

STRESSES IN THE L2 VERTEBRA UNDER DIFFERENT LOADING CONDITIONS

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INTRODUCTION

The low bone mass that characterizes osteoporosis renders the skeleton, particularly the spine, susceptible to fracture under physiological loads. Better means of risk assessment may reduce the considerable morbidity and mortality with which these injuries are associated. Finite element (FE) models may improve clinical predictions of loading effects on vertebrae, especially stresses and strains produced in the tissues that cannot be measured experimentally. To date, FE methods have been used to identify vertebrae at high risk for fracture. However, these models' accuracy and reliability depend on the geometry, material and boundary conditions selected and have been based on simplified loading or material properties (eg, Crawford et al. 2003; Guo et al. 2005). Our objective was to examine the effect of increasing anatomic fidelity in the boundary conditions and material properties of FE-based predictions of L2 vertebral stresses under loading.

METHODS

Computed tomography (CT) images from a 55 year old female cadaver were used to generate the exact geometry of the L1 and L2 vertebrae. First, surface geometry was extracted from 1mm thick axial CT slices with an in-plane voxel size of 0.453 mm (Mimics, Materialise, Belgium). Then the surfaces (STL-format) were converted to surface splines (Studio, Raindrop Geomagic, NC). Finally, the surface model (NURBS format) was converted to a FE mesh (Truegrid, XYZ Scientific Applications, CA).

Two FE models were created. The first model included only the L2 vertebra with loads applied through steel plates on the superior and inferior endplates of L2. The second FE model was an L1-L2 spinal motion segment including the intervertebral disc and structurally relevant ligaments and the facet joints (Fig.1). The vertebrae were modeled with 8-noded solid elements. For each model, two bone material conditions were simulated: a homogeneous elastic modulus of 1000 MPa, or a heterogeneous modulus assigned based on an exponential density-elasticity relationship (Morgan et al. 2003). The facet joints were modeled as frictionless contact surfaces braced with capsular ligaments.

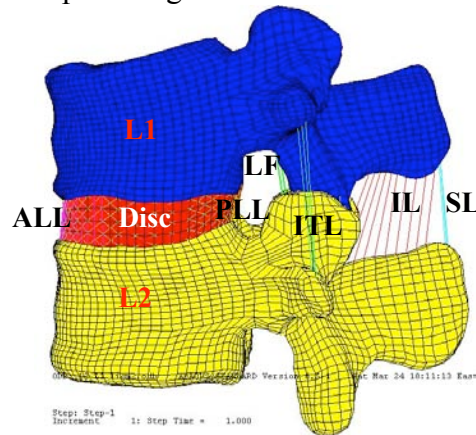


Figure 1: FE model of the spine segment

The disc model included the nucleus pulposus and the annulus fibrosus, represented as four layers of stiff fibers (Table 1) embedded in soft matrix ($E=4.2$ MPa). The nucleus, comprising ~40% of total disc volume, was modeled as a nearly incompressible solid with low stiffness ($E=0.2$ MPa). The ligaments and disc fibers

were modeled as tension-only axial elements. Locations, areas and material properties were obtained from the literature (Table 1) (eg, Goel et al. 1988; Shirazi-Adl et al. 1984).

Both models were fixed at the inferior-most endplate. Uniform compression (500 N) or flexion (7.5 Nm) loads were applied to the superior endplate. Stresses were calculated in L2 (ABAQUS, Hibbitt, Karlsson & Sorensen, Inc, RI).

Table 1: Ligament and fiber properties

	A	E		A	E
ALL	64	20	CL	40	20
PLL	20	20	Fiber1	0.35	550
ITL	10	50	Fiber2	0.30	475
SL	30	15	Fiber3	0.25	400
IL	40	10	Fiber4	0.20	360
LF	40	20			

A: Cross sectional area in mm², E: Elastic modulus in MPa, ALL: Anterior longitudinal ligament, PLL: Posterior longitudinal ligament, ITL: Inter-transverse ligament, SL: Supraspinous ligament, IL: Interspinous ligament, LF: Ligamentum flavum, CL: Capsular ligament, Fiber1: Outer most anular fiber layer, Fiber4: Innermost anular fiber layer

RESULTS AND DISCUSSION

Heterogeneity of bone substantially altered the distributions of von Mises stresses in the midtransverse section of L2 for both compression and flexion (Fig. 2,3). The stress distributions changed markedly when a more physiological loading was applied to L2 through L1 and the disc, ligaments, and facets (Fig. 2,3). Stress magnitudes differed most in the cancellous tissue. The mid-centrum stresses differed up to 450% in flexion and -15% in compression across the four models. The stress differences were less in the posterior (-67% in flexion and +11% in compression) and anterior (-21% in flexion and -68% in compression) cortices.

CONCLUSIONS

Accurate heterogeneity of the bone and physiological loading are critical to accurate

stress predictions in the L2 vertebra. We expect these models to better assess vertebral fracture risk and treatment outcome.

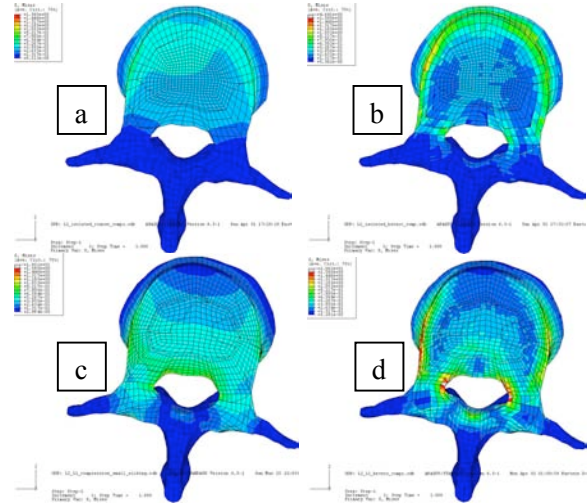


Figure 2: Stresses due to compression for a) homo- and b) heterogeneous L2 alone; c) homo- and d) heterogeneous L1-L2 segment

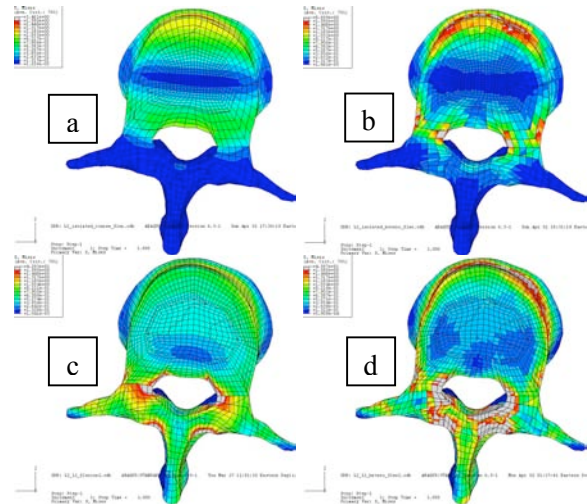


Figure 3: Stresses due to flexion for a) homo- and b) heterogeneous L2 alone; c) homo- and d) heterogeneous L1-L2 segment

REFERENCES

- Crawford *et al.* (2003) *Bone* **33**, 744-750.
- Goel *et al.* (1988) *Spine* **13**, 1003-1011.
- Guo *et al.* (2005) *Spine* **30**, 631-637.
- Morgan *et al.* (2003) *J Biomech* **36**: 897-904.
- Shirazi-Adl *et al.* (1984) *Spine* **9**, 120-134.