Biomechanics of a lumbar functional unit using the finite element method

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I. INTRODUCTION

Recent studies have shown that the lumbar spine is susceptible to injury in severe axial loading [1]. Although models have been developed for the cervical spine at high rates [2], that is not the case for the lumbar spine. Additionally, there is a suggestion that load sharing between different structures of a functional spinal unit (FSU) changes with posture [3], but this has not been studied in detail or at high rates. The aim of this study is to develop a finite element (FE) model of the L4-L5 FSU in order to look into its biomechanics at high rate axial loading.

II. METHODS

A patient-specific FE model of the L4-L5 FSU was developed (Fig. 1(a)). The geometry was based on scans of a cadaveric lumbar spine from a male donor. The nucleus pulposus (NP) of the intervertebral disc (IVD) was modelled as a fluid-filled cavity, with an initial pressure to simulate the pressure of the NP at a seated posture (0.3 MPa). Ligaments were modelled as non-linear springs. The anulus fibrosus (AF) of the IVD was modelled as a fiber-reinforced composite using brick and solid rebar elements. The host matrix of the AF was modelled as a Neo-Hookean material, whilst the fibers of the AF were modelled as linearly elastic with an area of 0.03212 mm^2 and spacing 4.35 fibers/mm (Table I). The facet joints (FJ) were modelled using beam and rigid body elements to allow for transfer of forces and moments. In all simulations the proximal side of the L4 was fixed, while the load was applied at the distal side of the L5. Two simulations were performed: 1. displacement-driven quasi-static compression up to 1 mm; and 2. impact of a 7 kg mass at a speed of 1 m/s. These simulations represent experiments conducted in our laboratory on the same cadaver.

TABLE I
THE MATERIAL PROPERTIES IMPLEMENTED IN THE FE MODEL OF THE FSU
E – YOUNG'S MODULUS, *N* – POISSON'S RATIO

Structure	Material values
Cortical Bone	E=16.8 GPa, v= 0.3
Trabecular Bone	E=0.3 GPa, v= 0.3
AF fibers	$E = 35.5 \ln \dot{\varepsilon} + 527.5$, v= 0.3
FJ beams	E= 1.2 GPa, v= 0.2
AF matrix	Neo Hookean; c1 = 0.2 MPa

III. INITIAL FINDINGS

Load distribution through the FSU and the model's response in quasi-static and impact axial compression are shown in Fig. 1. The model compares well with experiments in both quasi-static and impact axial compression (Fig. 1 (c) and (d)). Maximum principal rebar stresses were observed at the inner layers of the AF, close to the interface with the NP. Higher von Mises stresses were observed on the posterior side of the IVD. On the vertebrae, areas of high stresses were observed at the mid and posterior column.

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IV. DISCUSSION

The model suggests that approximately one-third of the load is going through the facet joints (Fig. 1(b)); this is similar with literature static experiments [3]. Furthermore, the model has been shown to predict adequately the axial force going through the FSU at 1 m/s impact. This model can now be used to investigate the areas of higher stress, for different postures and threats, at the FSU level.

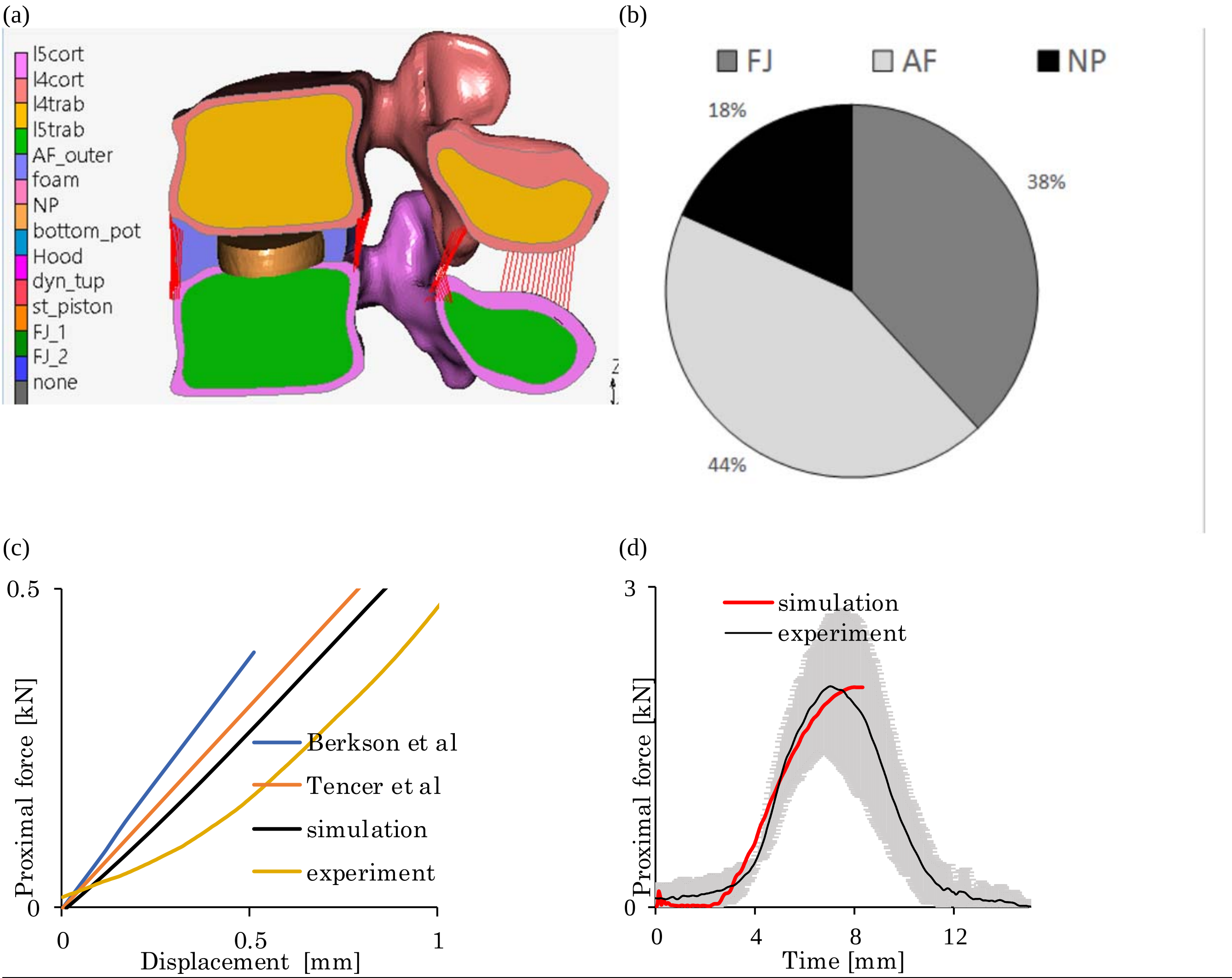

Fig. 1. (a) Lateral sagittal cross-sections of the FE model showing the IVD structures, the cortical and the trabecular of the FSU. L5cort and L4cort: cortical bone layer of L5 and L4 vertebra, respectively. L4trab and L5trab: trabecular bone of L4 and L5 vertebra, respectively. AF outer and NP: AF solid mesh and NP cavity, respectively. Bottom pot: rigid surface simulating the L4 fixation. FJ_1: Facet joint rigid surface for load transfer. The red lines indicate springs for modelling of ligaments of the FSU. (b) Load sharing between the different FSU components for static compression. (c) Force-displacement curves for quasi-static tests. Literature values are from [4-5]. (d) Force-time curves of the impact load case; with grey are three repeated impacts at 1 m/s of the same specimen.

V. REFERENCES

[1] Spurrier, E., *Spine*, 2016.
[2] Panzer, M. B., *J Biomech*, 2009.
[3] Adams, M., *J Bone Jt Surg Br*, 1985.
[4] Berkson, M. H., *J Biomech Eng*, 1979.
[5] Tencer, A., *J Biomech Eng*, 1981.