Rigid fixation of the lumbar spine alters the motion and mechanical stability at the adjacent segment level

Lomber omurgada rijit tespit komşu segment seviyesinde hareket ve mekanik stabiliteyi değiştirir

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Objectives: This study aims to examine the motion and stability of the adjacent segment following rigid fixation of the lumbar spine.

Materials and methods: The study included 17 fresh-frozen lamb lumbar spines (including the sacrum to T_{12}). Biomechanical testing was performed using an axial compression testing machine. Axial compression was applied to all the specimens using a loading speed of 5 mm min-1. A specifically designed fixture was used to generate torque ≤8400 Nmm. The fixture was used with each specimen to achieve flexion and extension, axial neutral compression, and right and left bending. All specimens were tested intact, and again after implantation using posterior pedicle screws and rod fixation. During testing intervertebral displacement at the adjacent level (L5-S1) was recorded continuously via extensometry.

Results: Axial compression and superior-inferior displacement were lower in the adjacent segment (L5-S1) than anterior-posterior displacement following rigid fixation. Statistical analysis showed that there was a numerical difference and a significant change between the intact spine and the adjacent segment in the axial compression and extension positions (p<0.027). The intact spines demonstrated the maximum displacement and the difference in extension positions were significant (p<0.015).

Conclusion: Rigid fixation of the lumbar spine altered the range of motion at the adjacent segment level. As such, abnormal stress on the adjacent segment causes spinal instability, which may subsequently cause facet joint degeneration and low back pain.

Key words: Adjacent segment instability; facet joint; intervertebral disc; lumbar spine.

Amaç: Bu çalışmada lomber omurganın rijit tespitinden sonra komşu segmentin hareket genişliği ve stabilitesi araştırıldı.

Gereç ve yöntemler: Bu çalışmada 17 taze donmuş kuzu lomber omurgası (sakrum T_{12}'yi içeren) kullanıldı. Biyomekanik test aksiyel kompresyon test cihazı ile yapıldı. Aksiyel kompresyon tüm numunelere 5 mm/dk. yükleme hızı ile uygulandı. Özel dizayn edilmiş fikstür ile 8400 Nmm tork oluşturuldu. Fikstür aksiyel yönde fleksiyon, ekstansiyon, sağ ve sola eğilme pozisyonlarında yüklenme uygulanacak şekilde numuneler ayarlandı. Tüm numuneler sağlam omurga, pedikül vida ve rod fiksasyonu sonrasında teste tabi tutuldu. Test esnasında komşu seviye L5-S1 arasındaki ayrılma değerleri süreğen bir şekilde ekstansometre ile kaydedildi.

Bulgular: Komşu segmentte (L5-S1), aksiyel yüklenme ve üst-alt ayrılma değerleri, ön-arka ayrılma değerlerinden düşük bulundu. İstatistiksel analizde sağlam omurga ile komşu segment arasında aksiyel kompresyon ve ekstansiyon pozisyonunda sayısal anlamlı değişiklikler tespit edildi (p<0.027). Bunun yanında ekstansiyon pozisyonunda komşu segmentte sağlam omurgaya göre daha yüksek çıktı (p<0.015).

Sonuç: Lomber omurganın rijit fiksasyonu komşu segment seviyesinde hareket genişliğini değiştirmektedir. Bundan dolayı, komşu segmentte anormal stres ve spinal instabiliteye neden olur; bu durum, faset eklem dejenerasyonuna ve bel ağrılarına yol açabilir.

Anahtar sözcükler: Komşu segment instabilitesi; faset eklem; omurlar arası disk; lomber omurga.

Instrumented lumbar spine fusion which is a common surgical procedure is indicated in the treatment of degenerative disorders and lytic spondylolisthesis.[1-4] The posterior structures of the facet joints are particularly important stabilizers of the motion segment. The orientation of the facets in the lumbar spine facilitates flexion and extension and aids in resisting torsion and shear load.[5] Instability is usually restored with surgical fusion using pedicle screws and a cage, following decompression. Lumbar interbody fusion with supplemental posterior pedicle screw fixation is routinely used for the surgical treatment of painful spinal disorders. Posterior lumbar interbody fusion (PLIF) is a popular lumbar arthrodesis and posterolateral graft, and fixation can be easily added to PLIF to enhance spinal stability and to induce fusion.[6-11]

Alteration of the biomechanics at the junction of fused and mobile segments is thought to accelerate degeneration in adjacent motion segments. Adjacent segment disease has been reported to occur in as many as 35% of patients following spinal fusion.[3,6] Initial positive results following posterior spinal fusion often degrade over time, as adjacent mobile segments proximal and distal to the fusion degenerate.[6] Following arthrodesis at L4-L5, the most common level of fusion, adjacent disc disease additional surgery is required in approximately 15% of patients.[2,3,12] Progression of the free mobile segment next to the spinal fusion is referred to as adjacent segment disease including disc degeneration, facet joint hypertrophy, spinal stenosis, and even acquired spondylolisthesis.[9] The etiology of adjacent segment degeneration is not fully known, however, two theories have been proposed thus far. According to the first theory, in vitro research suggests that fusion increases intradiscal pressure (IDP) on the adjacent segment and that relative hypermobility is induced; both observations suggest that there is an increase in the load on the segment. The second theory posits that degeneration of the adjacent segment is indicative of the natural degenerative course of an aging disc.[3,7-9,13,14]

In this study, we aimed to investigate the mechanical behavior and instability of the adjacent segment following rigid fixation.

MATERIALS AND METHODS

This randomized study included 17 fresh-frozen lamb spines aged ranging between six to 12 months. The specimens did not have any macroscopically or radiologically observed diseases (Figure 1). The spine of each specimen was dissected from the sacrum to the T_{12} level of the spine. All specimens were frozen and thawed immediately before testing. All specimens were potted with cement at the T_{12} vertebra and at the sacrum level. The specimens were tested twice; first as an intact spine and then following rigid fixation with an implanted rod and pedicle screws. Then, they were mounted for biomechanical testing. Biomechanical tests were performed using an axial compression testing machine (AG-I 10 kN, Shimadzu, Japanese), and two non-contact cameras (non-contact Video Extensometer DVE-101/201, Shimadzu, Japanese) obtained images of the gauge marks attached to the test specimens.

A specifically designed fixture was used to generate torque ≤8400 Nmm through the axial movement of the actuator to achieve flexion and extension, axial compression, and right and left bending (Figure 2).[15] Axial compression was applied in the axial position. First, the intact spines were tested. Then, transpedicular screws (30x4.5 mm mono axial titanium screws) were implanted into the L5, L4, and L3 vertebrae, and fixed with two rods (6x100 mm titanium) (Tipsan-Tibbi Aletler San. A.Ş.). During testing, intervertebral displacement at the L5-S1 level was recorded continuously using an extensometer. Gauge marks were applied to the test specimens with pins due to their sliding surface. Gauge marks were attached to L5 and S1 for measurement of superior-inferior and anterior-posterior displacement. Displacement values were recorded using a personal computer connected to the test machine and two non-contact cameras. Displacement data were evaluated using the Mann-Whitney U test and SPSS v.11.0 for Windows (SPPS Inc., Chicago, Illinois, USA).

RESULTS

Axial displacement findings are presented in Figure 3 and anterior-posterior displacement findings
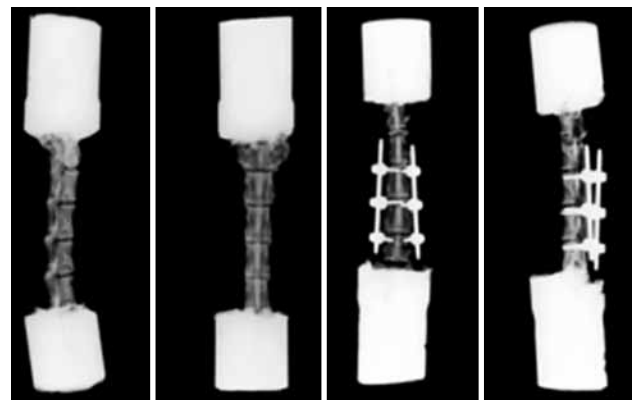
Figure 1. X-rays of intact spines and spines following rigid fixation.

Figure 2. Moment testing (8400 Nmm) of specimens in different positions; flexion-extension and right-left bending.

are shown in Figure 4. The rate of axial displacement in the axial plane was the highest in the intact spines (Table I). There was a significant difference in the axial compression position between the intact spines and the adjacent segments (p<0.027). The intact spines exhibited the highest displacement and the difference in extension was significant (p<0.015). The intact spines had the highest displacement in flexion, however, the difference between the intact spines and those with implanted rods was not significant. There was no significant difference in the left bending between the intact spines and those with implanted rods. The rate of anterior-posterior displacement of the adjacent segment was higher in the implanted spine than in the intact spine, while the adjacent segment exerted
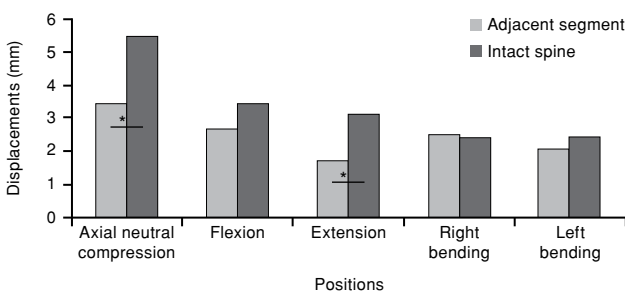
higher displacement in flexion, however, it did not reach statistical significance. The findings show that there was no significant difference in the extension of the in the right and left bending positions between the adjacent segment and the intact spine.

DISCUSSION

Rigid instrumentation including pedicle screw systems is widely used with an increasing popularity thanks to its higher initial stability and fusion rates, low need for external immobilization, and earlier return to work than other methods.[3,6,8,9,12,16,17] Although recent biomechanical studies have shown that a number of spinal devices can be used for rigid fixation and fusion at the treated level, little attention has been focused on the adjacent segment instability.[2,5,6,8,12,13,16-18]

The present study focused on the adjacent segment instability. As adjacent segment mobility increased, the anterior and posterior structures maintained stability and prevented instability. In the present lamb spinal model, displacement in intact spines was 1.12 mm in flexion and 3.83 mm in extension, versus 1.41 mm in flexion and 4.07 mm in extension following rigid fixation. In a porcine model, Tai et al.[2] reported that displacement in intact spines in flexion and extension was 1.03 mm and 0.90 mm, respectively, versus be 1.57 mm and 0.98 mm, respectively, following spinal laminectomy.

Several studies measured IDP or laminar strain in adjacent segments following rigid fixation and fusion and evaluated indirectly load transmission through both the anterior and posterior spinal columns. The authors reported that IDP increased to some degree in adjacent segments in all directions, except extension.[14] The total lumbar motion differed in a patient who had undergone fusion. In the present study, the range of motion (ROM) was 69% lower in flexion-extension, 73% lower in bending, and 34% lower in axial rotation in the spines implanted with rods than in the intact spines.[1,3,7,8,14,19,20]

Figure 3. Neutral vertical displacement.
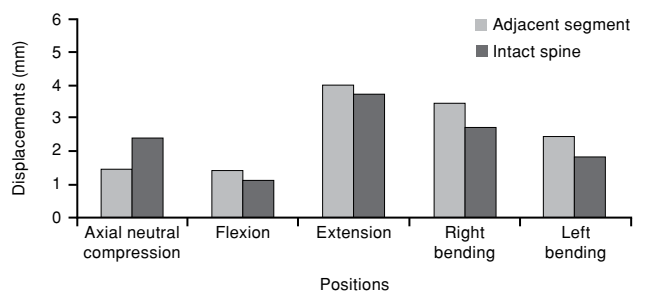
Figure 4. Transverse displacement.

TABLE I

Displacement in each position

	Superior inferior		Anterior posterior	
	Intact spine	Spine with implanted rods adjacent segment	Intact spine	Spine with implanted rods adjacent segment
	Displacement (mm)	Displacement (mm)	Displacement (mm)	Displacement (mm)
Axial neutral compression	5.46	3.43	2.42	1.46
Right bending	2.40	2.50	2.77	3.51
Left bending	2.41	2.05	1.85	2.46
Flexion	3.41	2.67	1.12	1.41
Extension	3.12	1.71	3.83	4.07

Rigid fixation and fusion of the mobile segment alter the biomechanics and kinematics of the entire lumbar spine.[1,3,6,9,14,17,20] The precise relationship between the local stiffness produced by segmental fixation and accelerated degeneration, however, remains unclear.[1,9,21]

In the present study, there was significant variation between the intact spine and the adjacent segment in the axial position. The rate of displacement was higher in the axial position in the intact spines than in those following rigid fixation. Additionally, the rate of displacement in extension was significantly higher in the intact spines. The present study's testing protocol[2] constantly tested the intact spines following rigid fixation of the L5, L4, and L3 vertebrae. Moreover, adjacent segment displacement and instability were analyzed under axial compression in both the intact spines and those following rigid fixation. The findings indicated that there was a significant difference in axial compression displacement in the adjacent segment and the intact spine (p<0.027). Furthermore, there was a significant difference in superior-inferior displacement in extension between the adjacent segment and the intact spine.

Dynamic fixation can reduce facet joint force at the level of fixation, however, cannot significantly reduce the disc load.[21] The maintenance of stability of the lumbar spine during movements, therefore, requires the coordinated movements of multiple motion segments.[22] In the present study, the rate of anterior-posterior displacement in all positions was higher at the adjacent segment level than in the intact spine, indicating anterior-posterior instability at the adjacent segment level. Following rigid fixation of the spine, the adjacent segment of the facet joint was overloaded compared to the intact spine. On the other hand, the limitation to this study was that the bone mineral density of the spines was not measured before testing. Another limitation was that the specimens did not contain any living tissue, as the study was designed *ex vivo*.

Conclusion

The rate of anterior-posterior displacement of the lumbar spine following rigid fixation was significantly higher at the adjacent segment level than in the intact lumbar spine. The rate of anterior-posterior displacement in the implanted spine was higher than intact spine in all positions, except the axial position. There was a significant difference in between the intact spines and those with implanted rods in axial compression and extension. Moreover, abnormal stress on the adjacent segment may have caused spinal instability. Following rigid fixation, anterior-posterior instability at the adjacent segment level was observed. In conclusion, an increase in strain in the adjacent segment facet joint and disc may result in facet joint degeneration and low back pain. An understanding of the change in instability in the adjacent segment level and preventing facet joint hyper mobility should aid the development of new dynamic implant designs and the prevention of adjacent segment disease.

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