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LATERAL LUMBAR FUSION, A MINIMALLY INVASIVE SURGICAL APPROACH FOR LUMBAR INTERBODY FUSION

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ABSTRACT

The lumbar spine is one of the more complex structures of the human skeleton and the incidence of failure that may result from trauma or degenerative diseases is high. The knowledge of the lumbar spine kinematics is a very important tool for many clinical applications such as diagnosis, treatment and surgical interventions and for the development of new spinal implants. A nonlinear 3-dimensional finite element model of the L4-L5 functional unit is used to study the kinematic stability of a minimally invasive surgical approach for lateral lumbar interbody fusion. In this work the simulation of the direct lateral and posterior fusion of L4-L5 spine unit is performed using the finite element (FE) method.

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

INTRODUCTION AND METHODOLOGY

Degenerative disc diseases and spinal instabilities, pseudoarthrosis or failed spondylodesis, degenerative spondylolisthesis and isthmic spondylolisthesis are lumbar pathologies with indicated segmental spondylodesis. The comparison of different surgical approaches for lumbar interbody fusion like lateral and posterior approaches may help clinicians to understand the initiation and progression of disc degeneration and to treat lumbar discopathy problems even more effectively.

The Oracle Cage system is a modular and comprehensive set of implants and instruments designed to support a direct lateral approach to the lumbar spine (Synthes GmbH).

Fig. 1 - Lumbar interbody fusion using the direct lateral approach: Oracle cage insertion and supplemental fixation.

The direct lateral approach shown in Figure 1, is a minimally invasive approach that avoids direct exposure of the anterior vessels, posterior nervous and bony structures (Yuan et al. 2014; Talia *et al*., 2015). The Oracle Cage implant (Figure 2) is intended to replace lumbar intervertebral discs and to fuse the adjacent vertebral bodies together at vertebral levels L1 to L5. It is inserted via the lateral approach and is intended to be used in combination with supplemental fixation. Before Oracle Cage insertion, it is necessary to remove disc material from the intervertebral space. In order to prevent any risk of damaging vital structures, it is recommended to keep intact a few millimeters of the annulus on both anterior and posterior sides. The anterior and the posterior longitudinal ligaments (ALL and PLL) must also stay intact in all cases.

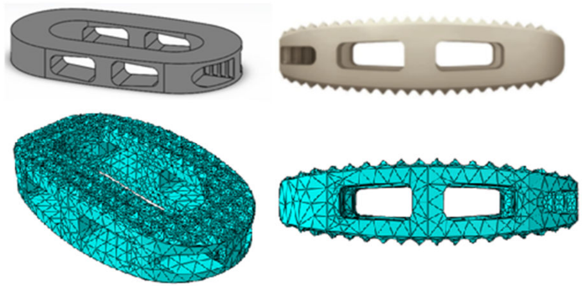

Fig. 2 - Oracle Cage anatomic shape and finite element mesh.

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 large central canal accommodates autogenous bone graft or bone graft substitute to allow 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.

Table 1 - Mechanical Properties of Ligaments

Ligaments	Young Modulus E [MPa]	Poisson Ratio ν	Section Area [mm^2]	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

Ref. (Moramarco *et al*. 2010)

Then the definition of the intervertebral disc and ligaments, and the assigning of material properties to each element of the FSU were performed. 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.

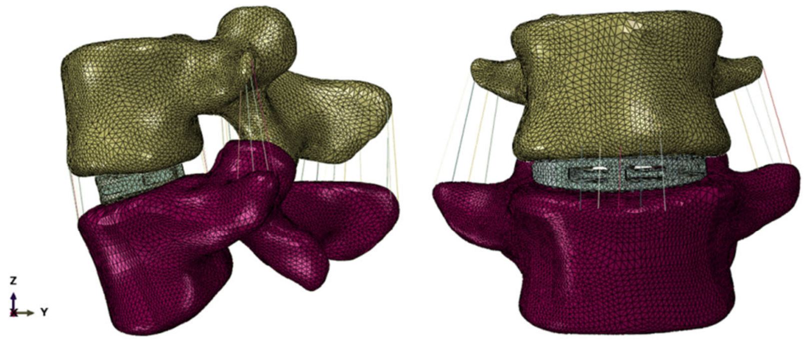

Fig. 3 - L4-L5 functional unit: vertebrae and oracle cage finite element mesh.

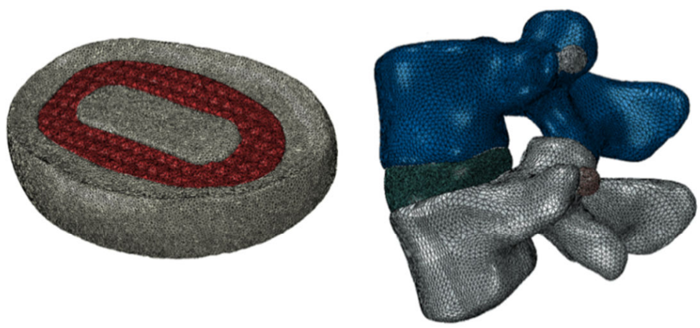

Fig. 4 - Finite element model of the L4-L5 functional unit.

Figure 3 shows the Oracle Cage position and Figure 4 the FE model of the L4-L5 functional unit used for the numerical simulations. A few millimeters of the annulus were kept intact on both anterior and posterior sides as it is recommended, in order to prevent any risk of damaging vital structures.

Boundary conditions were defined according literature (Kuo *et al*., 2010, Moramarco *et al*. 2010, Weisse *et al*.). On the inferior endplate of the L5 vertebra, all nodes were constrained from moving in any of the three mutually perpendicular directions. In order to apply the loads a point load was applied to a reference point in the centre of the superior surface of L4, which was connected to all the nodes of the superior endplate surface by kinematic coupling.

RESULTS AND DISCUSSION

Finally, the model was solved using Abaqus Explicit. Considering the load case compression, a load of 500 N was applied to the reference point. Figure 5 presents the displacement field where vertebra L4 and the spinous processes present the grater axial displacement.

Numerical simulations of lateral lumbar interbody fusion present low costs and no risks to the biological tissue (bone), and they are able to provide data that allow the prediction of surgery outcomes as the most stressed parts of the discs, corresponding to areas prone to damage. Simulation of orthopedic spine surgeries can also be used to optimize implants, which may help reduce post-surgical complications and recovery.

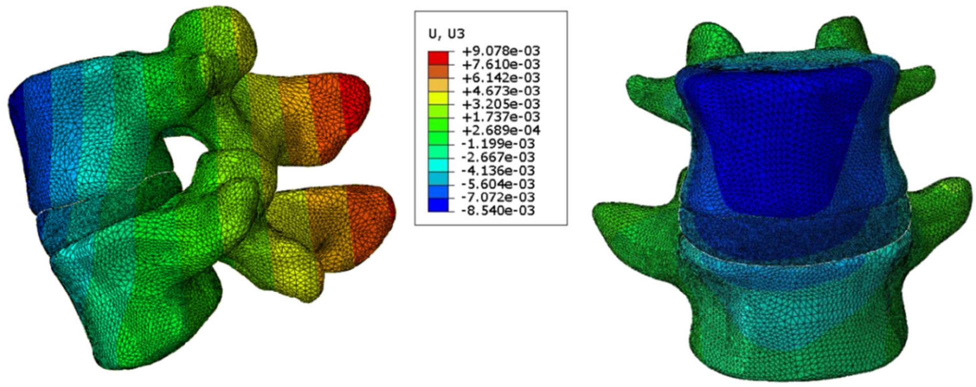

Fig. 5 - Displacement field of the L4-L5 functional unit.

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