Adjacent Segment Biomechanics after Lumbar Fusion Depends on Simplified or Realistic Spinal Loading Conditions: A Comparative Numerical Study

Robin Remus[1], Marisa Ritter[1], Sascha Selkmann[1], Marc Neumann[1], Beate Bender[1]
[1]Chair of Product Development, Department of Mechanical Engineering, Ruhr-University Bochum, Germany
Email: robin.remus@rub.de

Summary

The biomechanical effects of simplified and realistic loading conditions on the lumbar spine with a fused segment were compared using a new hybrid model. The results showed significant differences in the adjacent vertebral segments. This is to be considered in treatment planning and cage design.

Introduction

Interbody fusion surgery involves placing a cage between two vertebral bodies (VBs) to reduce segmental range of motion (ROM), restore disc height and lumbar lordosis, and achieve anterior load transfer. In the design process for new cages, traditionally passive finite element (FE) models of lumbar spine sections with simplified loading conditions (LCs) are used for structural mechanics analysis. The combination of follower load (FL) and bending moment (BM) has become established for this purpose. However, this neglects the complex interaction between active stabilizing musculature, spinal structures, and implants [1,2]. The aim of this study is therefore to compare and quantify the biomechanical effects of simplified and realistic *in vivo*-like LCs on a fused functional spinal unit (FSU) and adjacent spinal levels. For this purpose, a validated osteo-ligamentous lumbosacral spine (OLS) model [3] was modified and used with simplified LCs (FL+BM). Realistic LCs were predicted using a forward dynamic musculoskeletal lumbosacral spine (MLS) model with muscle-driven approach [4], based on the OLS model.

Methods

The passive hybrid OLS model built in ArtiSynth consisted of rigid body (RB) bones L1–Sacrum, fiber-reinforced FE discs, facet joints, and pre-tensioned ligaments. The FL (0–1500 N) was path optimized in terms of minimal intervertebral ROMs (<0.05°) and the BM (-5.5–7.5 Nm) was applied to RB L1. The MLS model (Figure 1A) was an extension of the OLS model and included 12 muscle groups of the lower trunk. To determine patterns of muscle activations, an optimization approach with forward dynamics assisted data tracking was used. Intra-abdominal pressure was considered. For fusion, the L4/5 FSU was augmented with FE VBs L4 and L5 (Figure 1B) with heterogeneous bone material properties. In line with TLIF procedures, the FE cage was inserted in place of the nucleus and expanded vertically during runtime for a press fit. After disc space distraction (6 % of mean disc height) a friction coefficient of 0.5 was set and bilateral FE posterior instrumentation (Figure 1C) was locked. To compare the LCs biomechanically, the MLS was moved by muscle forces to the equivalent postures of the OLS (L1 ROM as reference). The FL was increased until similar contact forces acted on the cage in both models (OLS and MLS): e.g., standing 728 N (FL = 695 N), or 23° flexion 1316 N (FL = 1312 N, BM = 7.5 Nm).

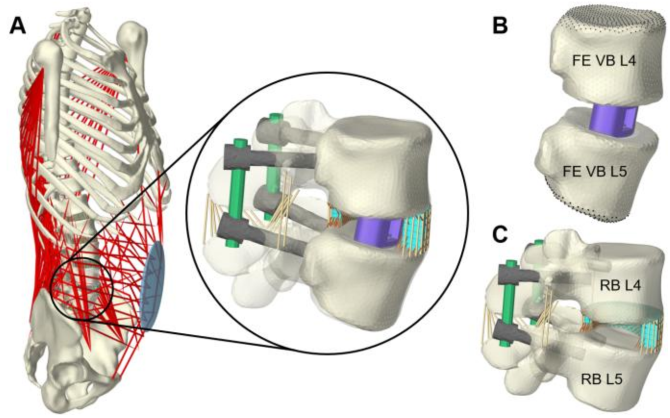

Figure 1: MLS model with a detailed view of the fused L4/5 FSU (**A**). The fusion consisted of a full FE model with a cage and VB (vertebral body) L4 and L5 (**B**), which were attached to the RB vertebrae of the hybrid FSU (**C**) via the VB FE nodes shown in black (**B**). The annulus fibrosus is shown in sectional view.

Results and Discussion

In MLS, axial compression forces in the fixator rods were higher and bending moments lower. Segmental ROMs varied, standard deviation σ without L4/5 was 0.2°/1.1° in OLS and 3.0°/1.8° in MLS, for 23° flexion/14° extension. Variations of the sagittal vertebral displacements and intra-discal pressures were increased in MLS: σ were 0.03 MPa/ 0.05 MPa in OLS and 0.26 MPa/0.18 MPa in MLS. Absolute value comparisons were limited despite FL variations. Results may be anatomy specific and validation with *in vivo* data was not feasible.

Conclusions

This study confirmed that loads are not constant at all spinal levels for different postures and that simplified loading conditions are likely to underestimate post lumbar fusion alterations in adjacent segments. This was enabled by a new hybrid approach that integrated complete FE bones and FE implants into a forward dynamic MLS model. The FE VB boundary conditions were equivalent to those of classic passive FE models but allowed for two-way interaction with the active muscles.

References

[1] Wang R and Wu Z (2023) *Front Bioeng Biotechnol*, **11**:1041973.
[2] Abbasi-Ghiri A et al. (2022) *J Biomech*, **141**:111173.
[3] Remus R et al. (2021) *PLoS ONE*, **16**(4):e0250456.
[4] Remus R et al. (2023) *Front Bioeng Biotechnol*, **11**: 1223007.