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A FINITE ELEMENT STUDY OF MECHANICAL BEHAVIOUR OF INSTRUMENTED LUMBAR SPINE WITH THREE DIFFERENT LONGITUDINAL RODS DESIGNS: SLIDING ARTICULATED, FLEXIBLE AND RIGID

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SUMMARY

Spinal fusion is the gold standard treatment for severe pathologies in lumbar spine. However, fusion can yield adverse effects, such as Adjacent Segment Degeneration (ASD). Alternatively, non-fusion techniques were proposed. Although infrequent, mechanical complications were reported such as screw loosening and screw breakages. This work aims to use Finite Element Model (FEM) to investigate implants with different rod designs: articulated sliding, flexible and rigid (fusion). A L3-S1 validated spine model was used. Surface contact elements modeled connector-rod interface for the sliding implant. Beam elements modeled the rod with different Young modulus between the rigid and the flexible implant. Rigid to flexible Young's modulus ratio was 10000. The instrumented segment was L4-L5. S1 was rigidly fixed. Imposed rotations were applied to L3 vertebra considering physiologic L3-S1 ROM. These values were the same for each modeled configuration: intact, injured, injured with sliding implant, injured with rigid implant and injured with flexible implant. Screw and discs stress and Range of Motion (ROM) were obtained for all configurations and different loads. Modeling of the sliding implant was validated by comparing the instrumented model ROM with experimental *in-vitro* corridor on 6 cadaveric segments. Bending moment in the sliding rod was significantly smaller than others configurations. Flexible implant decreased peak stress compared to fusion in adjacent segments. They did not reduce axial rotation ROM.

INTRODUCTION

Severe pathologies in lumbar spine can cause pain and handicap. When rehabilitation treatments are insufficient for reducing pain to an acceptable level, spinal fusion is the gold standard treatment. However, fusion can present mechanical complications such as adjacent segment degeneration [1]. Alternatives implants were proposed [2], among which different types of articulated or flexible rods connected to pedicle screws. However clinical results are variable, studies reported until 17% of screw breakage or loosening in non-fusion outcomes [3].

This project aims to investigate the mechanical behavior with emphasis on screw and adjacent discs stresses for three different longitudinal rods designs: sliding articulated, flexible and rigid (fusion).

METHODS

A L3 to S1 validated Finite Element spine model was used [4,5]. Bone was modeled by hexahedral elements with isotropic material behavior and a differentiation between trabecular part (E = 100 MPa) and cortical outer layer (E = 12000 MPa). In the intervertebral disc, annulus fibrosus fibers were modeled by cable elements inside a hexahedral matrix with a multilinear elastic modulus as material behavior. Nucleus is modeled by a hexahedral mesh with a quasi-incompressible (Poisson's ratio = 0.499) material behavior. All ligaments are modeled by cable elements and facet contact is modeled by surface contacts elements.

Simulations were performed in different configurations i.e. intact, injured and instrumented with different kinds of rod: sliding, rigid and flexible.

The decompression procedure was mimicked by suppressing elements from posterior arch of L4 vertebra to simulate a bilateral facetectomy and a laminectomy. Supraspinal, interspinal and flavum ligaments between L4-L5 were also removed.

In the sliding articulated device a 30° angulated rod is inserted and fixed at the level of the superior monoaxial pedicle screws. This rod is linked to the inferior pedicle screws using a polyaxial connector which allows movements in flexion/extension, lateral bending, and axial rotation. Both rods are additionally connected to each other by a crosslink aimed to avoid excessive axial rotation [6]. The four pedicle screws were modeled by beam elements attached to the pedicle. The curved longitudinal rod of the sliding rod was modeled by a hybrid model, where the upper elements were modeled as beam elements and lower ones were modeled as hexahedral elements. The connectors were modeled by 8-node hexahedral elements. The spherical and cylindrical joints were coated by frictionless contact elements. Validation of the instrumented spine with the sliding rod model was performed by comparing its ROM behavior with respect to an experimental *in-vitro* corridor [6] for instrumented spine without lesion and with facetectomy.

Rigid implant was modeled by beam elements with Young Modulus of Cobalt-Chromium-Molybdenum alloy (E = 241000 MPa). Evaluation of the rigid model was checked using existing *in-vitro* data. Flexible implant was modeled by lowering Young Modulus of longitudinal rods (E = 241 MPa) to represent axial stiffness of flexible implants as referenced in the literature (200N/mm²) [7].

S1 vertebra was rigidly fixed. A compressive follower load of 400 N was simulated as described in [8]. Angular physiological rotations were applied to the superior L3 vertebrae: 17° in flexion, 14° in extension, 13° in lateral bending and 9° in axial rotation. These values were the same for each modeled configuration. Simulations were performed using Ansys version 10.0 software. Geometrical nonlinearities were taken into account.

Range Of Motion (ROM) of each segment (L3-L4, L4-L5 and L5-S1) for all configurations and loads were obtained. Von Mises stress was calculated for a middle axial section of Annulus. Screws axial and shear forces, and bending moment were also obtained.

RESULTS AND DISCUSSION

All results of validation procedure of the sliding implant were within the corresponding experimental corridors. Moreover for the rigid implants, models were built for L5-S1 levels for which we had previously experimental data on 8 cadaveric segments and again the results were inside *in-vitro* corridors. This demonstrates the global coherence of the model.

The injury procedure changed significantly repartitioning of ROM in axial rotation. In intact configuration, L4-L5 rotation represented 35% of total ROM and for injured it was increased to 53%. The sliding and rigid implants limited ROM of L4-L5 in axial rotation to 21% and 26% respectively. Flexible implant did not limit L4-L5 axial rotation (49%).

Bending moment in the sliding configuration was significantly smaller than flexible and rigid configuration (Fig 1). Normal and shear forces were similar for all kind of implants.

Von Mises stress in annulus for intact, injured and with sliding implant were comparable in flexion , extension and lateral bending (max= 0.6 MPa, max= 0.7 MPa , max= 1.3 MPa respectively). Rigid implant increased peak stress in annulus (from 1.1 MPa in flexion; to 2.2 MPa in lateral bending). Flexible implant decreased stresses compared to fusion (13% for flexion, 10% for extension, 14% for lateral bending and 50% for axial rotation). In axial rotation, injury reduced peak stress from 0.86 MPa in intact configuration to 0.58 MPa. Sliding was comparable to fusion in axial rotation due to the presence of a transversal crosslink (1.2 MPa).

This study compared different types of implant designs for physiologic rotations, adjacent segment stresses; screws generalized forces and ROM for a spine with an injury in posterior arch. The sliding implant decreases stresses in adjacent discs and screws, it could be an alternative in cases where intervertebral disc is not degenerated and stands compressive forces. *In-vivo,* clinical cases are highly variable and there are others important factors to be taken into account by surgeons. For many clinical cases maintaining or increasing disc's height of the instrumented segment is essential. Future *in-vivo* studies could clarify limits and advantages of non-fusion devices.

CONCLUSIONS

This finite element study allowed to investigate the effect of rod design on adjacent discs and screw stresses, and differences were found according to the design. Although such results have to be considered with caution because *in-vivo* factors such as muscles are not taken into account, the FEM appeared powerful to better understand mechanical behavior of the lumbar instrumented spine.   .

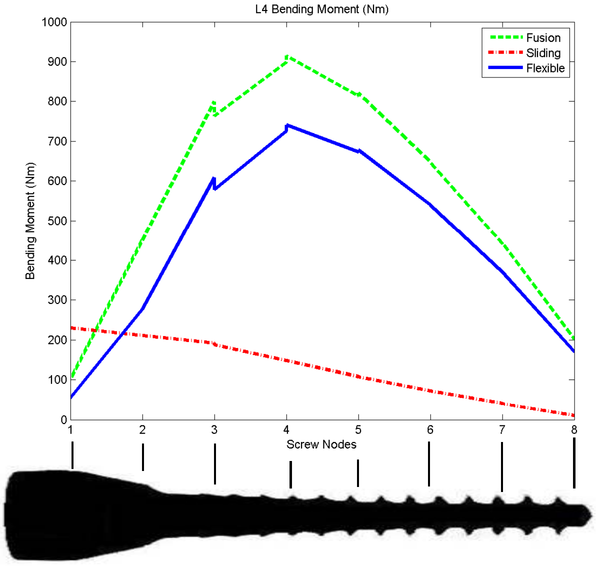

Figure 1: Bending moment on a screw for 17° flexion of a L3-S1 spine for different rods designs.

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