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COMPARISON OF TITANIUM SCREW WITH POLYESTER BAND WITH CLAMP (LOTUS) AND RIGID TITANIUM TRANSVERSE BINDER SYSTEM USING THE FINITE ELEMENT ANALYSIS

SONLU ELEMENT ANALİZİ KULLANILARAK TİTANYUM VİDA POLYESTER BAND KELEPÇE YÖNTEMI (LOTUS) VE RİJİD TİTANYUM TRANSVERS BAĞLAYICI SİSTEMİN KARŞILAŞTIRILMASI

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SUMMARY:

Objective: There are many studies in the literature for posterior spinal instrumentations. In this study, we compared a titanium screw with a polyester band with a clamp (LOTUS) and a rigid titanium transverse binder system, which are used in the lower lumbar region and to examine the strength and superiority of the systems against each other with the finite element (FE) analysis.

Material and Methods: A Ti6Al4V grade 5 titanium biocompatible alloy support for a pedicle-based posterior stabilization system and a polyethylene band support for a pedicle-based posterior stabilization system were compared as testing material.

Results: Range of motion was decreased by 95.8 % when a pedicle-based stabilization system was used at L4–L5. Range of motion was decreased further, about 1%, when the polymer band was used in conjunction with a posterior stabilization system in axial rotation.

Conclusion: Similar results were observed when a titanium transverse connector was used. In light of the results of all finite element analyses, neither the titanium screws with a polyester band with a clamp (LOTUS) nor the rigid titanium transverse binder system has a significant superiority over the other. Equivalent results in the limitation of movement and rigidity allow the use of these systems in short-segment posterior spinal instrumentation with the same indications.

Key words: Finite element analysis, spinal biomechanics, pedicular screw

Level of evidence: Retrospective clinical study, Level III

ÖZET:

Amaç: Literatürde posterior spinal enstrümantasyon için pek çok çalışma vardır. Biz bu çalışmada lomber bölgede, sonlu eleman (FE) analiziyle, polyester bant sıkılaştırıcı ve rijit titanyum transvers bağlayıcı sistemleriyle bağlanmış titanyum vidanın, birbirlerine üstünlüklerini ve güçlerini değerlendirdik.

Materyal – Metot: Test materyali olarak, Ti6Al4V grade 5 biyolojik uyumlu alaşıma sahip pedikül temelli posterior stabilizasyon sistemi ve polietilen bantla desteklenmiş pedikül posterior stabilizasyon sistemi karşılaştırıldı.

Bulgular: Sonuç olarak, pedikül temelli stabilizasyon sistemi L4-5'de kullanıldığı zaman hareket oranı % 95.8 azaldı. Posterior stabilizasyon sisteminin bağlantısında polimer bant kullanıldığında, posterior stabilizasyon sistemi aksiyel rotasyonunun hareket oranı yaklaşık % 1 azaldı.

Sonuç: Titanyum transvers bağlantı kullanıldığında benzer sonuçlar gözlendi. Tüm sonlu eleman sonuçlarının ışığında ne polyester bant kullanılan titanyum vidalarda ne de rijit titanyum transvers bağlantı sistemi kullanılan sistemde diğerine önemli bir üstünlük gözlenmemiştir. Aynı endikasyon ile rijit alaşımların kullanıldığı kısa segment posterior spinal enstrümantasyon sisteminin hareketin sınırlandırılmasındaki sonuçları eşit bulunmuştur.

Anahtar Sözcükler: Sonlu eleman analizi, omurga biyomekaniği, pediküler vida

Kanıt Düzeyi: Retrospektif klinik çalışma, Level III

INTRODUCTION

Rigid stabilizations with pedicle screw and rod-plate systems in patients with degenerative lumbar stenosis are the most widely accepted and applied fusion systems in the literature [1-2,6].

It has been reported that the transverse binders increased the mechanical strength of the system in the system stabilizations. The systems, which were connected with clamps to two rods made of titanium, are used widely as transverse binders. The idea of allowing minimal movement in the system has emerged with the development of science and technology. It is believed that the polyester band system, which is seen among new systems, may allow the minimal amount of movement. These systems are now used for instability due to spinal trauma, infection, tumor, deformity and degenerative disease [1-10].

In the study, a titanium screw with a polyester band with a clamp (LOTUS) and a rigid titanium transverse binder system were compared at flexion, extension and rotation in the systems where the transpedicular screw system is placed at the L4 and L5 levels. Besides the new system's ease of use, the superiority against the rigid titanium transverse binder system and the disadvantages are not exactly known [1].

MATERIAL AND METHODS

Intact FE model

A three-dimensional (3D) FE model of L1 to sacrum segments of the lumbar spine was developed. The geometry of the vertebrae was obtained from the CT scan data of a healthy 35-year-old male. The CT data were processed in MIMCS software (Mimics® Version 14.1; Materialise, Inc., Leuven, Belgium). The segmentation process was utilized to obtain the three-dimensional surface representation of each vertebra in STL format. The lordosis curvature was measured to be 25°. The multi-block approach introduced in the IA-FEMESH software (University of Iowa, IA) by Kallemeyn et al. was used to generate mesh [7]. The STL model of each vertebrae and disc was separately imported into the IA-FEMESH software in a three-dimensional surface. The blocks helped create the volumetric hexahedral mesh of the disks and vertebrae [4]. Three-dimensional gap contact 31 elements (GAPUNI) were used to simulate the facet joints between the vertebrae. ABAQUS software (ABAQUS®, Version 6.10-2; Abaqus, Inc., Providence, RI, USA) was used for all the simulations.

The circular mesh pattern on the disc helped to model the concentric rings of the annulus ground substance [3]. The rebar option of ABAQUS, oriented ±30° to the horizontal plane, was used to model the fibers in the annulus. The "no compression" option of the ABAQUS software was used to restrict the fibers only under tension loading. The Neo-Hookean hyperelastic model was used to simulate the behavior of the annulus. Further, the fluid behavior of the nucleus was simulated using a hexahedral element, which was assigned a very low stiffness (1 MPa) and near-incompressibility (Poisson's ratio υ = 0.4999).

The ligaments were simulated using 3D truss elements, which were constrained to act nonlinearly only in tension. All seven major ligaments, i.e., the anterior longitudinal ligament (ALL), posterior longitudinal ligament (PLL), ligamentum flavum (LF), intertransverse ligament (ITL), interspinous ligament (ISL), supraspinous ligament (SSL) and capsular ligament (CL), were represented. The complete model consisted of 72,193 nodes and 55,650 elements that represented the entire structure of the lumbar spine **(Figure-1,2).**

The material properties of various components of the lumbar model (Table-1) were obtained from the literature [3] **(Table-2,3).**

Instrumented FE models

The effect of the two different support systems used for the pedicle-based rigid posterior stabilization system was studied on the biomechanics of the lumbar spine. The Ti6Al4V grade titanium biocompatible alloy support for the pedicle-based posterior stabilization system and the polyethylene band support for the pedicle-based posterior stabilization system were compared as testing material. The range of motion (ROM) of the intact model; the intact model with the posterior stabilization system, including titanium alloy support; and the intact model polyethylene band support was compared.

The ROM of the index and adjacent levels after implantation of the posterior stabilization system, including **a)** titanium alloy support and **b)** polyethylene band supports, was compared to the intact model. Two different support systems that can be used with the pedicle-based posterior stabilization system have been shown **(Figure-3).**

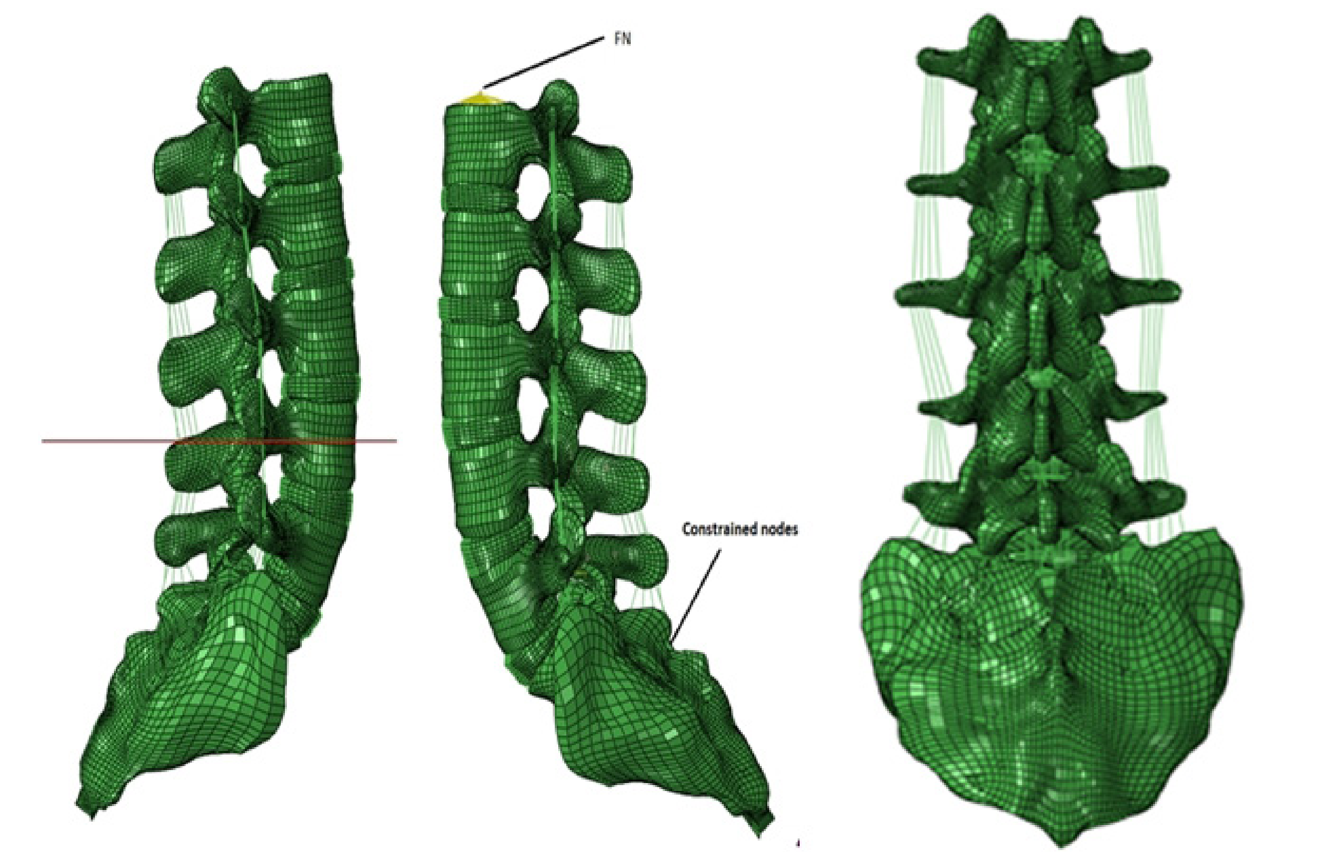

Figure-1. FE model of the intact lumbar spine

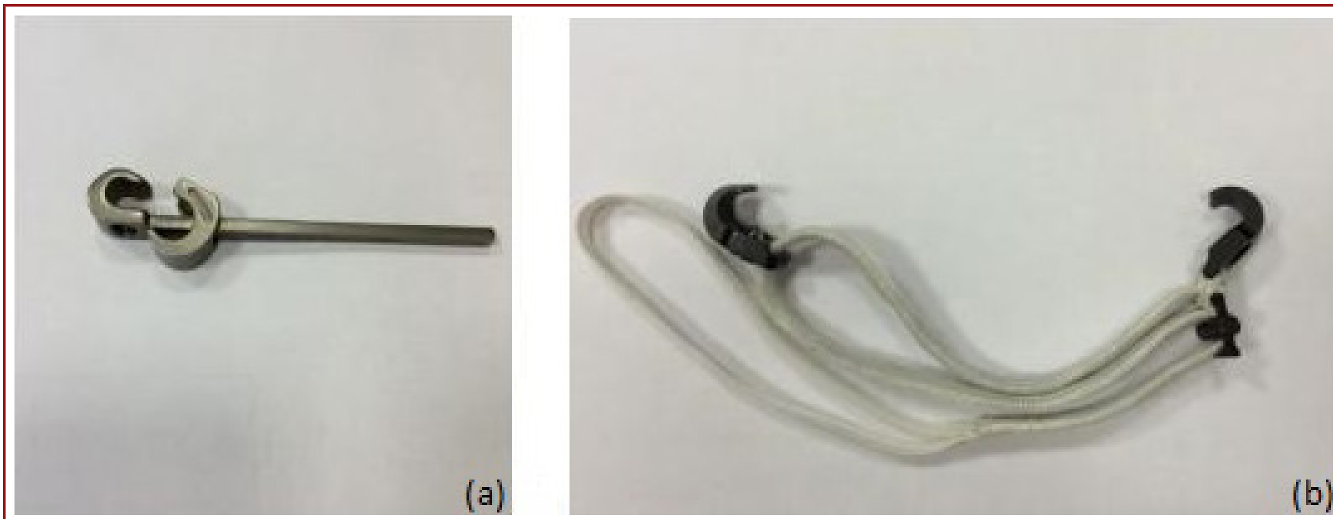

Figure-2. A support system for posterior stabilization constructs: **a)** Titanium alloy support **b)** Polyethylene support.

Table-1. Mechanical properties and element types of the different parts of the lumbar spine model.

Component	Element Formulation	Modulus (MPa)	Poisson's Ratio
Vertebral Cancellous Bone	Isotropic, elastic hex elements	450	0.25
Vertebral Cortical Bone	Isotropic, elastic hex elements	12000	0.3
Posterior Bone	Isotropic, elastic hex elements	3500	0.25
Nucleus Pulposus	Isotropic, elastic hex elements	9	0.4999
Annulus (Ground)	Hyperelastic, Neo Hooke	C10=0.3448, D10=0.3	
Annulus (Fiber)	Rebar	357-550	0.3
Ligaments			
Anterior Longitudinal	Truss elements	7.8 (<12%), 20.0 (>12%)	0.3
Posterior Longitudinal	Truss elements	10.0 (<11%), 20.0 (>11%)	0.3
LigamentumFlavum	Truss elements	15.0 (<6.2%), 19.5 (>6.2%)	0.3
Intertransverse	Truss elements	10.0 (<18%), 58.7 (>18%)	0.3
Interspinous	Truss elements	10.0 (<14%), 11.6 (>14%)	0.3
Supraspinous	Truss elements	8.0 (<20%), 15.0 (>20%)	
Capsular	Truss elements	7.5 (<25%), 32.9(25%)	0.3
Apophyseal Joints	GAPUNI		

Table-2. Range of motion for intact and intact with instrumented FE lumbar spine

Axial rotation				
	Intact	**Rod-fusion**	**Titanium-support**	**Polyethylene Band support**
L1-2	34.064	34.535	34.597	34.534
L2-3	3.354	3.372	33.717	33.782
L3-4	37.829	37.418	37.419	3.742
L4-5	39.243	0.161	0.1544	0.1544
L5-S1	46.391	46.354	46.354	46.353

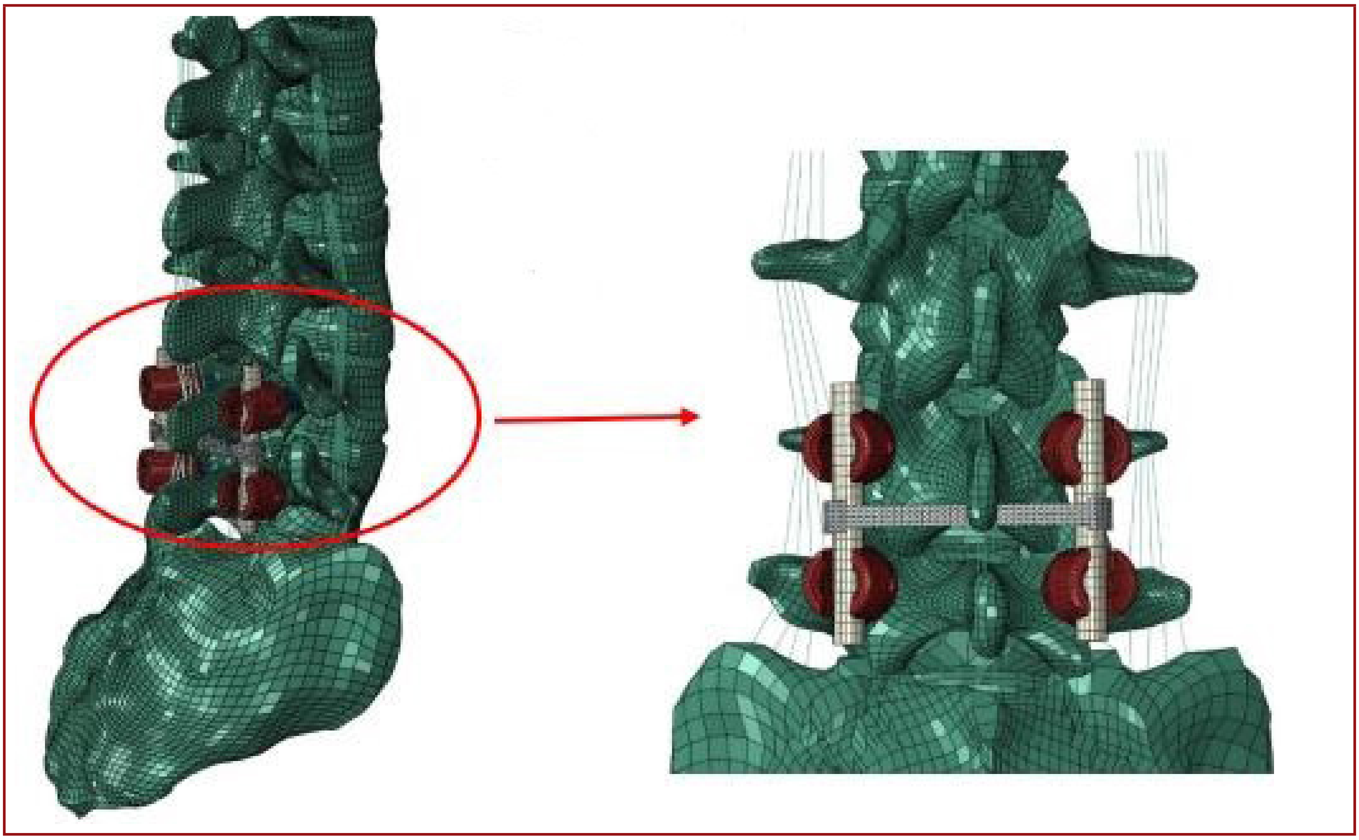

Figure-3. FE model of the lumbar spine with pedicle based posterior stabilization system with Titanium alloy support

Table-3. Range of motion of intact with instrumented FE model in % of intact

	Axial rotation		
	Rod-fusion	**Titanium-support**	**Polyethylene Band support**
L1-2	1.4	1.6	1.4
L2-3	0.5	0.5	0.7
L3-4	1.1	1.1	1.1
L4-5	95.9	96.1	96.1
L5-S1	0.1	0.1	0.1

Boundary and loading conditions

In all directions, the nodes lying on the upper endplate of L1 were coupled to a flying node (FN) higher than the surface of the L1 endplate; then, a pure moment was applied to the FN (Figure-1). The follower load was applied on each side of all segments such that the unwanted segmental rotation was less than 0.2° 19. The follower load was simulated using the connector elements between each set of adjacent vertebrae. The nodes lying at the outer surface of the sacrum were constrained in all directions (Figure-2).

A 10 Nm bending moment was applied to the superior surface of the L1 vertebra in the intact spine, and the segmental and overall ROM was obtained in flexion (Flex), extension (Ext), lateral bending (LB) and axial rotation (AR). The follower load concept was used to apply 400 N as the body weight in each segment.

RESULTS

Range of motion was decreased by 95.8 % when the pedicle-based stabilization system was used at L4–L5. Range of motion was decreased further about 1 % when the polymer band was used in conjunction with the posterior stabilization system in axial rotation. Similar results were observed when the titanium transverse connector was used.

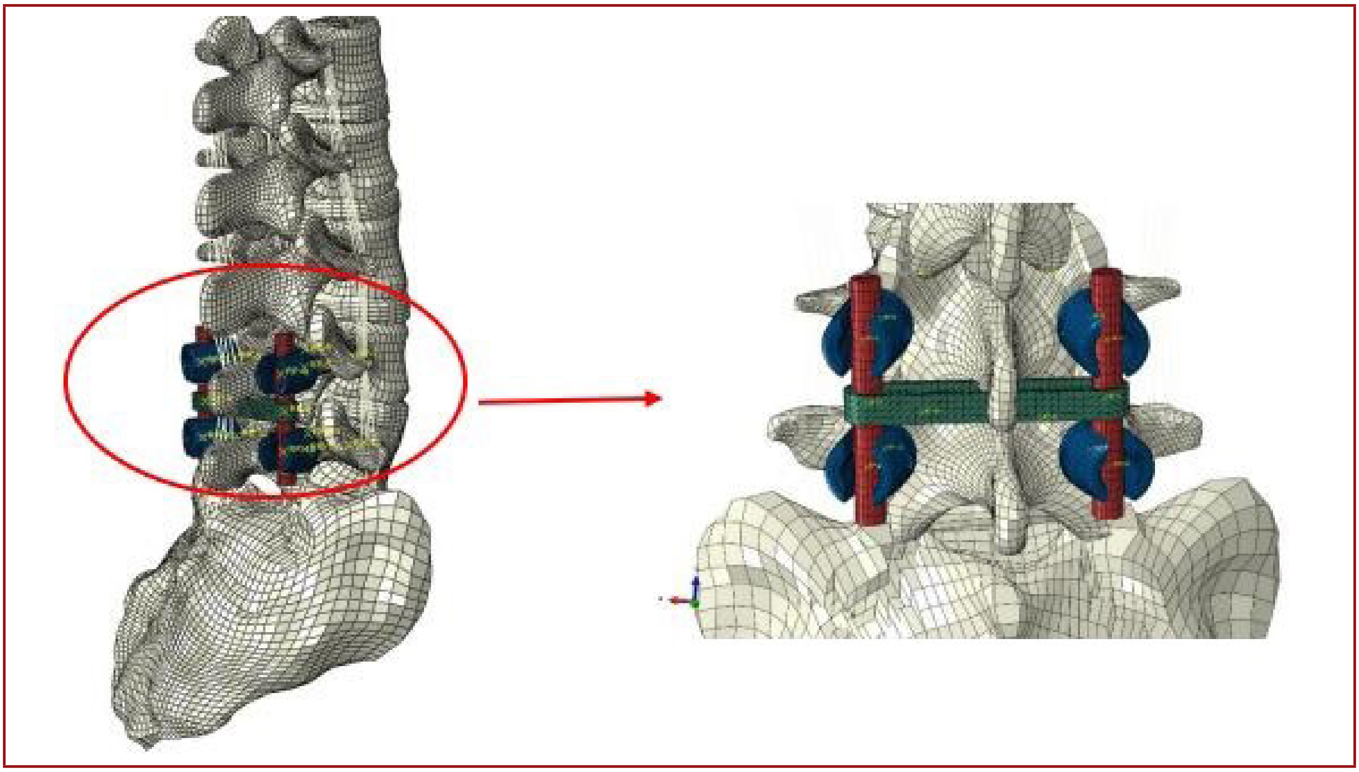

Figure-4. FE model of the lumbar spine with pedicle based posterior stabilization system with Polyethylene support.

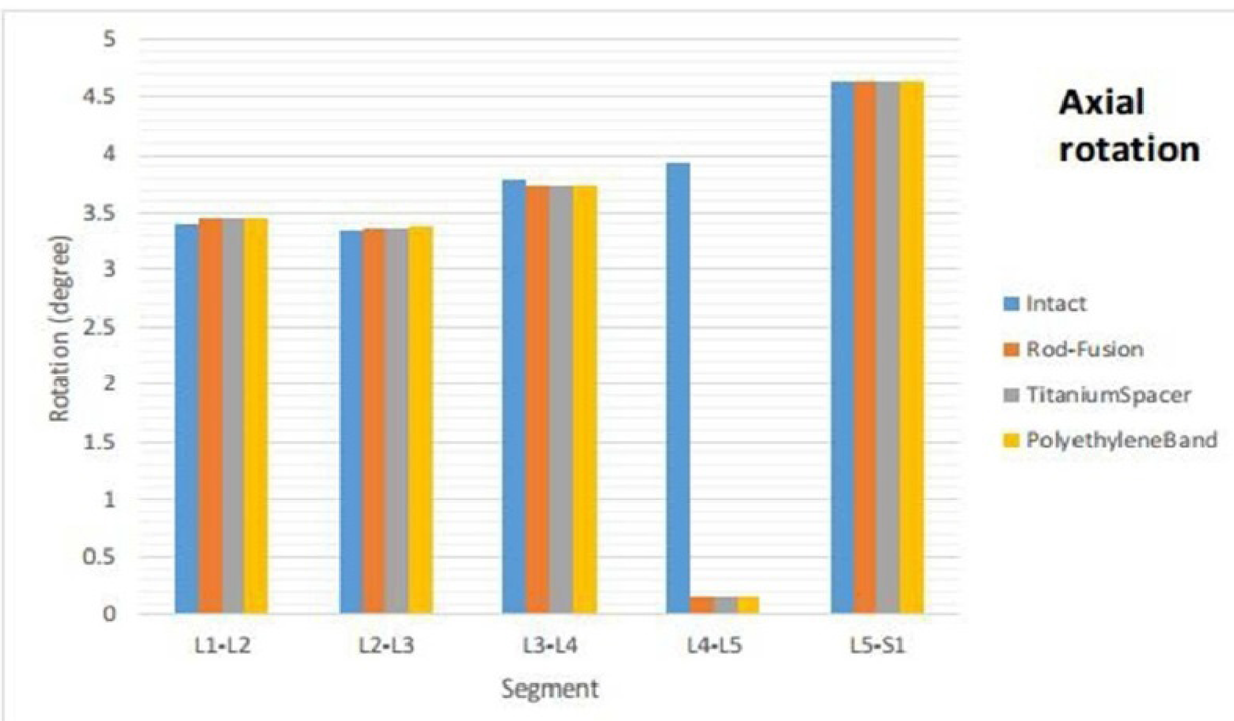

Figure-5. ROM of intact and intact with instrumented FE models in axial rotation

DISCUSSION

Surgery is the gold standard for lumbar degenerative disc disease. However, like many reports, inevitable side effects of fusion such as chronic back pain and adjacent segment degeneration have been documented [1-2,5]. The standard surgery is decompression through extensive laminectomy. The success rate of this procedure ranges from 62 % to 70 %. At the same time, failures caused by other reasons such as inadequate decompression in patients, who were selected incorrectly, are usually associated with iatrogenic postoperative spinal instability [6,8].

Iatrogenic instability is associated with incorrect detection and fusion. Motion preservation technologies are introduced as rigid stabilization and posterior dynamic stabilization systems to overcome these adverse effects [9-10]. Posterior dynamic stabilization systems have recently gained popularity. Abnormal load transmission along a degenerated spine motion segment leads to abnormal segmental motion. Dynamic systems were not effective in balancing this abnormal load distribution. The early clinical results of these systems have shown that they were effective in patients with degenerative spondylolisthesis and spinal stenosis [1,8,13].

Clinical results in the moving systems are still controversial despite the theoretical advantages over rigid fusion. One reason for the discrepancy between the two systems is caused by incorrect design. The ideal systems are ones that are normal kinematics, are capable of sharing the load with normal load transfer and may mimic a normal functioning spinal unit [11,12]. Ideal systems should have a stability and rigidity that will provide a fusion biomechanically and will not require external support. Technically, the application should be easy, tissue-compatible and easily found [2].

There are two types of lumbar spine displacement in all three action plans, including separately translation and angulation. Thus, the spinal column, and any part of it, can do six different movement [13]. The growth of the vertebra in the spine by going towards the distal, showing the physiological curvature for 4 times and anatomical features of the bone and soft tissue structures in accordance with the curvature are important in terms of spinal movements and the transport of the load over the spine. The rotational movement of the lumbar region is lumbar 5° [1-2,5].

The characteristics of an ideal instrument are as follows. It should provide an anatomic reduction and anatomic contour of the spine, an indirect decompression with distraction and a correction of the neural canal. It should have a stability and rigidity that will provide a fusion biomechanically and will not require external support. Technically, the application should be easy, it should be tissue-compatible and easily found [2].

Spinal instrumentations are among the medical supplies that are most discussed and developed in the last century [10,12]. Authors have always worked on something better. Except for a few issues, which have gained certainty, many techniques and application materials are controversial. The effects of the transverse binder systems' binding of the transpedicular screw rod system on the movements of the lumbar spinal region has not been fully studied.

Rigid transverse binders also minimize the rotational movements of lumbar spinal regions whose movements are largely lost. Newly developed polyester bands affect the rotational movement less.

In our study, both systems provided the rigidity needed in areas where they were applied for fusion. Significant superiority was not observed in the values, which is due to the application.

The most important short-term advantage of polyester band usage is the easy merging with the transpedicular screw and rod system in the perioperative period, which reduces the operation time and the amount and time of anesthesia received. The first priority in this process is patient comfort and bringing his/her everyday life as close to normal as possible. Other factors are the comfort of the surgeon, the amount of bleeding, surgical areas, time of the anesthesia and cost.

In light of all FE analysis results, neither of the systems applied had a significant superiority over the other. There are not enough studies in the literature on the use of transverse binder systems in spinal transpedicular screw systems. We believe that the advantages of the use of the polyester band in axial rotation will assure superiority over rigid systems.

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