KINEMATIC RESPONSE OF THE L4-L5 FUNCTIONAL SPINAL UNIT AFTER A LATERAL LUMBAR FUSION SURGERY

RESPOSTA CINEMÁTICA DA UNIDADE FUNCIONAL L4-L5 APÓS FUSÃO INTERVERTEBRAL LOMBAR RECORRENDO À ABORDAGEM LATERAL

S. C. Caetano[1], B. Areias[2], L. C. Sousa[2(*)], M. Parente[2], R. Natal[2], H. Sousa[3], J. M. Gonçalves[4]
[1]MEB, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal, Portugal
[2]INEGI e DEMec, Faculdade de Engenharia da Universidade do Porto, Porto, Portugal
[3]Centro Hospitalar de Vila Nova de Gaia / Espinho, Vila Nova de Gaia, Portugal
[4]Faculdade de Medicina da Universidade do Porto, Hospital da Luz Arrábida, Porto, Portugal
[(*)]*Email:* lcsousa@fe.up.pt

RESUMO

Este trabalho tem por objetivo o estudo do comportamento biomecânico da unidade funcional L4-L5 quando sujeita a uma fusão intervertebral recorrendo à abordagem lateral. Nesta abordagem minimamente invasiva, o implante Oracle Cage destina-se a substituir discos intervertebrais lombares e a fundir os corpos vertebrais adjacentes em níveis vertebrais de L1 a L5. Um modelo tridimensional de elementos finitos (FE), da unidade funcional L4-L5, foi criado para estudar a estabilidade cinemática da fusão intervertebral recorrendo à abordagem lateral.

ABSTRACT

The present work aims to develop a numerical simulation of the direct lateral interbody fusion of L4-L5 spine unit using the finite element (FE) method. In this minimally invasive surgical approach for vertebrae fusion, the Oracle Cage implant is intended to replace lumbar intervertebral discs and to fuse the adjacent vertebral bodies together at vertebral levels L1 to L5. A 3-dimensional, nonlinear finite element model of the L4-L5 functional spine unit is used to study the kinematic stability of the lateral lumbar interbody fusion.

Keywords: Finite element method, Oracle Cage system, minimally invasive lumbar fusion, lateral lumbar interbody fusion.

1. INTRODUCTION

Spinal Fusion (Spondylodesis) is a spinal surgery used to relieve the pain caused by unstable vertebrae in the human spine (Spondylolisthesis). This surgery is required in cases of severe instability of the spine when the vertebrate bodies start to slip causing chronic back pain and symptoms of nerve compression. Spinal fusion will not interfere with the patient’s mobility or flexibility, particularly because the patient does already suffer reduced mobility from the symptoms of his spondylodesis. The linking of vertebrate bodies will put an additional mechanical strain on the adjacent segments of the spine and this increase in mechanical strain in some areas of the spine has the potential to increase spinal disc degeneration and discomfort.

Spinal fusion surgery simulations allow the knowledge of the lumbar spine kinematics, the development of new spinal implants and the optimization of surgical interventions.

The direct lateral approach shown in Fig. 1, is a minimally invasive approach that avoids direct exposure of the anterior vessels, posterior nervous and bony structures [1-2]. The Oracle Cage system includes a modular and comprehensive set of implants and instruments designed to support a direct lateral approach to the lumbar spine [3]. The Oracle Cage implant shown in Fig. 1, is intended to replace lumbar intervertebral discs. It is inserted via the lateral approach and requires supplemental fixation. Before Oracle Cage insertion, it is necessary to remove disc material from the intervertebral space. It is recommended to keep intact a few millimeters of the annulus on both anterior and posterior sides in order to prevent any risk of damaging vital structures. The anterior and the posterior longitudinal ligaments (ALL and PLL) must also stay intact in all cases.

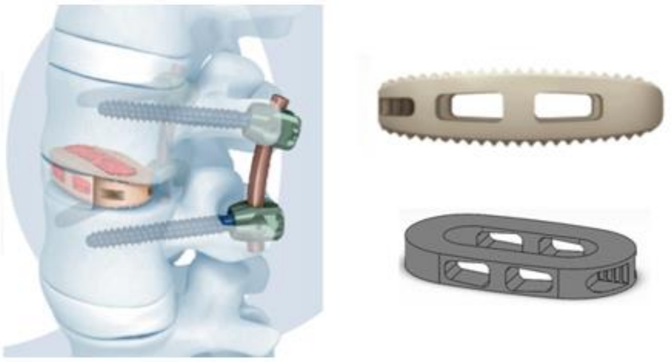

Fig. 1 – Lumbar interbody fusion using the direct lateral approach and Oracle cage implant.

The implant is available in 4 medial/lateral lengths, 5 heights, and 2 sagittal profiles to accommodate various patient anatomies. It is manufactured from a biocompatible polymer1 material embedded with four radiopaque marker pins, which allow the surgeon to radiographically determine the exact position of the implant, both intraoperatively and postoperatively. The implant has a large central canal that accommodates autogenous bone graft or bone graft substitute allowing fusion to occur through the cage. The modulus of elasticity of the polymer is approximately between cancellous and cortical bone, which enables adequate compression of autograft in and around the implant, to aid in stress distribution and load sharing.

2. METHODS

The definition of the intervertebral disc and ligaments of the L4-L5 functional spine unit (FSU) was performed using commercial software *Mimics* and *Abaqus/Cae*. Due to its lower density, the intervertebral discs are not visible in a CT. The geometry of the disc was defined using the lower surface of L4 and the upper surface of L5. A plane was defined slightly above the lower surface of L4 and the disc geometry was obtained, by extruding the elliptical sketch in direction to L5, and extending slightly below the superior endplate of L5. The disc was partitioned into two regions: the inner nucleus pulposus and the peripheral annulus fibrosus taking into account the volumetric ratio 3:7, respectively.

After the definition of L4-L5 FSU the Oracle Cage was inserted, removing the disc material from the intervertebral space, keeping intact a few millimeters of the annulus on both anterior and posterior sides, about 25% of annulus thickness. Fig. 2 shows the FE model of the L4-L5 functional unit used for the numerical simulations. Boundary conditions were defined according literature [4-6]. On the inferior endplate of the L5 vertebra, all nodes were constrained from moving in any of the three

Fig. 2 –L4-L5 functional unit: vertebrae and oracle cage finite element mesh.

mutually perpendicular directions. In order to apply the loads a point load was applied to a reference point in the center of the superior surface of L4, which was connected to all the nodes of the superior endplate surface by kinematic coupling. Table 1 shows the mechanical properties adopted for the different materials [5]. The FSU model was subjected to pure moments (10 Nm) in the three anatomical planes and a compression force of 150 N, and solved using Abaqus Explicit.

3. RESULTS AND DISCUSSION

Fig. 3 shows axial displacement field for the compression, flexion and extension load cases and Fig. 4 the displacement field for lateral flexion and torsion; for the compression load, the greater displacements are found at the posterior area of vertebra L4. As expected, considering load case flexion the spinous processes present positive axial displacements, while for extension in the same zone the displacements are negative. For these two load cases the highest displacement values are found at the spinous processes.

The highest displacements are found considering lateral flexion and torsion load cases. In lateral flexion this is due to the damaged lateral area of the fibrous annulus. From this study it can be concluded that lumbar torsion and lateral bend are movements that even after a lateral interbody fusion, can contribute to spine instability and lumbar disc degenerative changes.

Table 1 - Mechanical Properties.

Ligaments	Young Modulus E [MPa]	Poisson Ratio ν	Section Area [mm²]	Number of Elements
Anterior Longitudinal ALL	20	0,3	53	5
Posterior Longitudinal PLL	20	0,3	16	5
Intertransverse ITL	60	0,3	1,8	4
Interspinous ISL	10	0,3	26	6
Supraspinous SSL	10	0,3	23	3
Flavum LF	20	0,3	67	3
Capsular Ligament CL	8	0,3	43,8	6
Vertebrae Cortical bone	1200	0.3		
Vertebrae Trabecular bone	100	0,2		
Oracle (Peek)	3500	0,3		
Screws	110000	0,28		
autogenous iliac bone	1500	0,3		

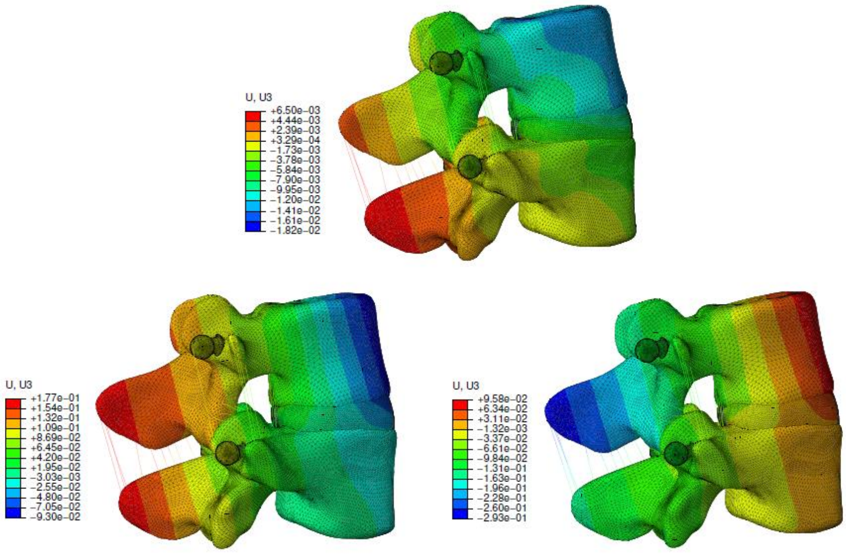

Fig. 3 – Axial displacement field of the L4-L5 functional unit: compression, flexion and extension loads.

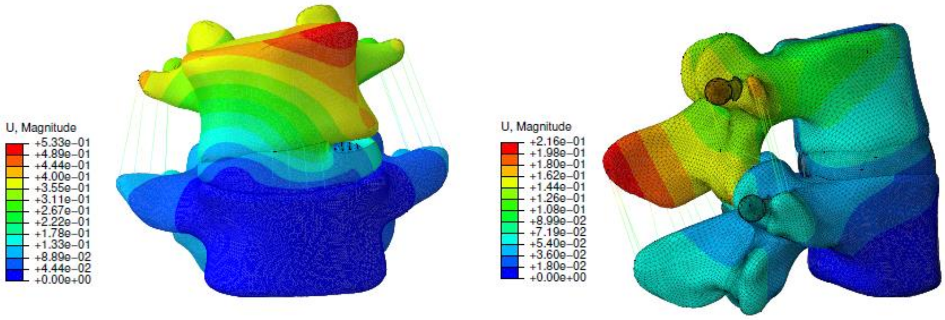

Fig. 4 –l Displacement field of the L4-L5 functional unit: lateral flexion and torsion.

4. CONCLUSIONS

Numerical simulations of kinematic response of lumbar functional spinal units present low costs and no risks to the biological tissue (bone). Simulations may be used for identifying and characterizing physiologic and pathologic motion and may find application to identifying indications for spinal fusion. Numerical simulations of lateral lumbar interbody fusion may also useful to optimize implants and surgeries.

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