# Experimental Evaluation of the Developmental Mechanism Underlying Fractures at the Adjacent Segment

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■ BACKGROUND: **Compression fractures at adjacent mobile segments have been reported as adjacent segment disease under trauma in several studies. In this study, the occurrence of fractures at the adjacent segment was evaluated experimentally under trauma.**

■ METHODS: **Static testing of different fixation systems was performed to show their biomechanical performances. The ovine vertebrae fixed with rigid, dynamic, and semirigid systems were used as test samples. The stiffness values of the systems were obtained by testing the vertebrectomy models under compression bending, lateral bending, and torsion tests. In addition, their effects on the adjacent segments were experimentally evaluated within a drop mechanism. A free-fall drop mechanism was designed and manufactured. Next, 3.5-kg, 5-kg, and 7-kg weights were released from 1 m above the test samples to generate compression fractures. The occurrence of compression fractures was observed with the use of radiograph of test samples, which were obtained before and after the drop test.**

■ RESULTS: **Dynamic and semirigid systems have advantages compared with rigid systems as the result of their lower stiffness values. Radiographs showed that epiphysis fractures occurred at fixed and adjacent mobile segments, which were fixed with semirigid fixation. In addition, dynamic fixation well preserved the fixed and adjacent mobile segments under trauma.**

■ CONCLUSIONS: **The dynamic system with a polyetheretherketone rod can better preserve both adjacent and fixed segments. However, because of the cantilever beam effect, the semirigid system exhibits a great disadvantage.**

## INTRODUCTION

In recent decades, posterior stabilization of the thoracolumbar spine with pedicle screws and rods has become the standard treatment for treating degenerative spinal disorders, segmental instability, or trauma. Posterior stabilization provides short-term satisfactory clinical results, with high rates of arthrodesis and pain relief advantages.[1-4] However, adjacent segment complications have been reported in the long term.[2,4] Complications that occur at the adjacent mobile segment above or below a spinal stabilization region are called adjacent segment disease (ASD). Furthermore, disk degeneration,[3,5,6] listhesis,[7,8] instability, stenosis,[7-9] herniated disks,[9,10] scoliosis,[7] osteophyte formation,[11] and compression fractures[7,12-15] are recognized as ASD, and revision surgery may be essential in the occurrence of ASD.

The underlying reason for the occurrence of ASD is not precisely known.[2,4,16] Altered biomechanical loading conditions and the kinematics of the spine after arthrodesis have been proposed to have a significant effect on ASD.[2,4,17-21] Spinal stabilization with rigid systems increases the stiffness of the stabilized region. The greater rates of stiffness directly decrease the range of motion. This rigid area obliges the nonstabilized regions to increase their range of motion to bare the decrement on the adjacent segment.[17-21] Changes in the range of motion affect the load distribution on mobile segments and facet joints.[17-21] In addition, disk pressure

**Key words**
- Adjacent segment disease
- Compression fracture
- Drop
- Dynamic fixation
- Rigid fixation
- Semirigid fixation

**Abbreviations and Acronyms**
**ASD**: Adjacent segment disease
**PEEK**: Polyetheretherketone

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increases with abnormal loading conditions at adjacent segments.[22] These 2 main abnormal loading conditions eventually cause ASD in the long term. Cheh et al.[11] investigated the long-term radiographic results of 188 patients and reported that radiographic ASD had developed in 42.6% of rigidly stabilized patients. Clinical ASD was 30.3% among these patients.

To prevent the aforementioned disadvantages of rigid stabilization, dynamic and semirigid fixation devices, which either have less rigidity or enable a specific, greater range of motion at the fixed segments, were developed. It is proposed that the use of dynamic or semirigid systems may prevent ASD. Several studies have investigated the clinical and biomechanical performance of dynamic and semirigid fixation systems at adjacent segments.[23-33] Only Stoll et al.[32] and Fay et al.[26] reported that semirigid and dynamic systems prevent ASD; however, most of these studies concluded that the performance of semirigid and dynamic systems in preventing ASD was either less or the same as rigid systems.[21-23,33] It is understood that further investigations and long-term follow-up are necessary to understand the effects of semirigid and dynamic systems.

Furthermore, vertebral body fractures may occur at the adjacent segments, although the prevalence is rare. In contrast to other adjacent segment problems, fractures generally are observed in acute loading conditions rather than over the long term. Fractures are the result of high-energy traumas for both healthy and osteoporotic bone cases. It is obvious that lower energy levels also may cause fractures in osteoporotic cases.

In the study by Etebar and Cahill,[7] 125 patients were treated with posterior rigid stabilization. Symptomatic ASD developed in 18 of the cases. In addition, 15 of 18 patients were postmenopausal women, and 28% of the ASD patients were reported as having compression fractures of the vertebral bodies. Kim et al.[13] investigated the proximal adjacent segment problems of more than 4 levels of rigid fixation. The patients suffered from adult lumbar spinal deformity. After a minimum of 2 years of follow-up, it was reported that 15 of 35 patients had developed ASD at the proximal segments. Two of 15 cases were vertebral compression fractures for this research domain.

Yang et al.[14] reported that all 18 patients who had been treated previously with lumbar circumferential rigid stabilization had undergone revision surgery because of osteoporotic vertebral compression fractures adjacent to the fixed segments. Toyone et al.[15] evaluated the long-term vertebral compression fracture developments of rigid spinal fixation patients. Next, 100 patients who were a minimum 55 years of age were treated with rigid spinal fixation, and all of the instrumentations were less than 4 levels. During a mean 10.2 years of follow-up, vertebral compression fractures occurred in 21 vertebrae within 15 patients. Furthermore, 14 of 15 patients were women. In studies performed by Kim et al.,[12] it was reported that vertebral body compression fractures developed in 25 patients who were treated with rigid spinal fixation. Some of these patients reported that they had slipped down. Fractures occurred at a mean of 47 months of follow-up.

Yasuhara et al.[34] showed that after a 4-level fusion in the lumbar vertebrae, a pedicle fracture might occur at the proximal instrumented level. They also reported that after a pedicle fracture, endplate fractures may occur at the first adjacent segment of the pedicle fracture.

In this study, the development of vertebral fractures at the adjacent segments after early-stage trauma was evaluated experimentally on ovine vertebrae with instrumentation. It is proposed that fractures at the adjacent segments after trauma may be caused by the high rigidity of the instrumentation: the stiffer the instrumentation, the greater the risk of the fracture at adjacent segments. These fractures may be prevented by the use of a fixation system that is more flexible and enables a greater range of motion at the fixed segments. More specifically, it is proposed that changing the stiffness of the fixation gradually is the key point for the prevention of fractures.

Three different fixations, rigid, dynamic, and semirigid, were tested, and their effects on the adjacent segment under trauma were investigated experimentally. To the best of the authors' knowledge, this is the first study that evaluates vertebral fractures at adjacent segments to the instrumentation site under trauma loading conditions. In addition, the fracture types at the adjacent level may be compression, endplate, and sagittal split fractures. Although sagittal split fractures at the adjacent level have not been reported, it is thought that they may occur after early stage trauma.

## MATERIALS AND METHODS

Rigid, dynamic, and semirigid pedicle screw-rod systems were used as the fixation systems. Pedicle screws (Osimplant Ltd., Ankara, Turkey) with a 5.5-mm outer diameter and 35-mm length and rods with a 5.5-mm diameter were used. Rigid titanium alloy (Ti6Al4V), polyetheretherketone (PEEK), and Isobar TTL Semi-Rigid Rod System (Ti6Al4V; Scient'x, Bretonneux, France) rods were used in the rigid, dynamic, and semirigid fixation systems, respectively.

Static tests were performed on the stabilization systems to determine the stiffness values under bending and torsion. Stiffness also may be called the rigidity of the system. Compression bending, lateral bending, and torsion tests were implemented on the vertebrectomy models to determine the stiffness values under each loading conditions. A drop test was also performed for the ovine samples.

### Compression Bending Test

One of the main loading conditions for the spinal stabilization unit is the flexion/extension moment and axial compression. To understand the physics underlying the fixation systems, compression bending tests are essential. First, vertebrectomy models were prepared for the compression tests according to ASTM F1717.[35] The compression bending test setup is shown in **Figure 1A**. The Instron 3300 (Instron, High Wycombe, United Kingdom) Compression-Tension Test Frame was used for the compression bending tests. Next, the axial load was applied to the samples by use of the instantaneous motion center. The crosshead speed was constant and 2 mm/min. The load versus displacement curves for each sample was recorded during the tests. The stiffness of a sample under compression was calculated by the slope of the linear elastic portion of the load versus displacement curve. Compression tests were repeated 5 times to obtain statistically meaningful results for each test group for different stabilization types.

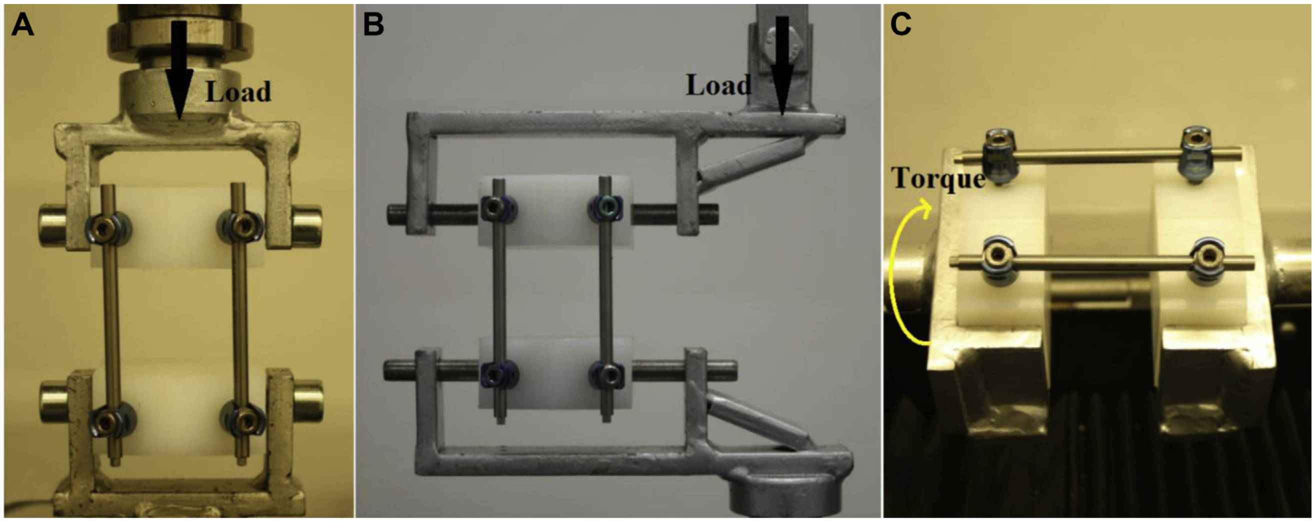


**Figure 1.** Test setups. (**A**) Compression bending, (**B**) lateral bending, and (**C**) torsion.

### Lateral Bending Test

The second important loading condition to the stabilized spinal unit is lateral bending. The system response to lateral bending conditions is crucial to understand the mechanical advantage of the fixation system. Lateral bending tests were performed to state the current position of the fixation systems under lateral bending loads. Previously described vertebrectomy models also were used in lateral bending tests. The test frame for the lateral bending test was the same as the compression bending test. However, in addition to compression bending tests, a moment arm was used to generate a moment for the lateral bending tests. The moment arm was set at 100 mm from the instantaneous motion center to the load application point. The crosshead speed was constant and 2 mm/min. The lateral bending test setup is shown in Figure 1B. The load versus displacement curves for each sample was recorded during the tests. The stiffness of the sample under lateral bending was also calculated by the slope of linear elastic portion of the load versus displacement curve. Lateral bending tests also were repeated 5 times to obtain statistically meaningful results for each test group for different stabilization types.

### Torsion Test

The last critical loading condition is the rotation of the stabilized spinal unit. The fixation systems also are limiting to the rotation motion. To compare the fixation systems, a torsional performance comparison is also crucial. Torsion tests were performed according to the ASTM F1717.[35] Instron 55MT Micro Torsion Test Frame (Instron) was used in the torsion tests. Torque was applied with a constant tumble angle of 2°/second. The torque versus angle curves for each sample was recorded. The torsional stiffness of the sample was calculated by the slope of the linear elastic portion of the torque versus angle curve. The torsion test setup is shown in Figure 1C. Torsion tests also were repeated 5 times to obtain statistically meaningful results for each test group for different stabilization types.

After we obtained the average stiffness and standard deviation values of the groups, statistical evaluation was performed with a 2-paired Student's *t* test (Excel 2010; Microsoft Corporation, Redmond, Washington, USA). If the *P*-value was less than 0.05, then the difference was considered to be statistically significant.

Compression tests, lateral bending tests, and torsion tests all were quasi-static loading condition tests. The focus of this study was the trauma (acute loading) conditions. The aim of performing such tests was to determine the stiffness values of the different systems. This study's main hypothesis was to determine the effect of the drastic stiffness differences between fixed and adjacent to fixed segments.

To understand the effect of stiffness changes on the vertebral fractures adjacent to the stabilized spinal segments after trauma, drop tests were performed on the ovine vertebrae fixed with the use of several fixation systems.

### Drop Test

To simulate a compression load-generating trauma, a free-fall drop mechanism was designed and manufactured. Panjabi et al.[36] designed and tested a drop test mechanism, which inspired our design. The designed and manufactured drop mechanisms are shown in Figures 2A and B. The drop mechanism consists of 2 main components, a steel box and drop tube. The steel box is the chassis of the mechanism, and the test samples were placed into the box. The drop tube was attached to the steel box with the use of a tube holder. The tube position was adjustable by tightening the tube holder using a hex. First, a trigger pin holds the weight at a specific height. Pulling the trigger pin releases the weight. The weight falls through the drop tube and crashes onto the test sample. The effect of the effect for fracture is

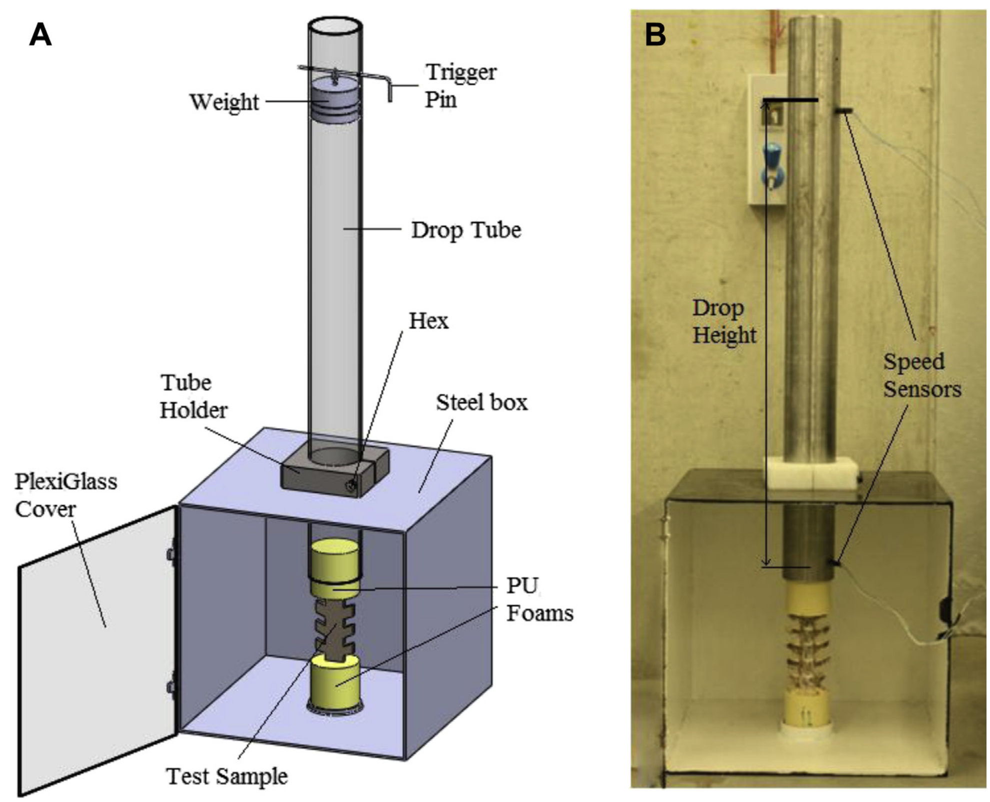


**Figure 2.** Drop mechanism. **(A)** Designed mechanism, and **(B)** manufactured mechanism.

delivered to the sample by this dropped weight. The dropped weight crashes onto the test sample with an impact energy that changes depending on the weight and drop height. The steel box has a Plexiglas cover in front of it to secure the test area.

The lumbar portion of ovine vertebrae was used as a test model in the drop test. Next, 54 ovine vertebrae, a number that satisfies the health conditions with a t-score of $T > -1$ according to the standard of World Health Organization, were used. The test samples were separated equally for the rigid, dynamic, and semirigid systems. Each fixation group had 18 samples. All of the samples underwent 2-level instrumentation at L3–5, and 2 levels above the fixation remained without any instrumentation. These segments were determined as adjacent segments. A single surgeon performed all of the instrumentation. After the instrumentation, a radiograph of each sample was obtained, and the initial fracture was controlled at the vertebrae. Next, the samples were embedded in Polyurethane blocks from their superior and inferior ends. This process was necessary to place the samples into the mechanism and to anatomically load the samples. Next, the samples were frozen at −20°C until further testing. Before the drop test, the samples were thawed 24 hours in physiological saline solution at room temperature (24°C).

Three different weights were used in the drop tests. Each fixation group, which had 18 samples, was separated equally for the 3 different weights. Thus, each fixation group had 3 subgroups, with 6 samples in each group for the 3 weights. Drop tests for each subgroup were repeated 6 times for each weight. The weights were 3.5 kg, 5 kg, and 7 kg. The weight fell from 1 m in height after the trigger pin was pulled. The occurrence of the fractures was observed by comparing the radiographs obtained before and after the tests. The theoretical impact energy values transferred to the test samples after the drop were 34.34 J, 49.05 J, and 68.67 J for 3.5 kg, 5 kg, and 7 kg, respectively. The velocity of the weight immediately prior to the crash was obtained by the use of speed sensors. The weights crashed for the samples with a velocity of 4.3 ± 0.2 m/second, and after 0.45 seconds, the samples were released. With this velocity, the real impact energy values were 32.35 J, 46.23 J, and 64.71 J for 3.5 kg, 5 kg, and 7 kg, respectively.

## RESULTS

### Compression Bending Test

The average stiffness values of the fixation systems, which were obtained from the compression bending tests, are shown in Table 1 with standard deviations. A comparison of the bending test results revealed that rigid fixation provided the greatest stiffness value, as expected. The stiffness values of the dynamic and semirigid fixations were close to each other, and the semirigid fixation had the lowest stiffness values under compression bending loads. Statistical comparison showed that

**Table 1.** Results from the Static Tests of the Fixation System

| | Stiffness Values of Fixation Systems | | | | | |
|---|---|---|---|---|---|---|
| | Rigid | | Dynamic | | Semirigid | |
| Static Tests | Average | Std. | Average | Std. | Average | Std. |
| Compression bending | 36.246 | 1.793 | 23.826 | 0.495 | 21.225 | 2.644 |
| Lateral bending | 20.796 | 1.018 | 2.023 | 0.057 | 14.841 | 0.690 |
| Torsion | 1.031 | 0.096 | 0.310 | 0.046 | 0.409 | 0.042 |

Std, standard deviation.

the rigid fixation was significantly stiffer than the dynamic and semirigid fixations, as shown in Table 2 ($P < 0.0001$). Under compression bending loading, there was no statistically significant difference between the stiffness values of the dynamic and semirigid fixations ($P > 0.05$).

### Lateral Bending Test

The average stiffness values of the fixation systems, which were obtained from the lateral bending tests, are also shown in Table 1 with standard deviations. A comparison of the lateral bending test results revealed that the stiffness value of the rigid fixation was significantly greater than other fixations ($P < 0.05$). The semirigid fixation also was significantly stiffer than the dynamic fixation under lateral bending loads ($P < 0.05$).

### Torsion Test

The average stiffness values of the fixation systems, which were obtained from the torsion tests, are also shown in Table 1 with standard deviations. The results of the torsion test showed that the rigid fixation was stiffer than the dynamic and semirigid fixations. Similar to the lateral bending test, the semirigid fixation was stiffer than the dynamic fixation under torsion loads. Statistical comparison showed that the differences between all of the fixations were statistically significant in the torsion test ($P < 0.05$).

**Table 2.** Statistical Comparison of the Stiffness Values of the Fixation System

| | *P* Values | | |
|---|---|---|---|
| | Compression Bending | Lateral Bending | Torsion |
| Rigid and dynamic | 0.0001* | 0.0001* | 0.0001* |
| Dynamic and semirigid | 0.0966 | 0.0001* | 0.0073* |
| Rigid and semirigid | 0.0001* | 0.0001* | 0.0001* |

*Statistical difference ($P < 0.05$).

Consequently, the rigid fixation provided significantly greater stiffness values than the dynamic and semirigid fixations in the 3 static tests. According to the static test results, it can be concluded that dynamic and semirigid fixations can be used as alternative systems to the rigid fixation with respect to stiffness. In contrast to the lateral bending and torsion tests, semirigid fixation had lower stiffness values than dynamic fixations under compression bending.

### Drop Tests

After the drop tests performed with a 3.5-kg weight, radiographs revealed no fractures at the adjacent and fixed segments in all of the samples of rigid, dynamic, and semirigid fixations. When the drop tests were performed with a 5-kg weight, no fractures occurred in the samples of rigid and dynamic fixations; however, sagittal split fractures at the superior fixed segments occurred in 33% (2 of 6) of the samples of semirigid fixation. These fractures were caused by high stressed regions at the pedicle screw insertion points. Under a loading condition, the fracture initiates from this excessive stress region and spreads throughout the vertebral body. Figure 3 shows a radiograph and image of the sample, which exhibits a sagittal split fracture at the superior fixed segment after the drop.

Similar to the drop tests performed with 3.5-kg and 5-kg weights, there were no vertebral fractures at the adjacent segments of the dynamic fixation samples after drop tests with the 7-kg weight. For the rigid fixation samples after a drop test with the 7-kg weight, the sagittal split fractures occurred at the fixed segments in 50% (3 of 6) of the samples. In Figure 4, the sagittal split fracture at the fixed L4 segment of a sample is shown. Lateral and posterior radiographs obtained before and after the test and the image of the fracture can be observed in Figure 4. For the semirigid fixation, epiphyseal fractures occurred at adjacent and fixed segments in 50% (3 of 6) of the samples. In Figure 5, a radiograph of a semirigid fixation sample, which had epiphyseal fractures at the adjacent L1 segment and fixed L3 segment, is shown. The epiphyseal fractures occurred at the posteriorly superior epiphysis of L3 segment and anteriorly inferior epiphysis of the L1 segment.

## DISCUSSION

Fixing a specific segment of vertebrae with pedicle screw rod systems causes dramatic changes in stiffness between fixed and nonfixed segments. These dramatic changes in stiffness are accepted as the main factor that alters ASD.[17,37,38] There have been several studies in which authors investigated the alternatives for posterior spinal stabilization to overcome the adverse effects of greater stiffness values of pedicle screw rod systems.[23-33] Dynamic and semirigid fixation systems are outstanding systems with lower stiffness values. The aim of using lower stiffness fixation systems was to compensate the stiffness differences, which may reduce the risk of long-term complications. However, many clinical studies have concluded that dynamic and semirigid fixations also lead to long-term complications.[23-31,33] Despite these studies, the main focus of this study was to determine whether the fractures that occurred after early-stage trauma can be prevented using dynamic and semirigid fixations. As an alternative to rigid systems,

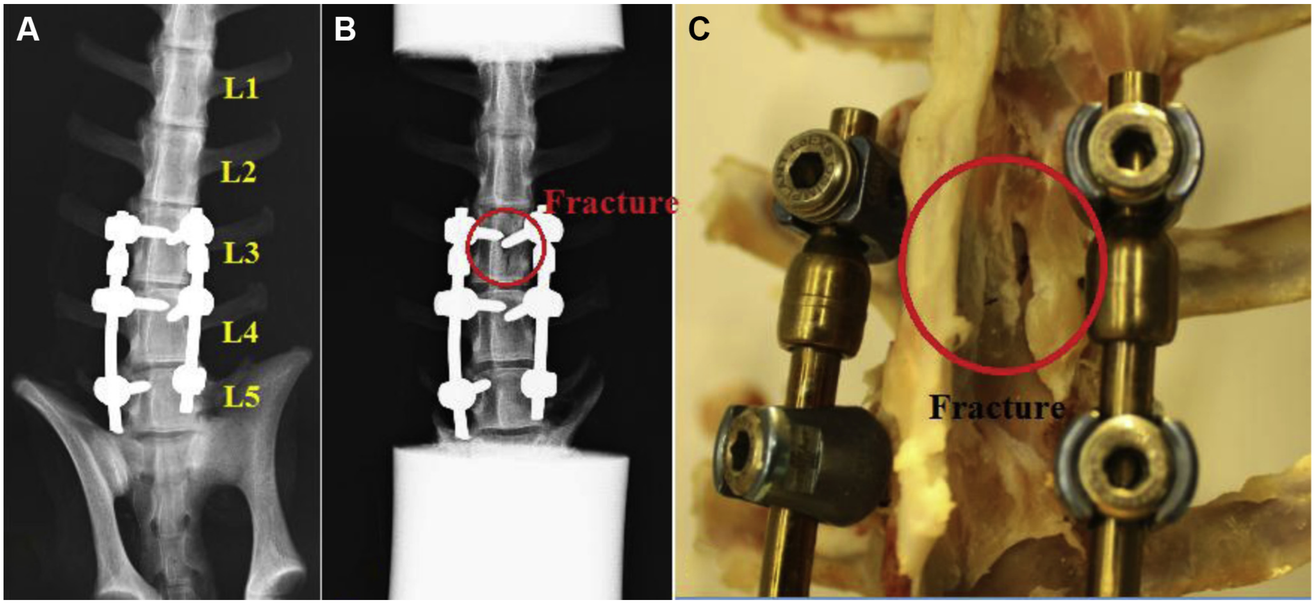


**Figure 3.** Fracture at the superior fixed segment of a semirigid fixation sample. Radiograph taken (**A**) before and (**B**) after the drop test with a 5-kg weight. (**C**) Image obtained after the test.

semirigid systems have been accepted as the best solution, with gradually increasing stiffness properties. The static test results showed that the rigid fixation presented significantly stiffer results compared with dynamic and semirigid fixations under compression bending, lateral bending, and torsional load conditions. The rigidity level of dynamic and semirigid systems was reliable for the fusion on vertebrectomy model tests.

Generation of a fracture on spinal segments has been studied experimentally by several researchers. Panjabi et al.[36] studied human cadaveric thoracolumbar spines to produce experimental burst fractures under trauma. They manufactured a drop mechanism and released weights above the samples similar to the procedures used in this study. The drop height was adjusted to 1.4 m. This group started the drop test with an initial weight of 3.3 kg. The burst fracture severity was evaluated by the use of measurements of canal encroachment. After the drop test, lateral radiographs were obtained to measure encroachment. If the desired canal encroachment was not achieved, then the test was repeated with 2 kg of increased weight. The procedure was repeated in this way until the desired encroachment was achieved. The used weights in the study performed by Panjabi et al. varied from 3.3 kg to 13.3 kg. The average weight that was required to produce burst fractures was 6.8 kg. They reported that to produce a burst fracture on the human vertebrae, the required mean impact energy was 94.2 J.

In a similar study, Kallemeier et al.[39] studied human cadaveric thoracolumbar spines to generate experimental burst fractures. For their drop mechanism, the drop height was 1.5 m. They started with a 6-kg weight and increased the weight to 8 kg if a fracture did not occur. Next, 88.29 J and 117.72 J impact energies were obtained for the test samples with 6 kg and 8 kg weights, respectively.

Jones et al.[40] also examined human thoracolumbar cadaveric human spines to produce experimental burst fracture. The drop height of their mechanism was 1 m, and the weight was 25 kg. The burst fractures was investigated with lateral and anteroposterior radiographs. Jones et al.[40] delivered 245.25 J of impact energy to the samples. Wilcox et al.[41] combined the experimental study with a finite element model of bovine specimen to investigate the production of burst fractures under trauma. They generated 140 J of impact energy to produce fracture on the samples.

In this study, the production of fractures under trauma was evaluated in ovine vertebrae. Wilke et al.[42,43] showed that sheep vertebrae can substitute cadaveric human vertebrae as a compatible model when the anatomical and biomechanical differences between the 2 groups are well considered. In this concept, ovine vertebrae were used in several biomechanical studies[44-48]; however, when considering the drop studies, researchers generally worked on cadaveric human or bovine vertebrae. To the best of our knowledge, this is also the first study to investigate the production of vertebral fractures under trauma in an ovine model. For this reason, this is a promising study to understand the impact energy that is needed to generate a fracture under trauma on ovine vertebrae. It is also important to determine a correlation between the impact energy values of ovine and human vertebrae.

When considering the impact energy values, 32.35 J, 46.23 J, and 64.71 J were transferred to test samples in a test with 3.5-kg, 5-kg, and 7-kg weights, respectively. The impact energy values of this study were less than the values of similar trauma studies for 2 reasons. The first reason was that ovine vertebrae have a lower load bearing capacity than human and bovine vertebrae. The second reason is that previous bovine and human studies generated burst

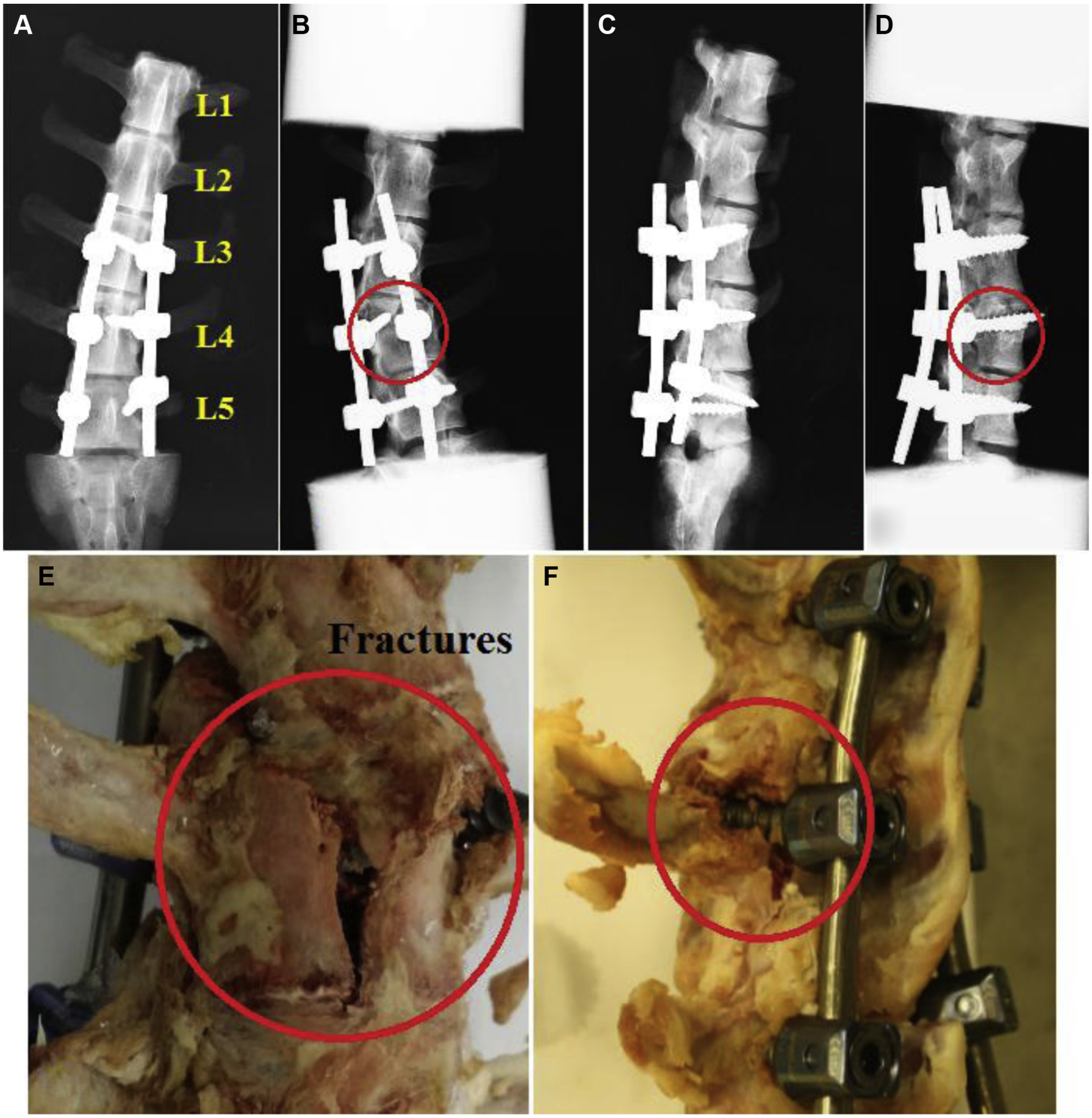


**Figure 4.** Fracture at fixed L4 segment for a rigid fixation sample after the drop test with a 7-kg weight. Radiograph obtained before the test from (**A**) posterior and (**C**) lateral, after the test from (**B**) posterior and (**D**) lateral. (**E**) and (**F**) were obtained after the test.

fractures on the vertebrae. The burst fractures were greater-energy traumas than compression, endplate, and sagittal split fractures. Thus, less impact energy is required to generate compression, endplate, and sagittal split fractures compared to burst fracture.

After the drop test with a 3.5-kg weight, there were no fractures at adjacent or fixed segments for all of the fixation systems according to the radiographic investigations. The impact energy generated with a 3.5-kg weight was not sufficient to produce a fracture at adjacent segments.

According to the results of with a 5-kg weight, radiographic investigations showed that there was no fracture occurrence at fixed or adjacent segments for rigid and dynamic systems. However, sagittal

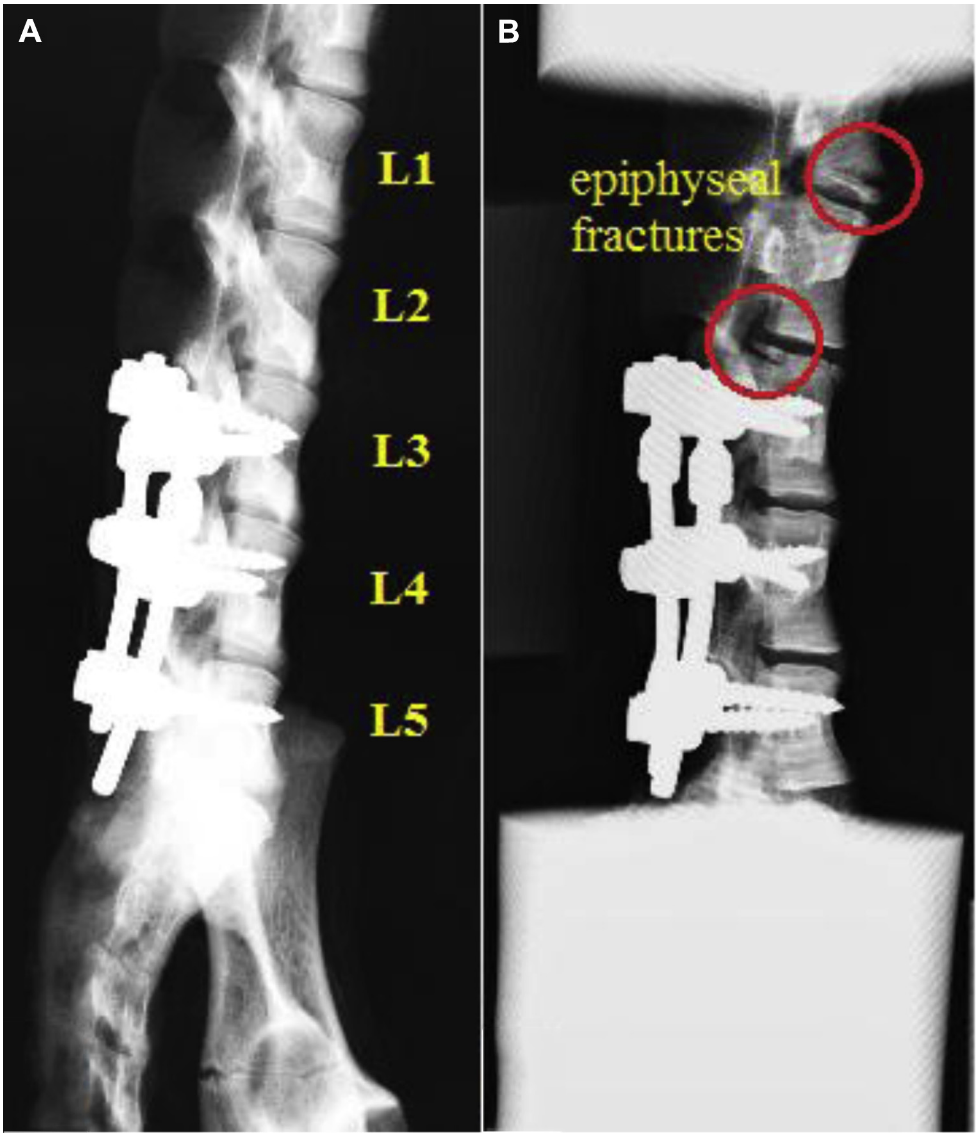


**Figure 5.** Epiphyseal fractures in a semirigid fixation sample after the drop test with a 7-kg weight. Radiograph obtained from the lateral (**A**) before and (**B**) after the test.

split fractures at the superior fixed segment were observed on some of the semirigid systems (Figure 3). It is thought that the fractures that occurred at fixed segments were caused by excessive stress regions in the screw insertion points. There have been several reported cases with similar fracture occurrences in fixed segments.[34,49]

After the test with 7-kg weights, radiographic investigations showed that there are sagittal split fractures at fixed segments in some rigid system samples (Figure 4). Similar to the drop tests with 3.5-kg and 5-kg weights, there were no fractures that occurred at the fixed and adjacent segments for the samples of the dynamic system. Finally, in some samples of the semirigid system, the epiphyseal fractures at the adjacent and fixed segments were observed on the radiographic investigations (Figure 5).

To understand the reaction mechanism, acute trauma loads were placed on several fixation systems (Figure 6). After the acute loading (impact), the disk heights at a rigidly fixed region were not reduced. The high stiffness of the rigid system did not enable the fixed segments to move. In addition, fractures at rigidly fixed segments occurred under trauma. Fixed segments may fracture even if there was no trauma because the higher stiffness of the rigidly fixed segments can cause the fracture. Several studies have reported fractures at rigidly fixed segments without trauma history.[34,49]

Dynamic systems are one of the alternatives to rigid systems with the advantage of lower stiffness. For the dynamic system, the disk heights in the dynamically fixed region decreased under acute loads, as shown in Figure 6. This was caused by the elastic

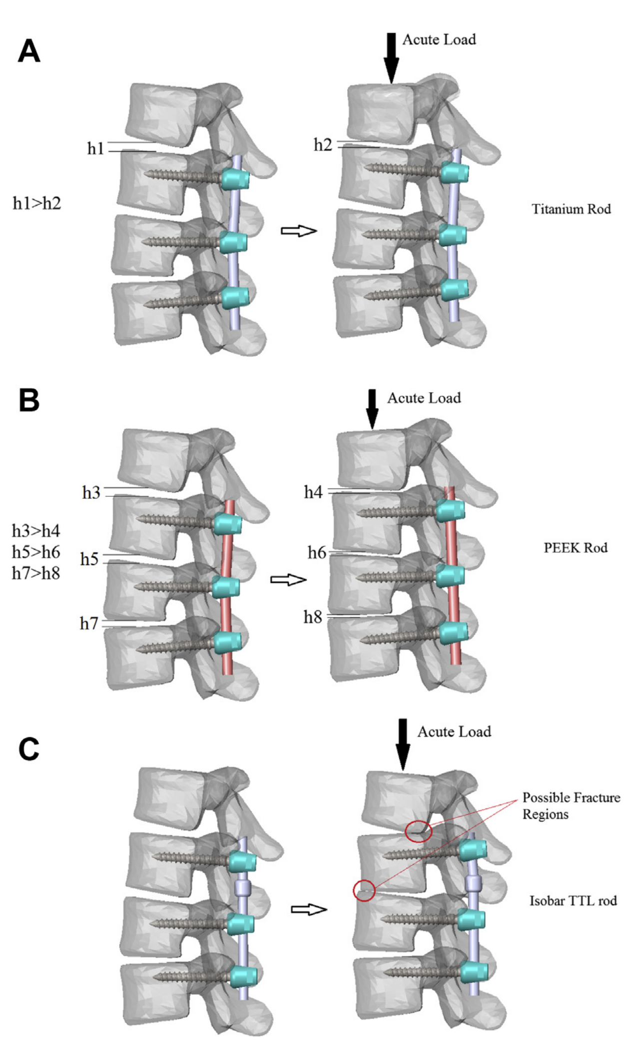


**Figure 6.** Reactions of the fixation systems under trauma. (**A**) Rigid, (**B**) dynamic, and (**C**) semirigid systems.

characteristic of the PEEK rod. PEEK rod, which enabled the fixed segments to move. With this advantage, the PEEK rod used fixation system can absorb the energy under static and acute loading. Under impact loading conditions, the elastic main structure, namely, the PEEK rod system, can absorb the generated energy and adequately preserve the both fixed and adjacent segments.

Semirigid systems have both rigid and dynamic levels. They also have lower stiffness values than standard rigid systems. However, the main advantage of the semirigid system is to provide gradual changes in stiffness to the segments rather than dramatic changes. Thus, the dynamic levels are less stiff than the rigid levels but more stiff than the unfixed adjacent segment. The load distribution of the fixed spine slightly decreases from the inferior to superior levels in this application. In recent years, semirigid systems have become popular in spinal surgeries. The disk height decreased under trauma for dynamically fixed regions. The damper-shaped structure in this region enables some range of motion and absorbs the impact energy. Nevertheless, the disk height at the rigid level of the semirigid system did not change. It is thought that the rigidity of the construct is the primary reason that causes the adjacent level fractures in fixed vertebrae. However, fracture at the adjacent level in semirigidly fixed vertebrae is only greater than the rigidity of the construct. Consequently, the less-stiff superior level of the semirigid system behaves like a cantilever beam above the stiffer inferior level. Because of the cantilever beam effect, the anterior epiphysis of the dynamically fixed segments crashes with each other, as described in Figure 6C. Depending on the level of the acute loads, epiphyseal fractures were observed on the anterior sides of the segments. Moreover, epiphyseal fractures also were observed on the posterior epiphysis of the adjacent segment and superior fixed segments. Potential fracture regions are shown in detail in Figure 6. In addition to the epiphysis fractures, the fixed segments may also fail due to excessively stressed regions via the screw insertion points.

## CONCLUSIONS

Dynamic and semirigid systems have advantages compared with rigid systems because of their lower stiffness values. The dynamic system with a PEEK rod can better preserve both adjacent and fixed segments. However, because of the cantilever beam effect, semirigid fixation has been shown to have a greater disadvantage. The mechanics of the low-energy fractures above the instrumented spine and use of the ovine model to evaluate the mechanics of low energy fractures is a topic that deserves further investigation. The range of energy in which low-energy fractures occur should be considered with further investigations.

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