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Original Article

The Effect of Single-Segment Unilateral Laminectomy and Facetectomy On Sheep Lumbar Spine Stability: An *In Vitro* Biomechanical Study

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Keywords: Biomechanical study; facetectomy; laminectomy; lumbar spine; spinal instability.

ABSTRACT

Objective: Decompressive spinal procedures (laminectomy, facetectomy) are performed to treat many pathologies including disk hernia, infection, tumor, and trauma. Knowing the level of instability under physiological loading can help the surgeon decide whether additional spinal fusion is required. Therefore, in this study, the biomechanical effects of unilateral and single-segment laminectomy and facetectomy on lumbar spine stability were investigated and we aimed to answer the question of whether these procedures cause lumbar spine instability.

Methods: For this study, 72 lumbar spines containing L1-L7 vertebrae were obtained from 3-4 years old female Merino sheep. The spines were classified as the control group, the unilateral single segment laminectomy group, and the unilateral single segment laminectomy + facetectomy group, and followed by biomechanical testing for compression, flexion, extension, and axial rotation. The statistical analyses were performed using IBM SPSS 21.0 (IBM Corp. Released 2012. Armonk) program. The statistical significance level was considered as $p<0.05$.

Results: There was no statistically significant difference in the measurement values except for the maximum torque of rotation between the groups ($p>0.05$). The rotation maximum torque values were different in at least one group from at least one of the other groups ($p=0.031$). The paired comparisons showed a significant difference in rotation maximum torque values only between the control group and the facetectomy group ($p=0.048$).

Conclusion: When the unilateral single segment laminectomy is combined with facetectomy, instability may occur in the lumbar vertebra against axial rotational forces.

INTRODUCTION

Decompressive spinal procedures (laminectomy, facetectomy) are performed to treat many pathologies including disk hernia, infection, tumor, and trauma. The most common decompression surgeries are facetectomy and laminectomy, with the choice of unilateral or bilateral intervention depending on the degree of stenosis.[1] The resection of lumbar posterior structures may cause iatrogenic posterior spinal structure injury and thus instability. However, studies have shown that total laminectomy increases segmental instability unless fusion is performed.[2–4] Spinal stability is essential for spinal functions. There are various definitions of spinal stability, but a widely-accepted definition still does not exist. The American Academy of Orthopedic Surgery defines spinal stability as "the capacity of the vertebrae to stay in alignment and maintain normal displacements for all physiological body movements".[5] The stability of the vertebral column is critical for bearing weight, allowing movement, and avoiding injury and pain.

Decompressive surgery is an important intervention for spinal stenosis but may cause spinal instability. In the decompression procedure, it is highly important to determine which anatomical segments are to be resected without interfering with stability. Also, knowing the level of instability under physiological loading can help the surgeon decide whether additional spinal fusion is required. Since posterior structures are preserved in unilateral laminectomy and facetectomy, they are more advantageous for instability compared to other procedures in which posterior interspinous structures are not preserved. Moreover, it has not been fully clarified to what extent it causes instability compared to a non-operated spine. Therefore, in this study, the biomechanical effects of unilateral and single-segment laminectomy and facetectomy on lumbar spine stability were investigated and we aimed to answer the question of whether these procedures cause lumbar spine instability.

MATERIALS AND METHODS

Specimens and specimen preparation

Several studies have verified that the sheep lumbar vertebra is a good biomechanical model for the human spine.[6–8] For this study, 72 lumbar spines containing L1-L7 vertebrae were obtained from 3–4 years old female merino sheep. To prepare every specimen for testing, the paraspinal muscles were completely excised, and all ligamentous components were carefully preserved, including supraspinous ligaments and the disk tissue. The spines were divided into 4 groups (18 for compression, 18 for flexion, 18 for extension, and 18 for axial rotation) to test the effect of compression, flexion, extension, and axial rotation on the stability of vertebrae following laminectomy and facetectomy. Each group was divided into 4 sub-groups, each containing 6 spines. Single-segment and unilateral (right) laminectomy at the L3-L4 level was applied to the first sub-group by keeping the facet joints intact, and this sub-group was called unilateral laminectomy (UL) group; laminectomy was applied to the second sub-group together with total facetectomy at the same level and on the same side, and this sub-group was called unilateral laminectomy-facetectomy (UL-F) group, and no decompressive procedure was applied to the third sub-group that was called the control group. In the control group, all posterior structures were preserved. Decompression procedures were applied to all groups other than the control group. After creating a defect in the lamina using burr as in the standard clinical practice, the lamina and ligamentum flavum were excised at the determined levels using a Kerrison rongeur.

Biomechanical testing

The specimens of the control group as well as other specimens prepared by laminectomy and facetectomy were subjected to biomechanical testing at the Mechanical Laboratory of Mechanical Engineering Department.

The compression tests were performed at room temperature using Shimadzu AG-IS (100 kN) axial tension-compression test system (Fig. 1). The processing speed for the compression tests was determined as 5 mm/min. For the axial rotation tests, the JINAN NDW-200 test system was used (Fig. 2). The rotation speed was 5 °/min. Before all tests, the specimens were mounted on the test apparatus with a pulling torque of 10 Newton x meters (Nm). For the compression evaluations, after the cephalic end of the vertebra was fixed to the upper jaw of the compression device and its caudal end to the lower jaw, compression was applied so that the upper and lower jaws of the device were in the same direction. For the flexion evaluations, after the cephalic end of the vertebra was fixed to the upper jaw of the compression device and its caudal end to the lower jaw, the lower jaw of the device was shifted by 7 cm towards the anterior to create an artificial flexion movement in the spine, and then compression was applied. Similarly, for the extension evaluations, after the cephalic end of the vertebra was fixed to the upper jaw of the compression device and its caudal end to the lower jaw, the

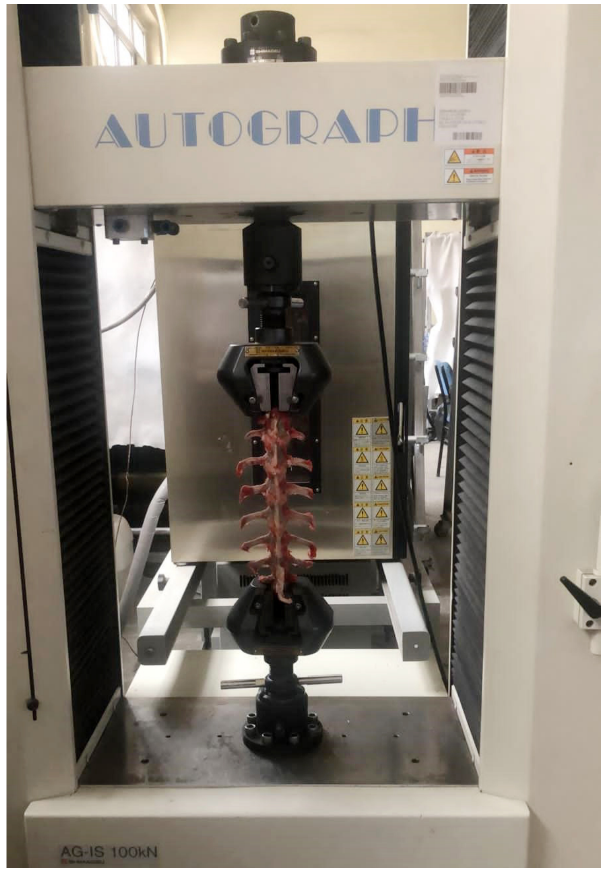

Figure 1. Compression tests system.

Figure 2. Axial rotation tests system.

lower jaw of the device was shifted by 7 cm towards the posterior to create extension movement in the spine, and then compression was applied. For the compression tests, the unit at which it started to decrease after reaching the highest compression levels in Kilo-Newton (kN) was considered as the value at which instability began, and the results were recorded by converting to Newton (N) unit. For the axial rotation tests, the value at which the highest torque level (in Nm) was reached and started to decrease was considered as the value at which instability started, and the values were recorded in Nm.

Statistical methods

The variables were summarized as the mean±standard deviation and median (minimum; maximum) values. To determine the differences between groups, the Kruskal Wallis test was used. The Mann-Whitney U test results with adjusted significance values by the number of comparisons (Bonferroni adjustment) were given for the multiple comparisons.

The statistical analyses were performed using IBM SPSS Statistics for Windows, version 21.0 (IBM Corp. Released 2012. Armonk) program. Statistical significance level was accepted as $p<0.05$.

RESULTS

In our study, the compression evaluation showed that instability started at 1899±246 N on average in the control group, at 1920±164 N in Group UL, and at 1832±132 N in Group UL-F, without a statistically significant difference (Table 1) (Fig. 3a).

The axial rotation evaluation showed the onset of instability at a mean of 3778±418 Nm in the control group, at 3702±450 Nm in Group UL, and at 3136±451 Nm in Group UL-F. The statistical evaluation revealed that the rotation maximum torque values were different in at least one of the sub-groups. ($p=0.031$) The paired comparisons showed that the difference was only between the control group and Group UL-F ($p=0.048$) (Table 1) (Fig. 3b).

The flexion evaluation showed onset of instability at a mean of 922±82 N in the control group, at 901±83 N in Group UL, and at 872±96 N in Group UL-F, with no statistically significant difference (Table 1) (Fig. 3c).

The extension evaluation showed the onset of instability at a mean of 780±63 N in the control group, at 738±61 N in Group UL, and at 681±95 N in Group UL-F. It was found that instability started earlier in the facetectomy sub-group of this group as compared to the control group, but without a statistically significant difference ($p=0.173$) (Table 1) (Fig. 3d).

DISCUSSION

Today, total laminectomy is widely applied due to spinal stenosis, vertebral canal tumors, infection, tumor, which is the standard approach in the treatment of degenerative lumbar spinal stenosis.[9,10] In a total laminectomy, when the spinous processes, the supraspinous and interspinous ligaments are excised, these posterior structures, which are highly important for spinal stability, are sacrificed. Spinal instability and deformity may occur as a result of damage to the posterior bony structure, interspinous ligament complex, and paraspinal muscles.[1,11,12] Therefore, unilateral laminectomy has been recommended to minimize iatrogenic trauma during surgery and the development of postoperative instability or deformity. The main advantages of UL include the complete preservation of posterior static structures of the vertebral column, such as the spinous processes, the interspinous and supraspinous ligaments, and the unilateral preservation of the intervertebral joints, laminae, ligamentum flavum, and paraspinal muscles. Unilateral laminectomy is widely performed in spinal surgery, especially degenerative spine disease.[13–15]

Table 1. Comparison of relevant variable values in groups

	Group			p*
	Control	UL	UL-F	
Compression max force (N)				
Mean±SD	1899±246	1920±164	1832±132	0.751
Median (min; max)	1890 (1553; 2290)	1862 (1778; 2221)	1842 (1618; 1986)	
Rotation max torque (Nm)				
Mean±SD	3778±418	3702±450	3136±451	0.031
Median (min; max)	3715 (3300; 4540)	3745 (3110; 4320)	3265 (2290; 3550)	
Flexion max force (N)				
Mean±SD	922±82	910±119	872±96	0.854
Median (min; max)	895 (837; 1065)	903 (790; 1084)	904 (726; 984)	
Extension max force (N)				
Mean±SD	780±63	738±61	681±95	0.173
Median (min; max)	772 (707; 882)	729 (659; 818)	700 (564; 818)	

*Kruskal Wallis test result. SD: Standard deviation; (min; max): Minimum; maximum.

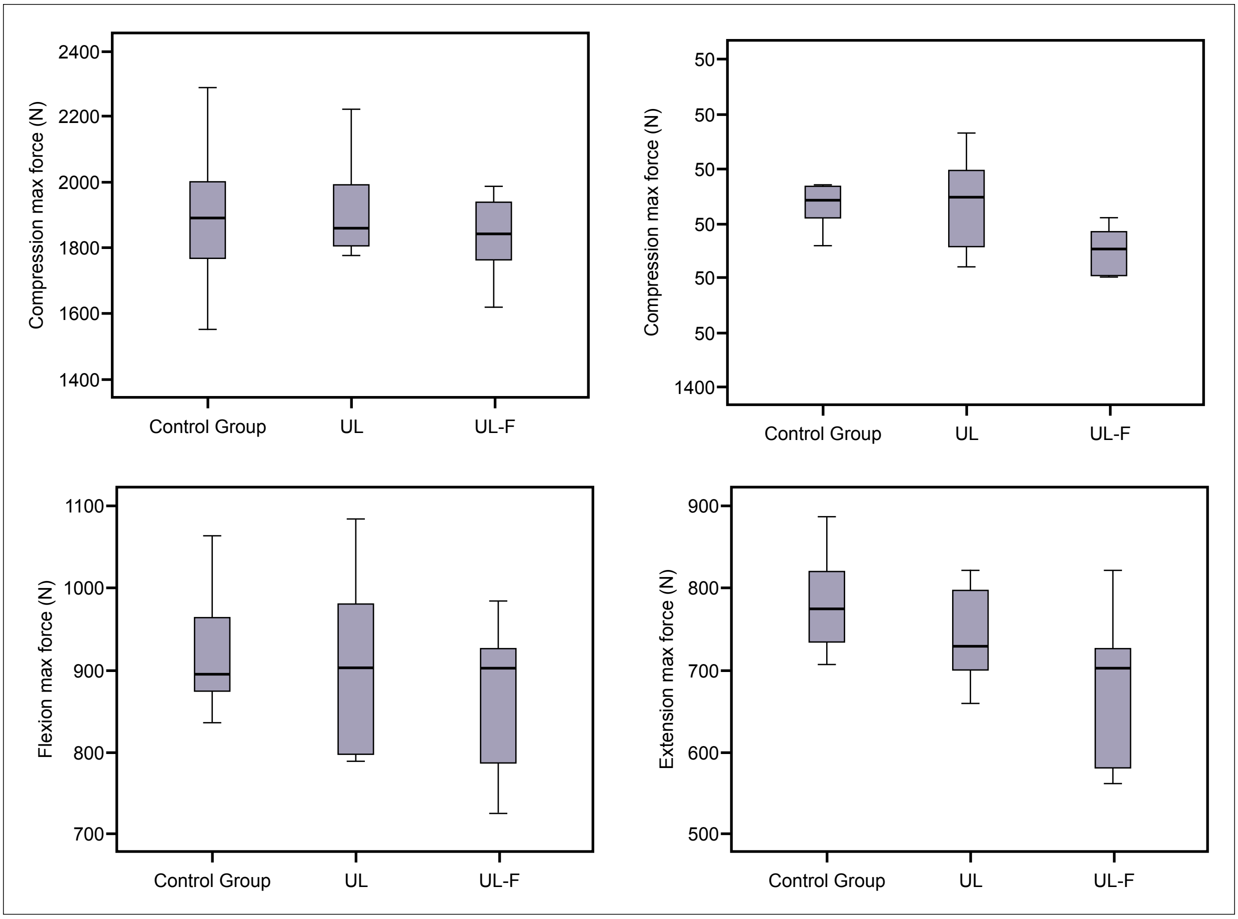

Figure 3. (a-d) Box-plot graphs for **(a)** compression, **(b)** axial rotation, **(c)** flexion and **(d)** extension.

With increasing knowledge and experience on this subject, unilateral laminectomy now also allows bilateral decompression.[16–19] Also, some authors have recommended unilateral laminectomy in the treatment of various spinal tumors.[20–23] In light of this information, we aimed to examine the effects of unilateral laminectomy procedure on spinal stability, which seems to have many advantages for spinal stability. At the end of the study, we concluded that despite the complete removal of the ipsilateral facet joint in unilateral laminectomy, there was no instability formed over the spine for compression, flexion, extension forces. revenge.

We think that this is associated with the positive effect of the preservation of the posterior bone structure, supraspinous and interspinous structure on stability, as frequently specified in the literature. Similarly, we found that unilateral laminectomy without facetectomy caused no instability for axial rotation forces. However, we found that in the combination of unilateral laminectomy and facetectomy, axial rotation forces significantly impaired stability compared to the control group. Consistent with our study, total facetectomy has been many times associated with the development of instability against axial rotation forces of the spine.[24–26] The experimental study by Kiapour et al.[27] showed that partial facetectomy has a minimum effect on the kinematics of the relevant segment among all loading cases except for axial rotation. However, when the facets were removed, the segmental motion was significantly increased in axial rotation. Similarly, Zhou et al.[28] performed in vitro unilateral graded facetectomy on 5 cadavers and found no significant negative effects on the range of extension and flexion. However, they stated that if the range of graded facetectomy exceeded 50%, spinal stability was significantly affected under axial rotation. As a part of the three-column structure of the vertebral column, the facet joints play a key role in maintaining the stability of spine motion. Due to their morphological characteristics, they transmit the load along the spinal column and restrict the movement of the vertebrae, especially in the rotation direction.[29] The resection of a large part or all facet joints may cause postoperative instability and spondylolisthesis because the medial direction of the facets plays a key role in preventing translational motion in the lumbar spine.[30] The study designed by Erbulut[24] with the finite element method reported that complete removal of the facet significantly increased the range of motion of the joint due to axial rotation. Abumi et al.,[31] in their in vitro study, reported that the ROM gradually increased for axial rotation as the degree of facetectomy increased.

We conducted our study in vitro using sheep lumbar spine materials. In vitro studies are the standard technique for analyzing the effect of decompressive procedures on the lumbar spine. The large differences in the geometric and mechanical properties of cadavers are a problem for the use of human cadaver specimens in vertebral biomechanical studies. In addition, the number of human cadaver specimens is limited, individual differences in anatomy are significant, and most specimens are obtained from elderly individuals with variable bone quality.[32] For this reason, most of the in vitro studies have been performed on animal vertebrae, which are easier to obtain and have more regular geometric and mechanical properties.[33,34] Many studies in the literature have shown striking similarities between the human spine and the animal spine.[6,35] Studies have shown that the sheep lumbar spines have similar biomechanical properties to the human lumbar spine and their mechanical properties are comparable, enabling them to be used as alternative models of the human lumbar spine.[6,7]

Our study had some limitations. Firstly, although the literature suggests that the sheep lumbar spine is a good biomechanical model for the human spine, it is impossible to say that our results will overlap with the human spine. Secondly, we performed our biomechanical study by removing muscles from the sheep lumbar spine (L1-7) segment and preserving all supraspinous ligaments and disc tissue. However, the biomechanical behavior of the non-segmental total vertebral column not separated from the muscles may have different results. Therefore, supporting our study with similar studies will enhance its contribution to the literature.

Consequently, in this biomechanical study, we concluded that unilateral laminectomy procedure without facetectomy applied to the sheep lumbar spine has no significant effect on stability. We found that when decompression is combined with excision of the ipsilateral facet join, then compression, flexion, and extension forces have no significant effect on stability, but stability cannot be maintained for axial rotation forces. In the light of this information, the excessive resection of the facet joints during spinal surgery should be avoided, and the need for posterior fusion should be questioned considering the extent of resection and patient-specific conditions. In this study, only biomechanical aspects have been taken into account, but clinical experiences are also highly important. With the joint effort of surgeons and biomechanical engineers, individual optimal treatment options may be created for particular patients.

Informed Consent

Prospective study.

Peer-review

Internally peer-reviewed.

Authorship Contributions

Concept: A.Ş.; Design: A.Ş.; Supervision: A.Ş.; Fundings: E.D.; Materials: E.D.; Data: S.O.; Analysis: S.O.; Literature search: E.D.; Writing: A.Ş.; Critical revision: E.D.

Conflict of Interest

None declared.

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Tek Segment Unilateral Laminektomi ve Fasetektominin Koyun Lomber Omurgasında Stabiliteye Etkisi: *In vitro* Biyomekanik Çalışma

Amaç: Omurganın dekompresif prosedürleri (laminektomi, fasetektomi) disk hernisi, enfeksiyon, tümör ve travma dahil olmak üzere birçok patoloji için gerçekleştirilir. Fizyolojik yükleme altındaki instabilite düzeyini bilmek, cerrahın ek spinal füzyonun gerekli olup olmadığına karar vermesine yardımcı olabilir. Bu nedenle bu çalışmada unilateral ve tek segment laminektomi ve fasetektominin lomber omurga stabilitesine biyomekanik etkileri araştırıldı ve bu prosedürler lomber omurga instabilitesine neden olur mu sorusuna cevap vermeyi amaçladık.

Gereç ve Yöntem: Bu çalışma için Merinos cinsi 3–4 yaşında dişi koyun lomber omurgalarından L1-L7 vertebraları içerecek şekilde 72 adet elde edildi. Kontrol grubu, unilateral tek segment laminektomi grubu ve unilateral tek segment laminektomi+fasetektomi şeklinde gruplandırılan vertebralar kompresyon, fleksiyon, ekstansiyon ve eksenel rotasyon açısından biyomekanik teste tabi tutuldu. İstatistiksel analizler IBM SPSS 21.0 (IBM Corp. Released 2012. Armonk) programı ile yapıldı. İstatistiksel anlamlılık düzeyi $p<0.05$ olarak kabul edildi.

Bulgular: Rotasyon maksimum tork dışında diğer ölçümlerde gruplar arasında istatistiksel olarak anlamlı düzeyde fark yoktur ($p>0.05$) Rotasyon maksimum tork değerleri en az bir grupta diğer grupların en az birinden farklıdır ($p=0.031$). Yapılan ikili karşılaştırmalar sonucunda; yalnızca kontrol ile fasetektomi grubu arasında Rotasyon maksimum tork değerleri açısından anlamlı düzeyde fark belirlenmiştir ($p=0.048$).

Sonuç: Tek taraflı ve tek segment laminektomiye fasetektomi eklenmesiyle eksenel rotasyon kuvvetlerine karşı lomber vertebrada bir instabilite oluşabilmektedir.

Anahtar Sözcükler: Biomekanik çalışma; fasetektomi; laminektomi; lomber vertebra; spinal instabilite.