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Biomechanical comparison of transdiscal fixation and posterior fixation with and without transforaminal lumbar interbody fusion in the treatment of L5–S1 lumbosacral joint

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Abstract

Transdiscal screw fixation is generally performed in the treatment of high-grade L5–S1 spondylolisthesis. The main thought of the study is that the biomechanical performances of the transdiscal pedicle screw fixation can be identical to standard posterior pedicle screw fixations with or without transforaminal lumbar interbody fusion cage insertion. Lumbosacral portions and pelvises of 45 healthy lambs' vertebrae were dissected. Animal cadavers were randomly and equally divided into three groups for instrumentation. Three fixation systems, L5–S1 posterior pedicle screw fixation, L5–S1 posterior pedicle screw fixation with transforaminal lumbar interbody fusion cage insertion, and L5–S1 transdiscal pedicle screw fixation, were generated. Axial compression, flexion, and torsion tests were conducted on test samples of each system. In axial compression, L5–S1 transdiscal fixation was less stiff than L5–S1 posterior pedicle screw fixation with transforaminal lumbar interbody fusion cage insertion. There were no significant differences between groups in flexion. Furthermore, L5–S1 posterior fixation was stiffest under torsional loads. When axial compression and flexion loads are taken into consideration, transdiscal fixation can be alternatively used instead of posterior pedicle screw fixation in the treatment of L5–S1 spondylolisthesis because it satisfies enough stability. However, in torsion, posterior fixation is shown as a better option due to its higher stiffness.

Keywords

Transdiscal fixation, pedicular transvertebral screw fixation, transforaminal lumbar interbody fusion, pediculo-body fixation

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Introduction

Lumbar spinal fusion is a widespread procedure being used in the treatment of spinal instability, spinal stenosis, spondylolisthesis, scoliosis, and other degenerative diseases. It is generally performed following posterior lumbar decompression if there is a sign of lumbar deformity or instability. It has been achieved with many spinal fusion procedures.[1]

Transforaminal lumbar interbody fusion (TLIF) was revealed as an alternative to posterior lumbar interbody fusion (PLIF) and these two are the most widely used ones.[2,3] Both are decompressive, restore missing disc height, and set biomechanical stability. These techniques contain posterior pedicle screw fixation and intervertebral fusion cage insertion to the disc space. When compared to PLIF, TLIF has a more lateral approach to disc space, and only unilateral facetectomy is needed with TLIF. Potential nerve root injury is reduced when disc is excised with a lateral approach. In addition, the risk of bone and soft tissue resection is

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also lower with a lateral approach. Although high fusion rates are accomplished with PLIF, it has increased operative time, nerve root injury, blood loss, and bone and soft tissue resection because of its surgical procedure.[3–6] Some studies showed that there is no difference in clinical outcomes, long-term complications, and fusion rates of these two procedures, or sometimes TLIF is even superior.[2–4,6–11] Because of these advantages of TLIF, it becomes favourable in lumbar decompression surgeries when fusion is necessary.[2–11]

Another fusion technique used in lumbosacral region is transdiscal screw fixation. Transdiscal screw fixation is generally performed in the treatment of high-grade L5–S1 spondylolisthesis. It contains at least single-segment posterior screw fixation, for instance, pedicle screw fixation which fixes two vertebral bodies to each other. Fundamentally, the technique has similar applications with different names. The starting point of the technique is presented by Abdu et al.[12] using pedicular transvertebral screw fixation in the treatment of spondylolisthesis. In their technique, screws were inserted through the pedicles of the lower vertebra and entered the body of the upper vertebra. Abdu et al.'s technique was safe, effective, and easy to perform in high-grade slips. Based on their study, studies have been conducted in the treatment of L5–S1 spondylolisthesis up until today. Grob et al.[13] used a similar technique, named as direct pediculo-body fixation, in which the cancellous bone screws were inserted bilaterally through the pedicles of the lower vertebra and entered the body of the upper slipped vertebra. They suggested that their technique is simple and minimally traumatic with successful clinical and radiological outcomes. Zagra et al.[14] also got satisfactory clinical results with direct pediculo-body fixation in the treatment of lumbar spondylolisthesis. Some researchers studied on oblique lumbar interbody fusion which is a similar method and reported satisfactory clinical results.[15,16] St Clair et al.[17] investigated the biomechanical behaviour of the oblique lumbar interbody fusion and showed that the technique provides comparable stiffness and failure load values with standard pedicle screw fixation. To get back to transdiscal screw fixation, in this method, the screws of lower vertebra are inserted to the pedicles, pass through the intervertebral disc, and enter the upper vertebral body from its inferior end plate. Additional screws can be inserted to the upper vertebra through its pedicles and linked with the lower screws by rods.[18] In Minamide et al.'s[18] biomechanical study, it has been shown that transdiscal screw fixation provides comparable biomechanical performance with combined interbody–pedicle screw fixation. The literature has more clinical and biomechanical studies about the issue in a broad range because the technique has several applications and can be performed in different regions of the spine not only lumbosacral spine.[19–24]

Besides the advantages of the intradiscal fixations, it has some difficulties and risk factors. Transdiscal fixation is generally performed following a careful reduction. After the slipped vertebra was reduced, the screw inferior must be placed in the accurate direction. This may generally be a challenge,[25] because the screw must pass through the intervertebral disc and reach the L5 vertebral body. The misplacement of the inferior screw may occur during implantations.[19,25] The misplacement of hardware and its failure may also occur.[19,25,26] In addition, dural tear[21,26–28] and infection[19,25,26] were also reported.

In this study, the main thought is that the biomechanical performances of the transdiscal pedicle screw fixation can be identical to standard posterior pedicle screw fixations with or without TLIF cage insertion. Three fixation systems, L5–S1 posterior pedicle screw fixation, L5–S1 posterior pedicle screw fixation with TLIF cage insertion, and L5–S1 transdiscal pedicle screw fixation, were generated. Axial compression, flexion, and torsion tests were conducted on test samples of each system and the results were evaluated.

Materials and methods

Sample preparation

Ovine vertebrae were used as biomechanical test samples in this study. Ovine vertebrae were preferred for its anatomical and load-bearing similarities to human vertebrae. Wilke et al.[29,30] showed that ovine vertebrae can be used in biomechanical tests when simulating human vertebra if the differences between them are well-evaluated. Lumbosacral portions and pelvises of 45 healthy lambs' vertebrae were dissected. Soft tissues and ligaments were kept on vertebrae. The healthy condition ($T > -1$) of the vertebrae was guaranteed by dual x-ray absorptiometry (DEXA).

Before surgical operation, animal cadavers were randomly and equally divided into three groups for instrumentation. Fixation groups were L5–S1 posterior fixation (PF), L5–S1 PF with TLIF cage (PF-TLIF), and L5–S1 transdiscal PF (T-PF). PF was used for control purposes and compared to study groups. Fixations were performed on L5–S1 vertebral bodies, and pelvises and superior adjacent segments were left without instrumentation for embedding procedure. The same individual surgeon performed all surgical operations. Pedicle screws which have 5.5 mm outer diameter and 35 mm length and rods which have 5.5 mm diameter were used in all instrumentations. In PF-TLIF, polyetheretherketone TLIF cages were used. Intervertebral cages were inserted in L5–S1 intervertebral disc space. In T-PF procedure, pedicle screws of S1 were inserted through S1 pedicles, passed through the intervertebral disc, entered L5 vertebral body from inferior end plate, and terminated in L5 vertebral body. Pedicle screws of L5 were directly inserted to the vertebral body. The fixation systems can be seen in Figure 1.

Following surgical operations, cadavers were embedded in polyurethane (PU) blocks through their

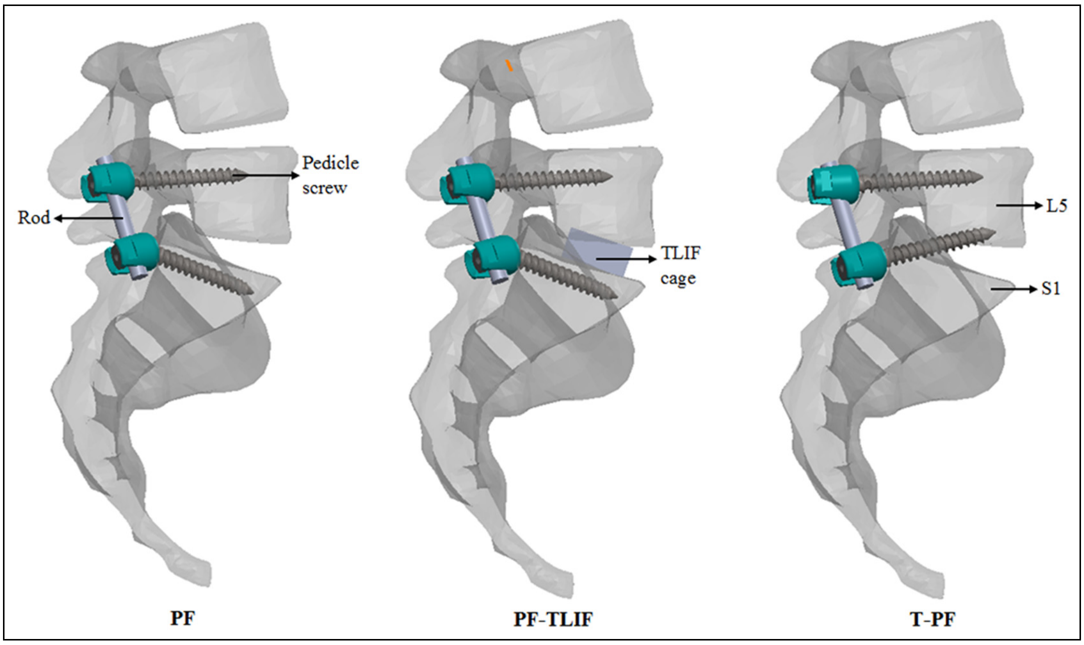

Figure 1. The fixation systems.

pelvises and L4 vertebral bodies. After embedding, the samples were stored in deepfreeze (−20 °C) until static tests. The sample uniformity is the critical point why all the samples were freezed.

Before static tests, all fresh frozen cadavers were taken out and thawed in physiological saline solution (24 h, at 24 °C). Each fixation group was equally divided into three groups for three different static tests. The static tests were axial compression, flexion, and torsion tests. These tests are prominent when considering the biomechanical performances of the instrumentation system under quasi-static loads. The quasi-static loads are applied similar to normal mechanical loading conditions of the spine.

Axial compression test

The test samples were attached to test frame through their embedded ends. Axial load was increasingly applied through instantaneous motion centre of the samples. Loading condition and test set-up are shown in Figure 2. Instron 3300 (Instron, UK) compression–tension test frame was used in axial compression test. Load versus displacement curve of each sample was recorded by software. Stiffness (N/mm) and yield load (N) values were obtained from the curves. The constant quasi-static loading speed was 5 mm/min. Five samples in each group, 15 in total, were tested in axial compression test.

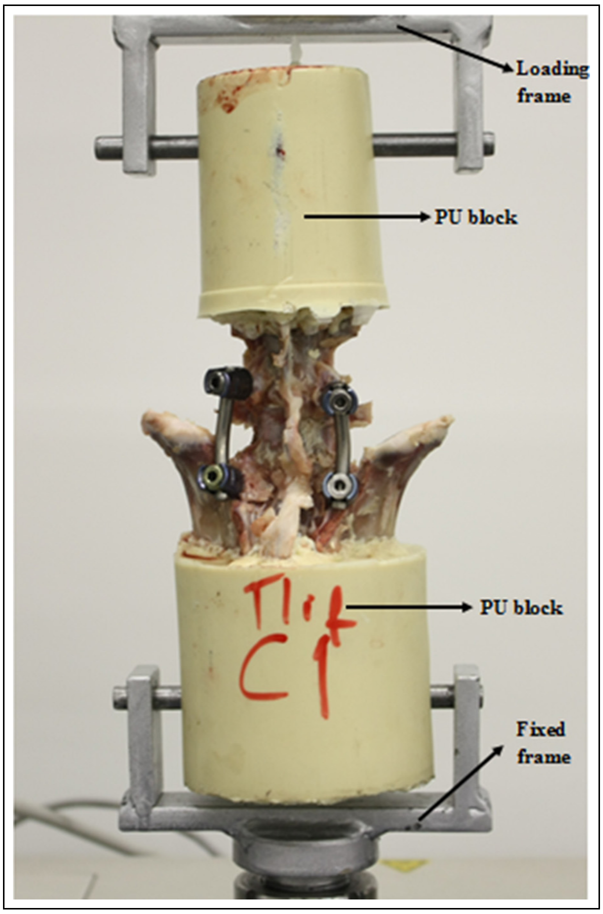

Figure 2. Axial compression test set-up.

Flexion test

The test frame was the same as the axial compression test. Compression load was applied to a 100-mm moment arm to generate bending moment on the test samples. The loading condition, critical measurements, and the test set-up are shown in Figure 3. Crosshead speed was constant and 5 mm/min. Stiffness (N/mm) and yield load (N) values were obtained from load

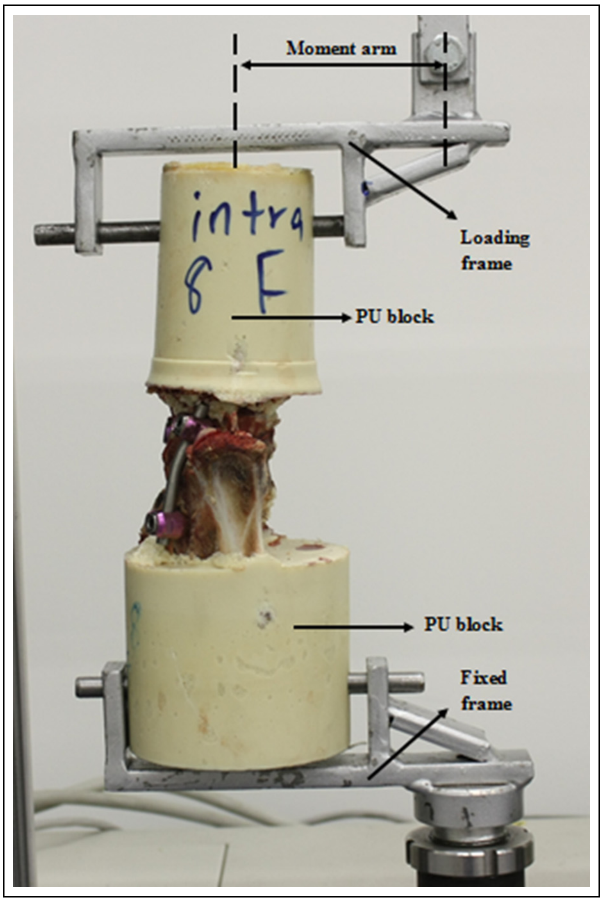

Figure 3. Flexion test set-up.

versus displacement curves. The test was repeated five times for each group, so there were 15 samples tested in total.

Torsion test

Torsion test was performed on the remaining samples. Embedded ends of the samples were attached to test frame and torque was applied to one end by tumble. Tumble speed was constant at 2°/s. Instron 55MT MicroTorsion Test Frame was used in torsion test (Instron). Loading condition and test set-up can be seen in Figure 4. Torque versus angle of rotation curves were recorded, and stiffness (N m/°) and yield torque (N m) values were obtained from the curves for each sample. In torsion test, five samples were tested in each group.

Statistical analysis

In each test, five samples were tested for each group to obtain comparable results. Groups were compared with each other by two-paired Student's t-test. Statistically significant difference level was described by $\alpha \leqslant 0.05$.

Results

Axial compression test

The stiffness and yield load values of the fixations under axial compression loads are shown in Table 1 with the mean values and standard deviations. The highest and lowest mean stiffness values were provided by PF + TLIF and T-PF, respectively. The mean stiffness of T-PF was 96.68 N/mm, and PF and PF + TLIF were 34% and 41% stiffer than T-PF, respectively. However, statistical comparison of the groups (Table 2) revealed that significant difference was only between T-PF and PF + TLIF for stiffness ($p < 0.05$).

When comparing yield load, the results were the same as stiffness. PF + TLIF had a mean yield load value of 1116.57 N. PF and T-PF showed close values to each other. PF + TLIF was 2.53 and 2.78 times stiffer than PF and T-PF, respectively. Statistical comparison showed that the differences between PF + TLIF and other groups were statistically significant ($p < 0.05$).

Flexion test

The test results of flexion test are also shown in Table 1. PF showed the lowest stiffness value with 63.54 N/mm, and the other two groups showed very close results. PF had approximately 8% lower stiffness value than other groups. A statistically significant difference was not observed between the groups for stiffness ($p > 0.05$).

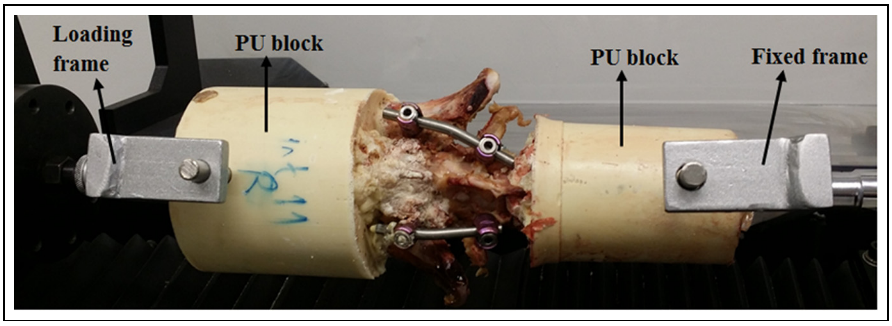

Figure 4. Torsion test set-up.

Table 1. Axial compression, flexion, and torsion tests' results.

		PF		T-PF		PF + TLIF	
		Mean	Std	Mean	Std	Mean	Std
Axial compression test	Stiffness (N/mm)	129.56	35.50	96.68[a]	16.07	136.71[b]	18.10
	Yield load (N)	441.13[a]	70.75	401.43[a]	50.41	1116.57[b,c]	129.12
Flexion test	Stiffness (N/mm)	63.54	5.33	69.01	9.33	69.18	6.39
	Yield load (N)	507.16	50.85	438.65	54.50	532.28	102.64
Torsion test	Stiffness (N m/°)	1.29[a,b]	0.14	1.05[a,c]	0.18	0.59[b,c]	0.10
	Yield torque (N m)	21.01[a,b]	1.11	14.00[a,c]	0.51	11.50[b,c]	1.23

PF: posterior fixation; T-PF: transdiscal PF; TLIF: transforaminal lumbar interbody fusion.
[a]Significant difference with PF + TLIF.
[b]Significant difference with T-PF.
[c]Significant difference with PF.

In addition, the test results indicated that the highest mean yield load was in PF + TLIF group with the value of 532.28 N. The yield load value of PF + TLIF was 5% and 21% higher than PF and T-PF, respectively. Similar to stiffness, there were no significant differences between the groups for yield load ($p > 0.05$).

Torsion test

Torsion test is another critical criterion when assessing the biomechanical performances of the fixations. The torsion test results are given in Table 1 with the mean values and standard deviations. The torsional stiffness value of the PF was highest and 1.29 N m/°. PF was 1.23 and 2.19 times stiffer than T-PF and PF + TLIF, respectively. Stiffness values of all groups were significantly different under torsional loads ($p < 0.05$).

Like stiffness, PF had highest yield torque value with 21.01 N m. The yield torque value of PF was 1.50 and 1.83 times higher than T-PF and PF + TLIF, respectively. Statistically significant differences were observed between all groups for yield torques ($p < 0.05$).

Discussion

Studies have been conducted on transdiscal fixation in the lumbosacral spine and many of them were clinical. Minimally traumatic intra-operative procedure and successful clinical and radiological outcomes were exhibited by clinical studies.[12–16,19,21–24] Besides clinical studies, biomechanical studies were performed to understand the biomechanical responses of transdiscal fixation under different loading conditions. In literature, three biomechanical studies have been found after our research.[17,18,20] Transdiscal screw fixation in cadaveric model and their biomechanical responses under different loading conditions were discussed in these studies. Among these, Minamide et al.'s[18] study is quite similar to ours. They compared the biomechanical stiffness of the transdiscal fixation with traditional pedicle screw fixation and with pedicle screw fixation combined with interbody fusion in L5–S1. They first created a spondylolisthesis with an average slip of 41.3% and then fixed the vertebrae. The compression, flexion, extension, right lateral bending, and left lateral bending were performed on the samples. The biomechanical tests showed that transdiscal fixation had 1.6–1.8 times higher stiffness values than pedicle screw fixation in all loading conditions. However, no differences were observed between transdiscal fixation and pedicle screw fixation with interbody fusion.

The axial compression test result of this study showed that PF + TLIF was significantly stiffer than T-PF. It also had higher yield load values than T-PF and PF. However, PF and T-PF showed similar behaviours under compression loads and there was no significant difference between them. According to these results, it can be said that additional TLIF cage to the disc space increases the load-bearing capacity of the anterior column. Also, it can be interpreted from the results that the direction of the screw insertion to the lower segment does not affect the rigidity of the fixed vertebrae because no difference was observed between T-PF and PF.

In flexion test, there were no significant differences between the groups in stiffness and yield load. The results demonstrated that in flexion, additional TLIF cage to PF does not affect the rigidity of the system as much as in the axial compression. It may be because of the posterior elements and PF which may generate a resistance to bending in the direction of flexion. When comparing the T-PF and PF + TLIF, our results were similar to Minamides et al.'s[18] study because the groups provided identical results in their study too.

The spine is most vulnerable under torsional loads. Therefore, the torsion test is crucial evaluating the biomechanical strength. In torsion test, the stiffest group was PF. In addition, PF has the highest torsional yield moment. Contrary to axial compression and flexion tests, PF + TLIF group had lowest stiffness and yield moment value. It can be interpreted from the results that the resection of the anterior element (intervertebral disc) ruins the rigidity of the spine and results in instability under torsional load. The intervertebral disc has a positive effect in resistance to the torsional movement. As a result, the resection of the intervertebral

Table 2. Statistical comparison.

	Axial compression		Flexion		Torsion	
	Stiffness	Yield load	Stiffness	Yield load	Stiffness	Yield torque
PF and T-PF	0.108	0.341	0.298	0.074	0.050*	< 0.001*
PF and PF + TLIF	0.702	< 0.001*	0.168	0.641	< 0.001*	< 0.001*
T-PF and PF + TLIF	0.006*	< 0.001*	0.974	0.122	0.002*	0.009*

PF: posterior fixation; T-PF: transdiscal PF; TLIF: transforaminal lumbar interbody fusion.
*Significant difference.

disc and TLIF cage insertion to the disc space does not have the same effect with PF with respect to stiffness. Also, T-PF does not have the same effect with PF.

When comparing this study with Minamide et al.'s[18] study, the results are majorly different with their results. The reason of this may be the difference in operational procedure. They fixed the vertebra after they created a L5–S1 spondylolisthesis with an average slip of 41.3%. However, L5–S1 spondylolisthesis was not present in our study. Most probably, the spondylolisthesis in L5–S1 alters the biomechanical behaviour and load-bearing capacity of the system.

Conclusion

When axial compression and flexion loads are taken into consideration, T-PF can be alternatively used instead of PF in the treatment of high-grade L5–S1 spondylolisthesis because it satisfies enough stability. In torsion, however, PF is shown as a better option due to its higher stiffness.

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Declaration of conflicting interests

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