Bending (º)</th>
</tr>
</thead>
<tbody>
<tr>
<td>intact</td>
<td>0.7 ± 0.3</td>
<td>1.7 ± 1.0</td>
<td>0.8 ± 0.7</td>
</tr>
<tr>
<td>T1–6 fixation</td>
<td>0.7 ± 0.3</td>
<td>1.4 ± 1.0</td>
<td>0.9 ± 0.8</td>
</tr>
<tr>
<td>+ C7–T1 SSL/ISL section</td>
<td>0.7 ± 0.2</td>
<td>1.5 ± 1.0</td>
<td>1.0 ± 1.1</td>
</tr>
<tr>
<td>+ C7–T1 unilt FC section</td>
<td>0.8 ± 0.3</td>
<td>1.7 ± 1.0</td>
<td>1.0 ± 1.2</td>
</tr>
<tr>
<td>+ C7–T1 bilat FC section</td>
<td>0.7 ± 0.3</td>
<td>1.8 ± 1.2</td>
<td>1.2 ± 1.5</td>
</tr>
<tr>
<td>C5–T6 fixation</td>
<td>0.1 ± 0.1</td>
<td>0.2 ± 0.1</td>
<td>0.1 ± 0.1</td>
</tr>
</tbody>
</table>

* Data are represented as degrees ± 1 SD.

In the lumbar spine, but these factors may have an even larger effect at spinal transition zones, such as the CTJ. Given the current controversy and the paucity of data regarding optimal stopping points for posterior spinal fixation at such regions, the primary objective of this study was to determine the effect of construct length and posterior ligamentous/FC integrity at the CTJ as they pertain to pedicle screw fixation in the upper thoracic spine.

The effect of construct length was first assessed by fixing the thoracic spine from T-1 to T-6 with bilateral pedicle screw/rod constructs. Potting of each specimen to the T8–9 level also effectively increased the construct moment arm for further simulation of long-segment thoracic pedicle screw fixation. Results from the current study showed trends toward increasing ROM at the CTJ in both flexion-extension and lateral bending caused by the construct alone; however, these trends did not reach statistical significance. Unlike the significantly destabilizing results reported by Cardoso et al.⁴ in the lumbar spine, the smaller magnitude of effect noted in our study is probably due to the inherently stiff thoracic segment. In contrast to the mobile lumbar spine, the thoracic region is stabilized in vivo by the sternum and rib cage, so that at baseline the CTJ is subjected to the combined effects of the rigid thoracic spine. The incremental increase in stiffness that was provided by the construct in relation to the in vivo thoracic region was probably not enough to produce significant changes in ROM at the CTJ in either flexion-extension or lateral bending. The lack of statistical significance for construct length in the current study may also relate to a combination of factors, including advanced specimen age, facet joint orientation, and variables unique to the biomechanical testing conditions, such as the applied moment.

In the case of axial rotation, the present study showed a stabilizing rather than a destabilizing effect caused by T-1 pedicle screw instrumentation, decreasing ROM to 83% of the intact state. In the lumbar spine, the sagittal orientation of the facet joints and lateral entry point for pedicle screw insertion yield no mechanical interaction of instrumentation at the superior segment. This is different from the thoracic spine, in which the coronally oriented facets and more medial site of pedicle screw insertion cause an interaction between the pedicle screw head and superior rod segment, thereby providing a mechanical “stop” to excessive axial rotation ROM. Based
on these results, it appears that the placement of thoracic pedicle screw instrumentation alone, ending at T-1, does not significantly destabilize the CTJ, and may even provide some stabilizing effects in axial rotation.

To determine the role of the SSL/ISL complex in CTJ stability, the posterior tension band was then sectioned, and multidirectional ROM testing was repeated. Although the increased moment arm caused by instrumentation alone did not significantly destabilize the CTJ, loss of posterior ligamentous integrity significantly increased flexion-extension ROM at the uninstrumented C7–T1 level by 35% relative to the intact condition. This finding agrees with that reported by Cardoso et al. in the lumbar spine, and also with individual thoracic segment motion testing performed by Anderson et al., in which disruption of the SSL/ISL complex significantly reduced flexion

**Fig. 5.** Bar graph showing axial rotation values: ROM at C7–T1 is presented as the percentage of the intact condition. Bar height indicates the mean value, and error bars represent 1 SD. The symbols above individual bars denote statistical significance (p < 0.05). See Fig. 4 legend for explanation of pluses.

**Fig. 6.** Bar graph showing lateral bending values: ROM at C7–T1 is presented as the percentage of the intact condition. Bar height indicates the mean value, and error bars represent 1 SD. The symbols above individual bars denote statistical significance (p < 0.05). See Fig. 4 legend for explanation of pluses.
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stability. Clinically, these results are particularly relevant for avoiding PJK following scoliosis surgery, in that particular care should be taken to avoid violation of the SSL/ISL complex above such thoracic constructs. Based on the results of this study, for thoracic constructs stopping at T-1, disruption of the posterior tension band at C7–T1 during surgical dissection or following T-1 laminectomy for neural decompression would warrant extension of instrumentation into the cervical spine.

The final destabilization performed in this experiment involved sequential FC sectioning at C7–T1. Due to the position of the pedicle in relation to the facet joint in the thoracic spine, FC violation can occur with either surgical dissection or with decortication for screw insertion.2 Whereas Cardoso et al.4 noted a significant increase in axial rotation ROM following supra-adjacent facet violation in the lumbar spine, the results of our study exhibited minimal change in ROM after facet violation due to the facet joint–T1 screw interaction previously described. This finding is potentially important because supra-adjacent facet violation at the CTJ following thoracic pedicle screw instrumentation may not be as destabilizing as initially presumed, and does not appear to warrant extension of constructs into the cervical spine. This is also clinically relevant because it is technically challenging to insert T-1 pedicle screws without at least partial disruption of the C7–T1 FC. It remains unclear, however, whether such facet violation could cause pain in the absence of overt instability.

Several limitations exist in this cadaveric biomechanical study that must be addressed. First, this experiment did not take into account the thoracic stabilization provided by the sternum and rib cage. Although it is unlikely that these anatomical structures would have had any effect on our findings as they relate to construct length, it is possible that further stabilizing the thoracic spine may magnify flexion-extension ROM changes at the CTJ caused by posterior ligamentous disruption. Second, as with any cadaveric biomechanical experiment, the testing paradigm did not assess the effects of the paraspinal musculature on CTJ stability. Although contraction of the paraspinal muscles strengthens the CTJ in vivo, surgical dissection and segmental denervation of these muscles during pedicle screw placement may further destabilize the CTJ and add to the effects noted in this study. Third, due to the advanced age of the specimens available for this experiment, ROM may be underestimated relative to younger patients undergoing surgical fixation in this region. Attempts were made to alleviate this concern by only using specimens that were devoid of disc degeneration, osteophytes, or other pathological features at C7–T1. Fourth, global sagittal balance of the spine has been implicated as a factor in the development of PJK following thoracic spinal fixation.2 Due to the size of the testing apparatus used, which necessitated sectioning of the specimens in the upper cervical and lower thoracic regions, it was impossible to include an assessment of sagittal balance in the experiments performed. Finally, this cadaveric study tested acute changes in ROM after 3 loading cycles. It is possible that with fatigue testing, supra-adjacent level motion may be magnified by cyclic loading of the specimens, thereby showing effects either due to construct length or soft-tissue disruption that were not apparent in the current testing regimen.

Conclusions

For thoracic constructs stopping at T-1, the posterior SSL/ISL complex plays a key role in CTJ stability. Although a long-construct moment arm in the thoracic spine was not shown to increase ROM significantly at the supra-adjacent segment, disruption of the posterior tension band significantly destabilizes the CTJ in flexion-extension, which may manifest clinically as PJK. Based on the findings in this study, we suggest that careful identification and preservation of this structure may reduce the incidence of PJK during surgery for kyphosis and/or scoliosis correction, cases of upper thoracic trauma, and upper thoracic tumor resection. Violation of the SSL/ISL complex, as might be required in the case of T-1 laminectomy or during inadvertent surgical dissection, warrants extension of upper thoracic constructs into the cervical spine. Facet capsule violation at the CTJ during T-1 pedicle screw placement does not seem to be acutely destabilizing, and does not justify rostral extension of upper thoracic instrumentation.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Kretzer, Tortolani, Cunningham. Acquisition of data: Kretzer, Hu, Umejoki, Cunningham. Analysis and interpretation of data: Kretzer, Hu, Tortolani, Cunningham. Drafting the article: Kretzer. Critically revising the article: Kretzer, Sciubba, Jallo, Tortolani, Cunningham. Reviewed final version of the manuscript and approved it for submission: all authors. Statistical analysis: Kretzer, Hu, Cunningham. Study supervision: McAfee, Tortolani, Cunningham.

References


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