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Case Report

Biomechanical Comparison Using 3-D Finite Element Method between Cortical Screw Trajectory Fixation and Pedicle Screw Fixation for Fusion of the Lumbar Degenerative Spine

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ABSTRACT

Posterior fusion has been popularized for degenerative and traumatic spine conditions thanks to its convenience and facilities including direct access to the spinous processes, laminae, facets and exposure of spinal canal through posterior approach and neurological decompression while various surgical instruments and implants and techniques have been developed to enhance stability and apply maneuvers easily. As technology for spinal fusion has rapidly evolved in recent years, a new technique of cortical screw trajectory fixation has been reported minimal invasion and further constructs stiffness compared to pedicle screw fixation. Hence, we purposed to find biomechanical properties of cortical screw trajectory fixation and pedicle screw fixation in lumbar spine model and compare them. Biomechanical analysis was conducted using 3-D geometrical and Finite Element Method (FEM) models of fusion of the lumbar spine at the level of L4-L5 treated by cortical screw trajectory fixation and pedicle screw fixation fewer than four types of loads: flexion, extension, axial compression and torsion. The values of stiffness and displacement in the intervertebral disc and facet joints at the L4-L5 level when treated with the cortical screw trajectory fixation were the same or lower compared to the pedicle screw fixation. Cortical screw trajectory fixation provides greater stability than traditional pedicle screw fixation in fusion of the degenerative lumbar spine.

Keywords: Biomechanical comparison, 3-D finite element method, Cortical screw trajectory fixation, Pedicle screw fixation, Lumbar degenerative spine.

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INTRODUCTION

Hippocrates and Galen both described the chronic sequelae of spinal cord injuries and the Byzantine Paul of Aegina for the first time postulated surgical decompression for the treatment of spinal fractures.[1] Meanwhile between 1990s to 2010s, chronic low back pain, which usually originates from degenerative lumbar spinal diseases, has been prevalent with aging population, thereby, authors focused on treatment of this problem. Consequently, numerous surgical techniques have been developed for the treatment of degenerative lumbar spine conditions.[2]

Of these surgical treatments, posterior fusions with or without internal fixation have been an acceptable treatment choice in whom conservative treatment has failed, because posterior approach itself provides direct access to the posterior components including bony and neurological structures.[3-5] In addition, interbody fusion combined with internal fixation has considerable advantages of great fixation intensity, excellent stability and high fusion rates.[6-13] However, this technique has also been found to have a high morbidity rate due to iatrogenic injury of soft tissue which supplies stability of the spine and develop complications of pedicle wall breach leading to spinal cord or nerve root injury and damage to other vital structures due to misplaced screws.[11,14-17]

Complications and pitfalls produced by posterior fusion in degenerative lumbar spinal conditions as mentioned above have inspired orthopedists and spinal instrument manufacturers to develop minimally invasive spinal exposure techniques.[17,18] In this developing trend towards minimally invasive surgery, cortical screw trajectory fixation technique, a new concept, has been invented as an alternative method of pedicle screw fixation by Santoni *et al.* in 2009.[19] Authors reported some biomechanical studies by cadaveric investigations and clinical outcomes in relation to this technique.[16,20-22]

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We purposed to find biomechanical properties of cortical screw trajectory fixation and pedicle screw fixation in lumbar spine model and compare them.

METHODOLOGY

On the basis of the geometrical configurations of cortical screws (Myohyangsan, Pyongyang, Figure 1) and pedicle screws with CT scans of the lumbar vertebrae 1 to 5, sacrum and coccygeal bone, 3D geometrical and FEM models of bilateral cortical screw trajectory fixation and pedicle screw fixation at the level of L4-L5 were built by using Solidworks 2012 software. With ANSYS 15.0 program, the models were meshed into 49805 pieces of parabolic tetrahedron elements. By combining these models, L1-S (Sacrum) including cortical screw trajectory fixation and pedicle screw fixation at the level of L4-L5 was modeled. The mechanical values which were inputted to this FEM model are as follows (Table 1).

To conduct finite element analysis, it was supposed that cortical screw trajectory fixation was performed by Santoni technique and pedicle screw fixation employed by literature 3; 39 years old, 1.72 m tall and 60 kg weighted.

While the coccygeal bone was being constrained, flexion, extension, axial compression and torsion forces of 500N respectively were applied to the superior surface of L1 vertebral body.

According to cortical screw trajectory fixation and pedicle screw fixation, values of stiffness and displacement at the intervertebral disc and facet joints of L4-L5 level were obtained.

RESULTS

Stiffness

When applied flexion, extension, axial compression and torsion forces by 500N to the superior surface of the L1 body respectively in the cortical screw trajectory fixation and pedicle screw fixation models, the values of stiffness (Figures 2-9) at the intervertebral disc and facet joints of L4-L5 level are shown in Table 2. The values of stiffness obtained under flexion, extension and axial compression loads in the cortical screw trajectory fixation model were less than those of the pedicle screw fixation model. The torsion load, however, demonstrated the same in the both fixation models contrary to the other external forces.

Displacement

As shown in Table 3 and Figures 10-17, the displacements measured at the intervertebral disc and facet joint of L4-L5 level in the model with cortical screw trajectory fixation were found to be less than the measurements of the test by pedicle screw fixation under all the four loads.

Table 1: Modulus of elasticity and Poisson ratio of the lumbar spine, intervertebral disc and stainless steel.

Compartment	Modulus of elasticity (MPa)	Poisson ratio
Cortical bone	12000	0.3
Cancellous bone	100	0.2
Annulus fibrosis	4.2	0.45
Vertebral pulp	1.0	0.49
Stainless steel	1.172×10^5	0.31

Table 2: Values of stiffness in cortical screw trajectory fixation and pedicle screw fixation under flexion, extension and axial compression and torsion forces.

External forces	Cortical screw trajectory fixation		Pedicle screw fixation	
	Intervertebral disc	Facet joints	Intervertebral disc	Facet joints
Flexion	0.008	0.136	0.011	0.180
Extension	0.008	0.119	0.010	0.162
Axial compression	0.008	0.123	0.010	0.149
Torsion	0.003	0.118	0.003	0.123

Table 3: Values of displacement in cortical screw trajectory fixation and pedicle screw fixation under flexion, extension and axial compression and torsion forces.

External forces	Cortical screw trajectory fixation		Pedicle screw fixation	
	Intervertebral disc	Facet joints	Intervertebral disc	Facet joints
Flexion	1.59	1.15	2.88	2.89
Extension	1.84	1.84	2.26	2.19
Axial compression	6.34	4.12	7.29	5.18
Torsion	1.90	2.24	2.02	2.59

Figure 1: Cortical screw (Myohyangsan, Pyongyang).

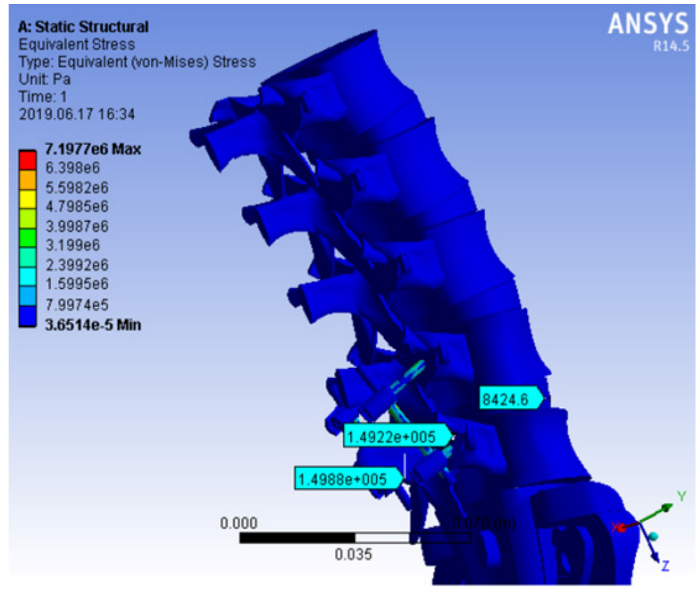

Figure 3: Extension stiffness of cortical screw trajectory fixation in intervertebral disc and facet joints at L4-L5 level.

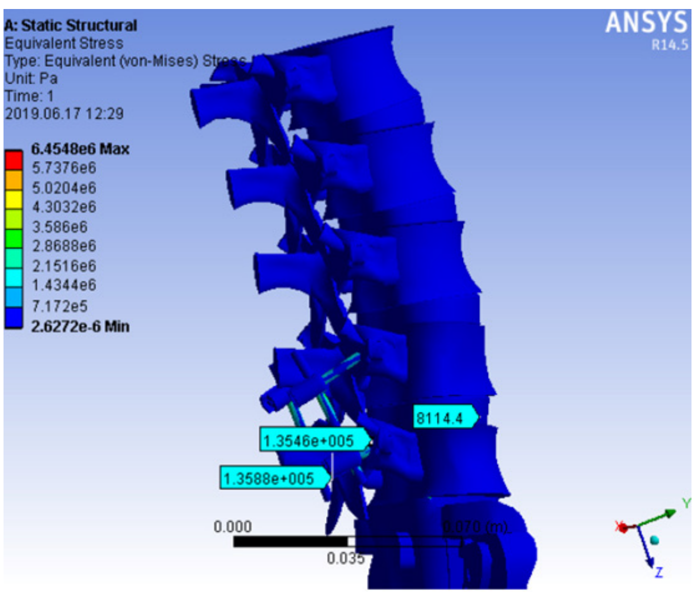

Figure 2: Flexion stiffness of cortical screw trajectory fixation in intervertebral disc and facet joints at L4-L5 level.

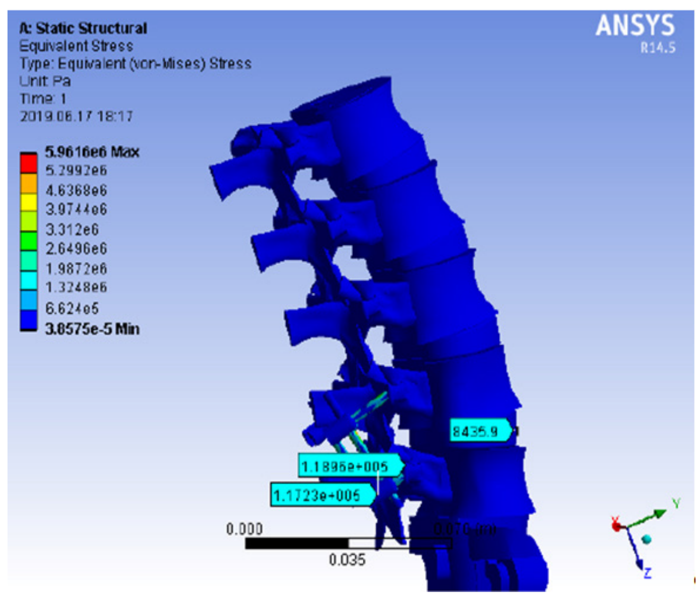

Figure 4: Axial compression stiffness of cortical screw trajectory fixation in intervertebral disc and facet joints at L4-L5 level.

DISCUSSION

The traditional pedicle screw fixation commonly used in the past for degenerative lumbar spinal fusion has proved to be invasive and require significant lateral spinal dissection in order to properly insert the screws.[21,23] In contrast, minimally invasive approaches to surgical procedures have gained popularity over the past several decades.[17] Posterior fusion has also achieved its own development leading to introduction of a new instrumentation, cortical screw trajectory fixation technique.[19,24-27]

In addition, it is said that degenerative spondylolisthesis is the most common type of spondylolisthesis and most frequent at the L4-L5 level.[3] From this we selected the L4-L5 level as a posterior fusion and biomechanical analysis object of our study. To estimate biomechanical properties of the two techniques, we measured stiffness and displacements in the intervertebral

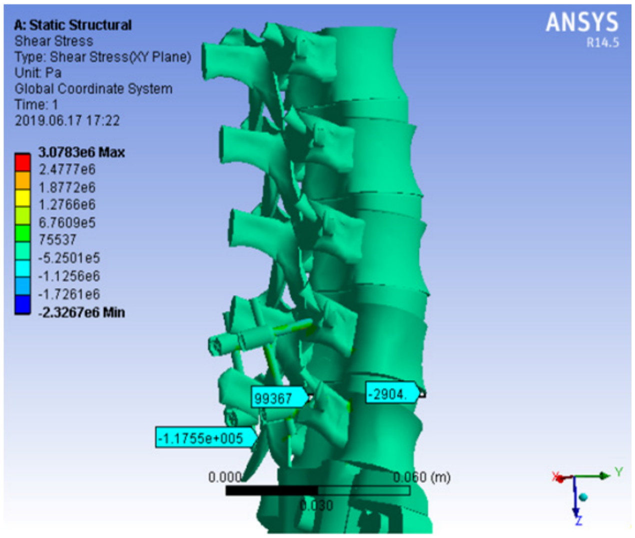

Figure 5: Torsion stiffness of cortical screw trajectory fixation in intervertebral disc and facet joints at L4-L5 level.

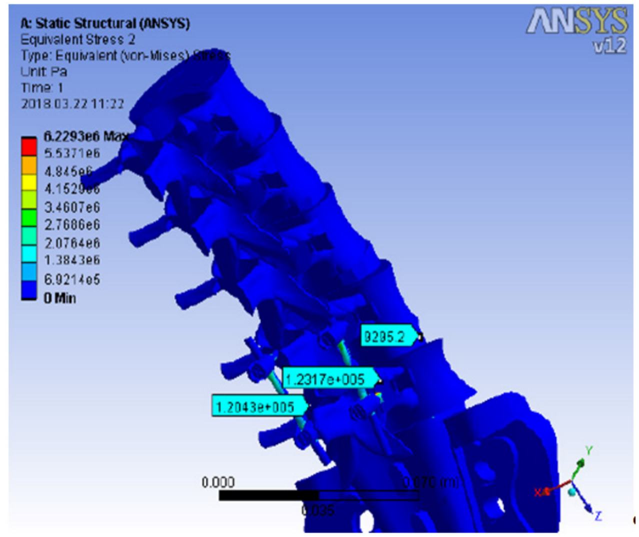

Figure 8: Axial compression stiffness of pedicle screw fixation in intervertebral disc and facet joints at L4-L5 level.

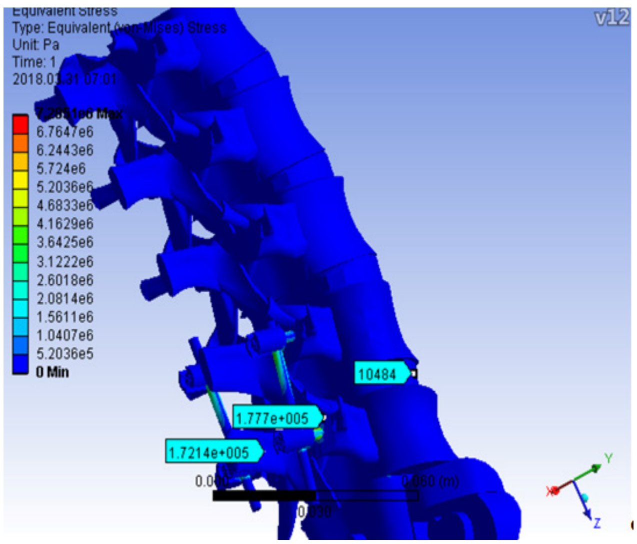

Figure 6: Flexion stiffness of pedicle screw fixation in intervertebral disc and facet joints at L4-L5 level.

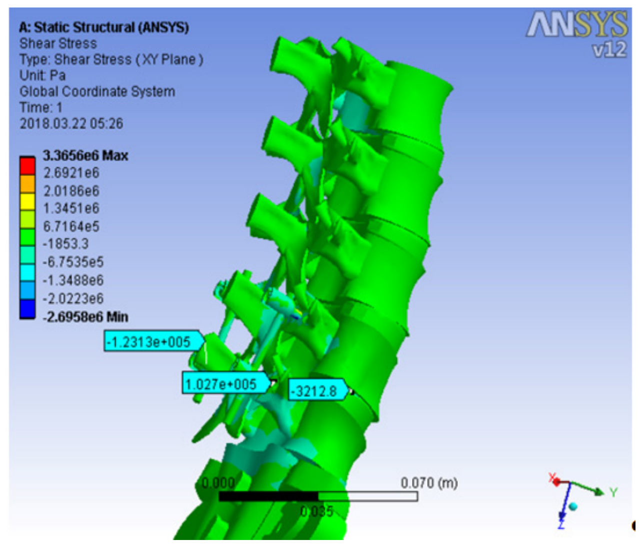

Figure 9: Torsion stiffness of pedicle screw fixation in intervertebral disc and facet joints at L4-L5 level.

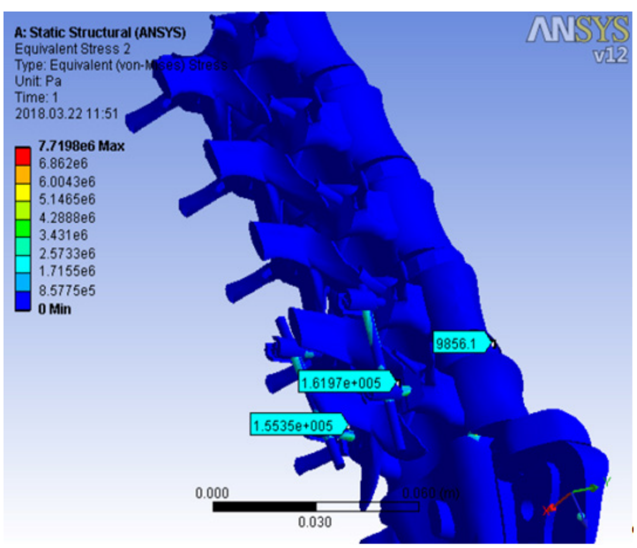

Figure 7: Extension stiffness of pedicle screw fixation in intervertebral disc and facet joints at L4-L5 level.

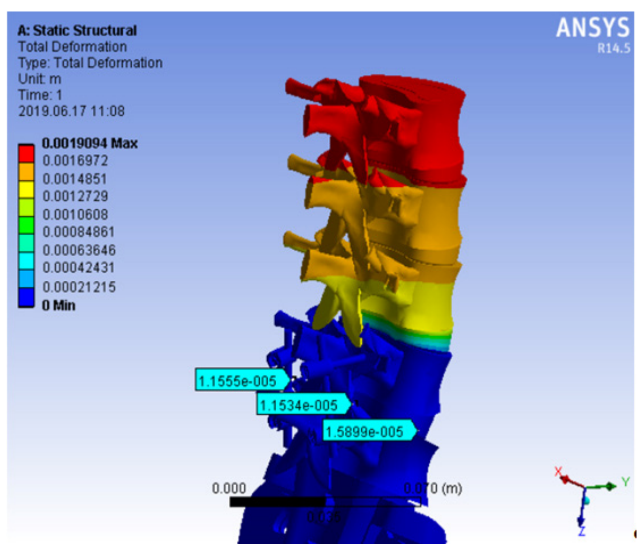

Figure 10: Flexion displacement of cortical screw trajectory fixation in intervertebral disc and facet joints at L4-L5 level.

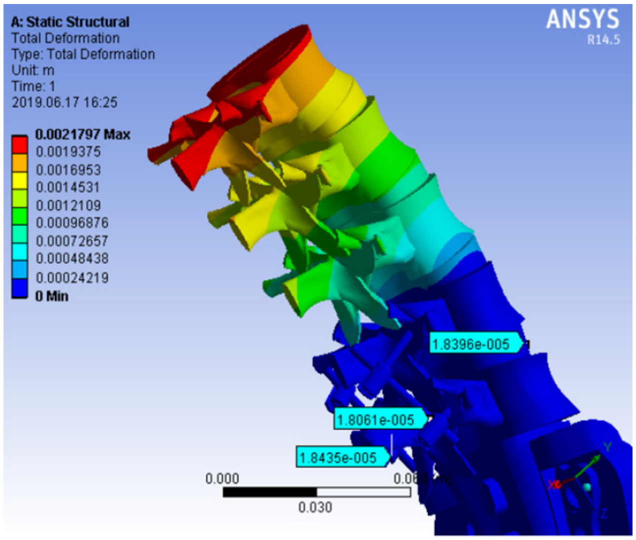

Figure 2: Extension displacement of cortical screw trajectory fixation in intervertebral disc and facet joints at L4-L5 level.

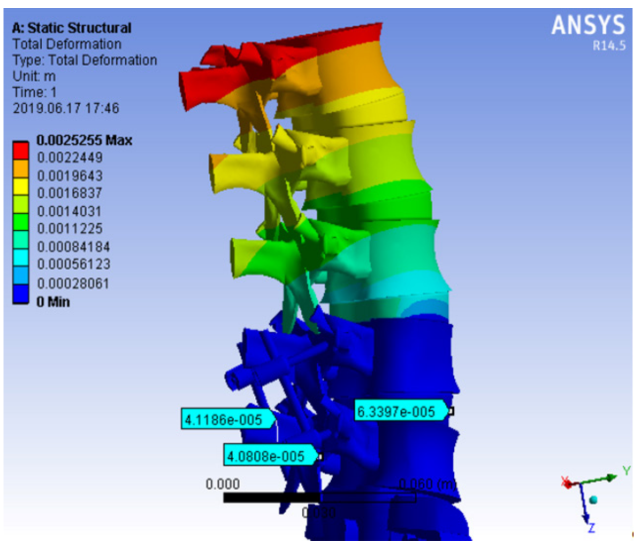

Figure 12: Axial compression displacement of cortical screw trajectory fixation in intervertebral disc and facet joints at L4-L5 level.

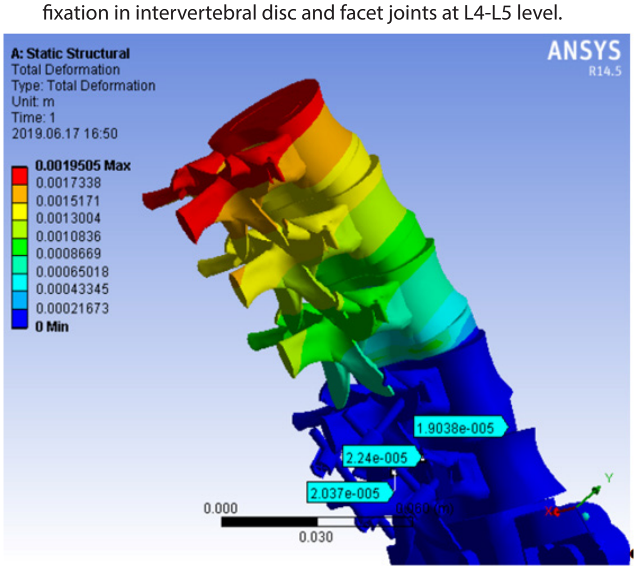

Figure 13: Torsion displacement of cortical screw trajectory fixation in intervertebral disc and facet joints at L4-L5 level.

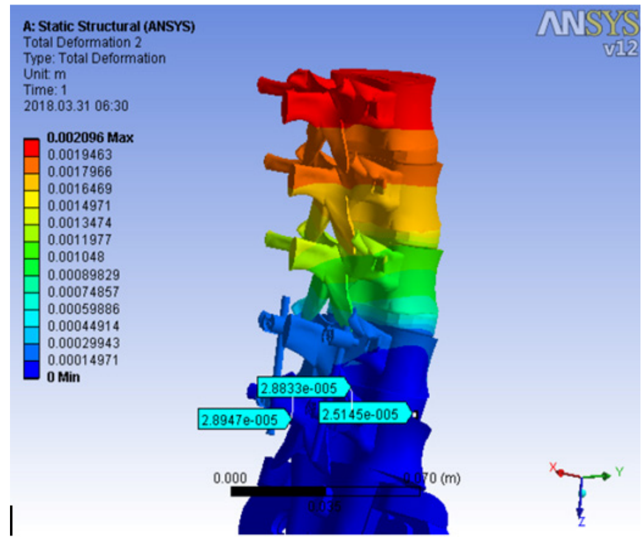

Figure 14: Flexion displacement of pediclel screw fixation in intervertebral disc and facet joints at L4-L5 level.

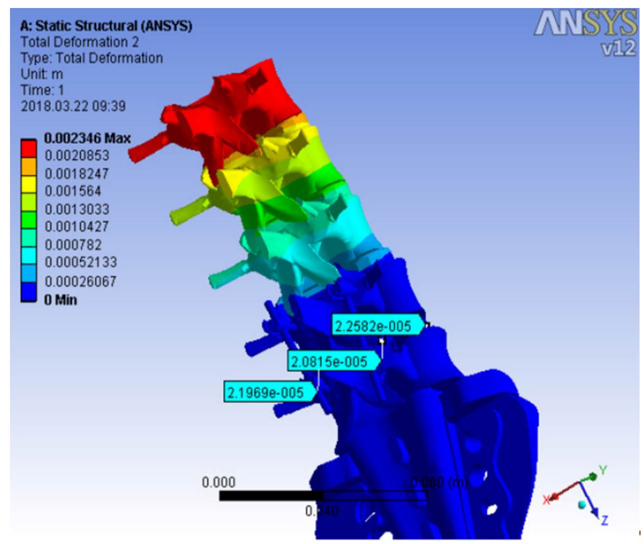

Figure 15: Extension displacement of pedicle screw fixation in intervertebral disc and facet joints at L4-L5 level.

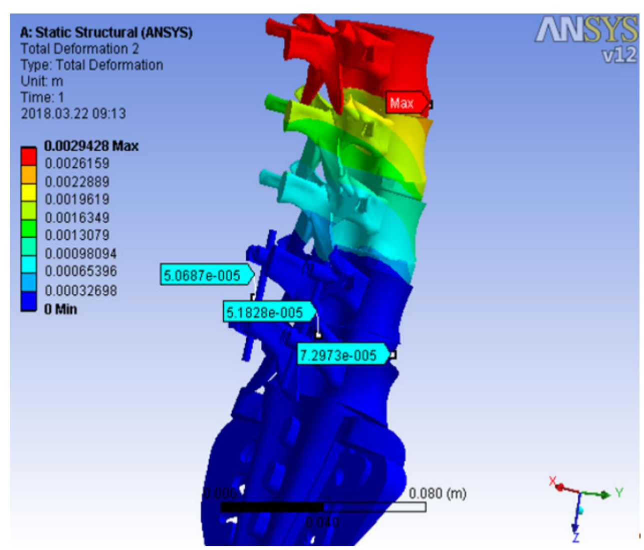

Figure 16: Axial compression displacement of pedicle screw fixation in intervertebral disc and facet joints at L4-L5 level.

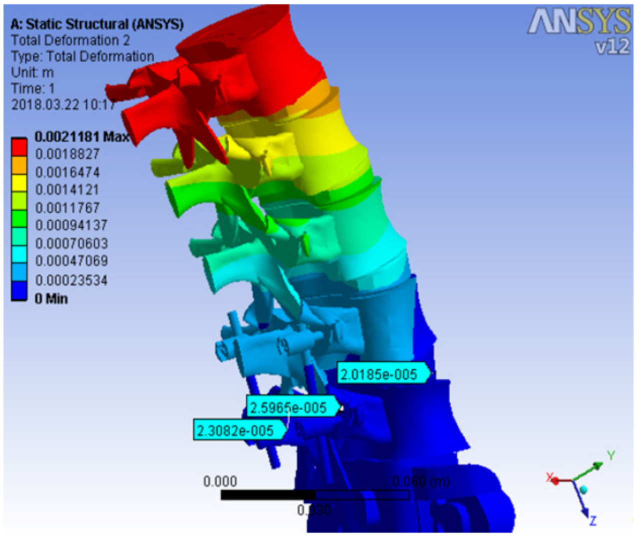

Figure 17: Torsion displacement of pedicle screw fixation in intervertebral disc and facet joints at L4-L5 level.

disc and facet joints at the level of L4-L5, contact surface of the adjacent vertebrae. The study revealed that all the biomechanical values measured in the sites mentioned above in the cortical screw trajectory fixation model are less than those in the pedicle screw fixation model or the same as those in the latter, which indicates the former provides stronger stability compared to the traditional pedicle screw fixation.

Authors have already found that the cortical screw trajectory fixation in the lumbar spine produce comparable construct stiffness to a traditional pedicle screw fixation construct in other types of biomechanical studies.[20,24] We also had a biomechanical study to compare the two fixation techniques, however, which was executed by 3-D FEM using software on computer leading to similar results.

There are several limitations in this study; therefore, it is necessary for surgeons to make allowances for these drawbacks prior to applying to clinical episodes. They include that the biomechanical analysis was conducted by means of 3-D FEM on computer without consideration of surrounding soft tissues involving muscles and ligaments which are expected to influence our results. The limitations are also thought that we selected only one person in age of 39 as materials and did not comprise lateral bending in the external loads applied to the lumbar spine.

CONCLUSION

To conclude, cortical screw trajectory fixation provides biomechanically greater stability than traditional pedicle screw fixation in fusion of the degenerative lumbar spine.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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