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Comparison of rigid and semi-rigid instrumentation under acute load on vertebrae treated with posterior lumbar interbody fusion/ transforaminal lumbar interbody fusion procedures: An experimental study

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Abstract

Rigid and semi-rigid fixations are investigated several times in order to compare their biomechanical stability. Interbody fusion techniques are also preferable for maintaining the sagittal balance by protecting the disk height. In this study, the biomechanical comparison of semi-rigid and rigid fixations with posterior lumbar interbody fusion or transforaminal lumbar interbody fusion procedures is conducted under trauma. There were four different test groups to analyze the effect of acute load on treated ovine vertebrae. First and second groups were fixed with polyetheretherketone rods and transforaminal lumbar interbody fusion and posterior lumbar interbody fusion cages, respectively. Third and fourth groups were fixed with titanium rods and posterior lumbar interbody fusion and transforaminal lumbar interbody fusion cages, respectively. The drop tests were conducted with 7 kg weight. There were six samples in each group so the drop test repeated 24 times in total. The test samples were photographed and X-rayed (laterally and anteroposteriorly) before and after drop test. Two fractures were observed on group 1. Conversely, there were no fractures observed for group 2. There were no anterior element fractures for both groups 1 and 2. However, one fracture seen on group 3 was anterior element fracture, whereas the other three were posterior element fractures. All three fractures were anterior element fractures for group 4. Treated vertebrae with polyetheretherketone rods and posterior lumbar interbody fusion cages showed the best durability to the drop tests among the groups. Semi-rigid fixation gave better results than rigid fixation according to failed segments. Posterior lumbar interbody fusion cages seem to be better option for semi-rigid fixation, however mentioned surgical disadvantages must be considered.

Keywords

Semi-rigid fixation, rigid fixation, posterior lumbar interbody fusion, transforaminal lumbar interbody fusion, polyetheretherketone rod, posterior fusion, drop mechanism, fracture energy, compression load, load sharing

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Introduction

There are different types of instrumentation for lumbar interbody fusion used in spine surgeries. Lumbar interbody fusion techniques may increase the loading capacity of spine, recover the missing disk height, restore the sagittal balance and distribute the loads applied to the vertebrae.[1] Posterior lumbar interbody fusion (PLIF), transforaminal lumbar interbody fusion (TLIF), anterior lumbar interbody fusion (ALIF) and extreme

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lateral interbody fusion (XLIF) are mostly used ones among anterior interbody fusion methods. Between those fusion techniques TLIF and PLIF are the most common ones.[2–5] Researchers indicate that there is no significant difference between TLIF and PLIF when surgical outcomes are compared.[2,5,6] In addition, most of the studies agreed on some disadvantages of PLIF.[2,7–9] Most mentioned disadvantages of PLIF can be listed as increased operation time, nerve root injury and blood loss. Furthermore, a finite element study of TLIF[4] stated the increased biomechanical stability and decreased stress at the cage endplate interface. However, they indicated also the increment of screw stress as a disadvantage of TLIF. Consequently, a review summarized those controversial circumstances by emphasizing the usage of TLIF and PLIF.[10] When there is a single-sided pathology, TLIF can be more proper, whereas for bilateral compressions PLIF can be preferable.

PLIF and TLIF cages are used for fusion surgeries. For the purpose of fusion, it is also important to choose the stabilization system, since the rigidity of the spine changes by the instrumentation technique. Rigid and semi-rigid systems are commonly used to stabilize the spine.[11–14] Titanium (Ti) rods are preferred for rigid fixation, whereas polyetheretherketone (PEEK) rods are chosen for semi-rigid fixation. Rigid fixation with titanium rods increase the stiffness of the fixed segment much more than desired. In that case, PEEK rods are advantageous with their stiffness property, which stays between the intact spine and spine fixed with rigid fixation. For this reason, titanium rods are slowly replaced by the PEEK rods, which provide more flexibility to spine by distributing the unbalanced loads caused by fused segment.[12–17] There are several studies which compare the biomechanical properties of the stabilization systems when constructed via Ti or PEEK rods.[15–18] While some studies emphasize no significant difference between the groups (Ti vs PEEK),[15,18] others refer advantages of the PEEK rod usage.[16,17] Patients treated with PEEK rods were subjected to a questionnaire based upon the clinical outcomes.[19] This questionnaire mentioned about the decrement of pain and revision surgery and increment of comfort when PEEK rods were used. In addition, biomechanical test results of segments treated with PEEK rods showed that they increase the anterior column load sharing and decrease the stress at bone to screw interface.[20] In the same manner, a finite element study about PEEK rod usage indicated that they allow less compressive load transmission to the pedicle screws.[21]

There were studies which separately compare TLIF versus PLIF procedures and rigid versus semi-rigid rod systems. However, there was not any study in the literature which compares these systems' biomechanical behaviors together. In addition, TLIF and PLIF procedures were only compared in order to their surgical outcomes. The aim of this study was to biomechanically compare the rigid and semi-rigid fixations with PLIF or TLIF procedures under trauma. In this study, four groups were prepared as follows; titanium rod used with either TLIF or PLIF and PEEK rod used either with TLIF or PLIF. Then, to simulate the trauma condition, a drop mechanism designed by Özkaya et al.[22] is used. To the knowledge of authors, this was the first study that investigates the biomechanical effects of TLIF/PLIF procedures on ovine vertebrae with both titanium and PEEK rods under acute loading condition.

Table 1. Groups with used materials.

Groups	Instrumentation and procedure
Group 1	PEEK rod + TLIF
Group 2	PEEK rod + PLIF
Group 3	Titanium rod + PLIF
Group 4	Titanium rod + TLIF

PEEK: polyetheretherketone;
TLIF: transforaminal lumbar interbody fusion;
PLIF: posterior lumbar interbody fusion.

Materials and methods

Embedding medium

In total, 24 lumbar ovine vertebrae, supplied from Turkish Meat and Milk Board, were used as embedding medium. The healthy ovines which satisfy the healthy condition ($T > -1$) were chosen to obtain the vertebrae. Surrounding tissues were dissected carefully from specimens where it was required such as the placement of the pedicle screw-rod systems. Besides, a careful discectomy was conducted on the fixation segment of the spine for the TLIF and PLIF procedures. All of the specimens underwent L4-L5 instrumentation by leaving the upper two levels and lower one level without any instrumentation.

Test groups

Four different test groups, seen in Table 1, are designed in order to investigate the effect of sudden loads on the treated vertebrae. After a careful discectomy, TLIF procedure with unilateral facetectomy and laminectomy was applied on groups 1 and 4. However, PLIF procedure with bilateral hemilaminectomy following the discectomy was performed to the groups 2 and 3. After placement of TLIF/PLIF, the vertebrae were fixed via PEEK rods for groups 1 and 2 and via titanium rods for groups 3 and 4. Table 1 shows the groups with the aid of materials used for fixation.

For each group, six specimens were prepared. Pedicle screws used for fixation had 4.0-mm outer diameter and 30-mm length and rods had 6-mm diameter. Rigid titanium (TI6A14 V) and PEEK rods were used.

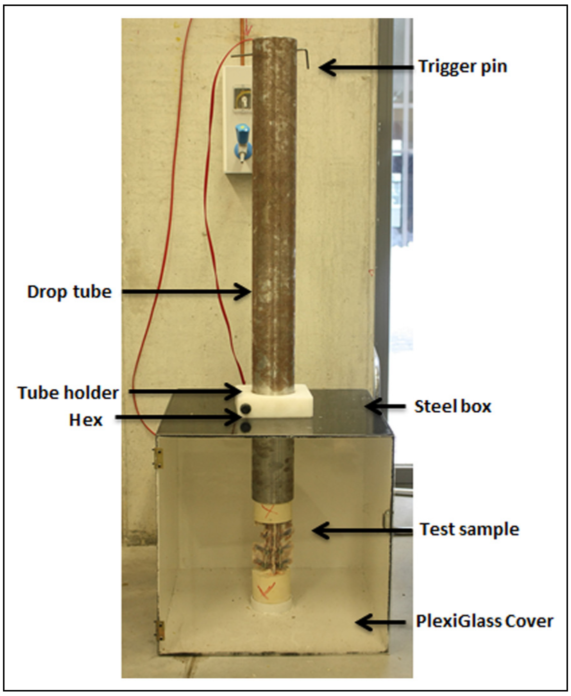

Figure 1. Drop mechanism.

TLIF and PLIF cages were made from PEEK and had 4.0-mm height and 10-mm length.

Imaging

Anteroposterior (AP) and lateral radiographs were taken from each specimen both before and after drop tests with the help of Shimadzu (Japan) RAD speed X-ray machine placed in the Yenimahalle Education and Research Hospital, Ankara. In addition, detailed photographs of segments were taken also before and after the tests. Both the photographs and X-rays were used later to determine the fractures of the vertebrae.

Drop tests

Before the drop tests were conducted, the vertebrae were held for 24 h in physiological saline solution at room temperature. A free-fall drop mechanism, designed before by Özkaya et al.,[22] was used to simulate a compression load generating trauma. Figure 1 shows the mechanism of the drop test.

The drop mechanism has a steel box and a drop tube as main components. The chassis of the mechanism is the steel box. The specimens were situated in the middle of this box. The drop tube is associated with the steel box by a tube holder. A hex is used to tighten the tube to adjust the tube's position. Before the test, the weight is held in a specific height by a trigger pin. To start the test, the weight is released by pulling the trigger pin. Then, the test sample is subjected to the sudden load, when the weight is crashing onto the sample. In addition, the steel box is covered with a Plexiglas to secure the test area.

The impact energy delivered by the crash depends on the weight and drop height. Özkaya et al.[22] conducted the drop tests with different weights on the specimen individually in order to compare their theoretical impact energy values. They observed fractures on specimens only with the energy value provided by 7 kg and set 7 kg as critical weight to create fractures. Therefore, the drop tests were conducted only with 7 kg. The weight was released from 1-m height with the help of the trigger pin, so that test samples are exposed to impact energy. Speed sensors were used to determine the velocity of the weight immediately prior to the crash. The measured velocity was 4.3 ± 0.2 m/s. The impact value measured with this velocity was 64.71 J. After the drop tests, failures occurred at the fixed segments were carefully investigated and classified either posterior or anterior element fractures. Afterward, stability conditions of the treated vertebrae were determined due to the fractures.

Results

The specimens were divided into two groups as failed or not in order to fracture occurrence. Two specimens had fractures out of six specimens for group 1. In group 2, all specimens were solid after drop test. However, four samples had major fractures out of six samples for group 3. And, half of the specimens were broken for group 4. Fractures of the vertebrae were determined with the help of both radiographs and photographs of the specimens. Specification of fractures is given in Table 2. For group 1, both fractures occurred at facets of the fixed vertebrae, which can be named as posterior element fractures. Posterior element fractures can be seen in Figure 2.

However, three out of four fractures were posterior element fractures, whereas one was anterior element fracture with endplate fracture for group 3. In addition, those three posterior element fractures were pedicle and facet fractures. Finally, in group 4, all three fractures can be classified as anterior element fractures. An anterior element fracture example can be observed in Figure 3.

For group 4, not only all the fractures were anterior element fractures but also two of those fractures can be declared as major fractures. Figure 4 shows one of those major fractures. In this fracture, treated vertebra was divided into two from the vertebral body where the screws pass through and it was held only by the spinal cord. As mentioned above, there was not any fracture observed for group 2. AP and lateral radiographs from one of the samples of group 2 can be seen on Figure 5.

Discussion

TLIF and PLIF procedures are widely used to deal with degenerative disk disease. Hence, their surgical outcomes are important for researchers. Some of the

Table 2. Detailed information about failed segments of groups.

	Number of failed specimen	Anterior or posterior	Specification of the fracture
Group 1	2	Posterior	Facet (Type A.3.2.1)
Group 2	None	–	–
Group 3	4	One anterior and three posterior	Endplate (Type A1.1), Pedicle and Facet (Type A.3.2.1)
Group 4	3	Anterior	Endplate (Type A1.1)

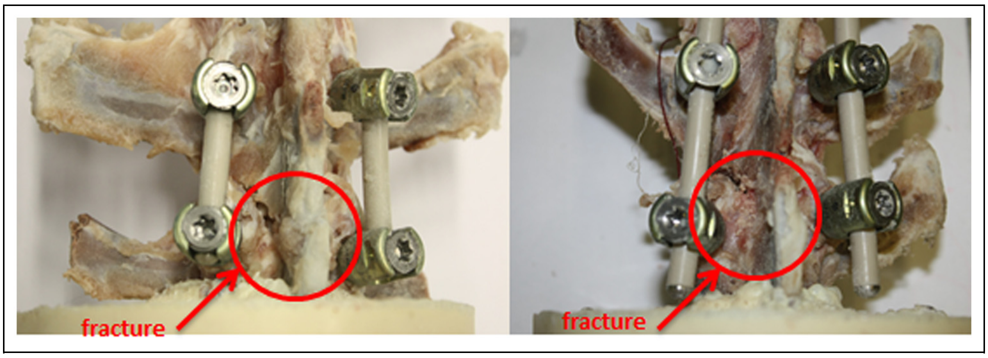

Figure 2. Examples for posterior element fractures of the group 1.

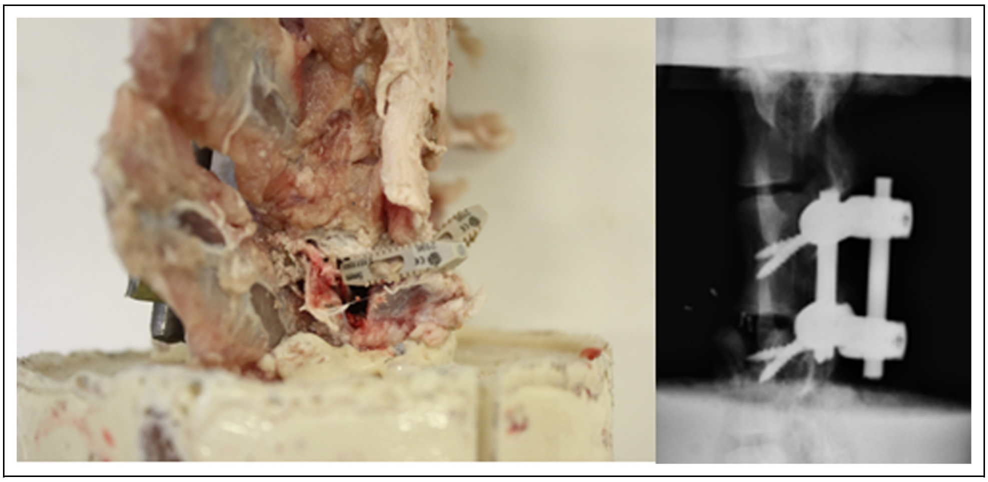

Figure 3. Example for anterior element fractures: an endplate fracture occurred in group 3.

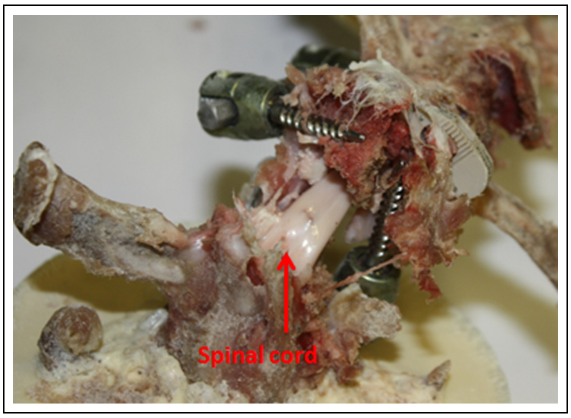

Figure 4. Major fractures of group 4.

researches believe that there is no significant difference between TLIF and PLIF applications. Although, others agreed on some surgical difficulties of PLIF such as blood loss and more operation time.

After choosing the interbody fusion technique, the desired segment of spine is fused via pedicle screws and rods. Rigid systems are still being used frequently, as they are advantageous with their fast fusion times. However, high rigidity of the fixed segment may cause fractures and/or adjacent segment disease in time.[23–26] In addition, PLIF and TLIF usage increases the rigidity of the spine, which is an undesirable condition;[27] therefore, semi-rigid and dynamic systems are becoming more preferable. Those systems decrease the loads transmitted to healthy vertebrae especially for acute

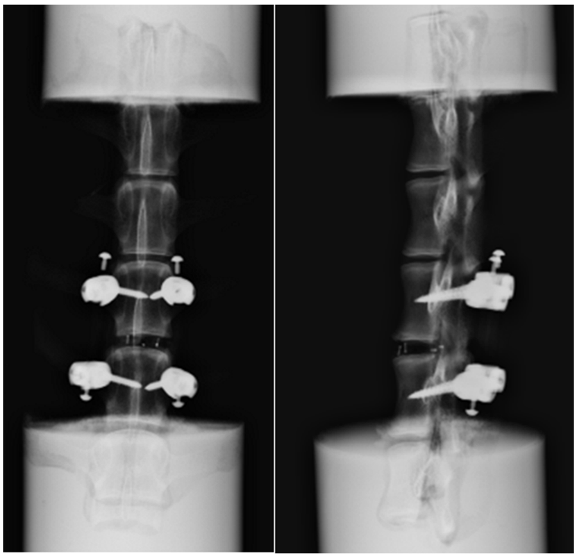

Figure 5. Radiographs of the sample 1 from group 2.

loading conditions.[22] PEEK rods used for semi-rigid fixation are elastic and allow limited motion to the fixed segment. Thus, they provide more homogeneous transition between the treated and untreated spine.

This study clarifies the responses of those mentioned systems, implemented on animal cadavers, under an acute load condition. Ovine vertebrae were prepared with PLIF/TLIF and titanium/PEEK rod constructs. A drop test mimicking the sudden load mechanism was conducted after preparation of specimen. Acute load mechanism on vertebrae was used before from several researchers.[28,29] For instance, Panjabi et al.[28] investigated the trauma conditions on human thoraco-lumbar vertebrae. In their study, they released 6.8 kg from 1.4-m height with the energy value of 94.2 J to create a fracture. Furthermore, Kallemeier et al.[29] let 6 and 8 kg fall from 1.5-m height by originating 88.2 and 117.7 J, respectively. In this study, 7 kg was dropped on to the vertebrae from 1-m height by causing 68.67 J.

After drop tests, lateral and AP radiographs and photographs were taken likewise before the tests. Those images then were compared to investigate and classify the fractures occurred in the treated segments. Two, four and three fractures were observed for groups 1, 3 and 4, respectively.

Rigid, dynamic and semi-rigid systems under acute loading conditions were previously investigated as mentioned above.[22] In Özkaya et al.'s[22] study, it is stated that for rigid system, fractures were observed in the pedicle and corpus where screw was inserted. They observed less vertebrae failures on fixed and adjacent segments when fixation was constructed via PEEK rods. Our study also claims that groups with PEEK rods were more durable after drop tests compared to groups with titanium rods. In fact, there was no fracture or failure of implants in group 2.

Moreover, there were anterior element fractures in groups treated with titanium rods, and this may be a proof for that rigid fixation has higher rigidity. By rigid fixation, posterior column becomes much more rigid than anterior column of the spine. Due to this higher rigidity of the posterior column, the anterior column is much more likely to be fractured. This explains why anterior column fractures were observed in groups 3 and 4. Conversely, PEEK rods allow the load to disperse smoother.

The fractures of anterior column in groups 3 and 4 can be classified as Type A1.1 fractures according to classification made by Magerl et al.[30] Also, Type A.3.2.1 posterior column fractures were observed in groups 1 and 3.

Furthermore, the biomechanical properties of TLIF and PLIF procedures are tested for the first time in this study. A finite element study about TLIF[4] mentioned that TLIF usage increases biomechanical stability and decreases stress at the interface between TLIF and endplate. However, TLIF increased the screw's stress. This is consistent with our results. If the stability of groups 1 and 2 with peek rods are compared, the group with PLIF showed higher stability than group with TLIF. This means when the rod allows more flexibility to the segment, TLIF's disadvantage is observable. On the other side, when the fixation is made via titanium rods, TLIF provided more durability to acute load than PLIF procedure.

Consequently, the drop test results of this study showed that the fractures occurred in the rigidly fixed vertebrae applied with TLIF or PLIF procedure. In addition, there were fractures in semi-rigid fixation applied with TLIF procedure. No fracture was seen in semi-rigid fixation with PLIF. According to these results, it can be said that semi-rigid fixation may decrease stress origination at the fixed system by providing a smooth load transition and treating the desired segment of spine. In addition, it is suggested that PLIF and TLIF procedures should be chosen in order to fixation type. PLIF may be better for fixation with PEEK rods, however; TLIF procedure may be superior for rigid fixation. To understand the mechanism of failure under acute loads clearly, the finite element simulations can be performed as further investigations. Finite element simulations can give comprehensible results about the response of the rigid and semi-rigid fixations with TLIF or PLIF procedures under trauma. Moreover, more measurements, such as force, displacement and strain, will be performed and high-speed cameras will be used to understand failure mechanisms for further studies.

Limitations

There was not enough number of test specimens to conduct statistical analysis. In further studies, statistical analysis may be performed with enough number of specimens to compare the study groups.

The vertebral dimensions of tested specimens were not evaluated because dissection of the specimens' soft tissues and cutting the vertebral bodies were needed to measure the anatomical dimensions of the vertebra. However we wanted to see the biomechanical performances of the fixed vertebrae with its soft tissues without dissection. The dissection of soft tissues was only made in the portions where required.

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Declaration of conflicting interests

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