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3DEXPERIENCE

A COMPUTATIONALLY EFFICIENT AND ACCURATE LUMBAR SPINE MODEL

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ABSTRACT

- Stiffness properties of lumbar spinal units were calibrated using a connector-based model combining motion capture experiments and kinematic modeling.
- The predicted stiffness of L23 was used to calibrate the material properties of a detailed finite element (FE) model.

BACKGROUND

- Realistic simulation of Functional Spinal Unit requires accurate representation of contact and deformational properties of biological tissues.
- Variation in stiffness among different FSUs is often neglected in spine modeling.

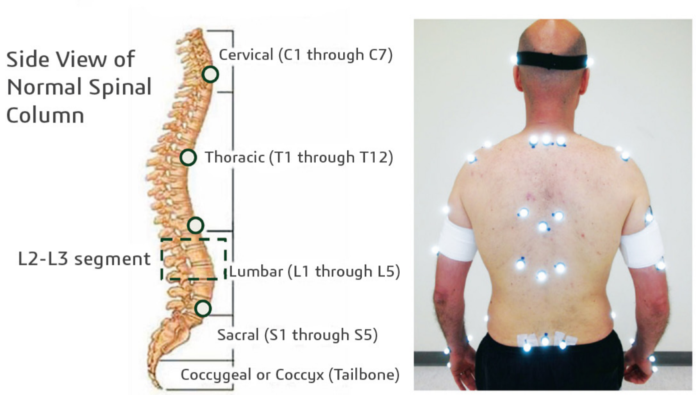

Fig 1. Positions of markers used to capture forward bending motion.

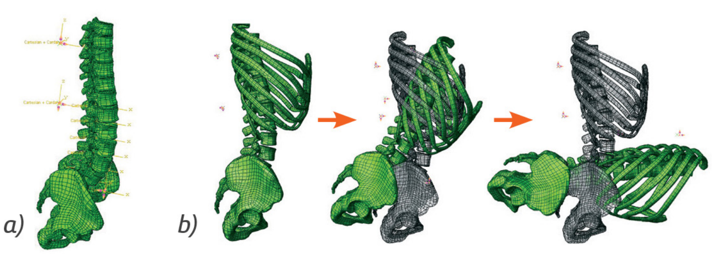

Fig 2. (a) Spine model with intervertebral connectors and motion capture complant drivers, (b) Simulated spinal motion after calibrating intervertebral connectors.

Part	Subpart	Material Properties
Vertebrae	L2 & L3	Elastic, $v = 0.3$, E = 2000 MPa
	Facet Joint Cartilage	Elastic, $v = 0.45$, E = 4 MPa
Intervertebral Disc	Nucleus Pulposus	Hyperelastic, Mooney-Rivlin $C_{10}=0.06$ MPa, $C_{01}=0.03$ MPa, $D_1=0.01$ MPa^{-1}
	Annulus Fibrosus	Divided into radial layers with alternative fiber directions (±30° to transverse plane). Anisotropic Hyperelastic, Holzapfel material $C_{10}=0.3$ MPa, D=0.01 MPa^{-1}, $k_1=0.1$ MPa, $k_2=310.3$, k=0.
Ligaments	ALL, PLL, FL, SSL, ISL, ITL, LF	Connector elements with no compressive stiffness, tensile stiffness from 1.2 to 8 N/mm

Table 1: Mechanical properties of the modeled tissues.

METHODS

Motion Capture Experiments

- Spine motion at T6, L1 and Pelvis during forward bending captured for a 50 yr old male (1.8m, 91 kg) (Fig 1).

Spine Model with Connectors

- Motion of the markers was applied in a compliant manner, using connectors to minimize signal noise and kinematic incompatibility (Fig 2).

Calibration of Intervertebral Connectors

- Flexion stiffness of L45 was assigned from [2].
- Motion catpure data was used to predict Intervertebral Flexion (IVF) Curves at all levels (spinal motion in Fig 2-b).
- Stiffnesses of other joints were optimized to match experimental data [7].

Calibration of Material Properties

- Detailed geometry of L23 was generated in [1] for a 33 yr old male (1.78m, 59 kg).
- Material properties were taken from literature [3,4,5,6].
- Predicted L23 stiffnesses were matched between the connector model and the detailed model to optimize material properties of soft-tissues (Table 1).

REFERENCES

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3. Holzapfel et al. 2000
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5. Pintar et al. 1992
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RESULTS

Calibration of intervertebral Connectors

- Linear pattern of IVF curves was accurately predicted by the calibrated connector spine model (Fig. 4-a).
- Analysis time: **<2 minutes** (quad core PC- Intel 1.6 GHz, 8G RAM).

Calibration of Material Properties

- Detailed FE model and the connector spine model predicted similar rotational stiffness.
- About 40% of the bending stiffness was contributed by ligaments at the posterior of the intervertebral disc with no contribution from anterior ligaments.
- Analysis time: **20 minutes** (24 CPUs on a HPC Cluster).

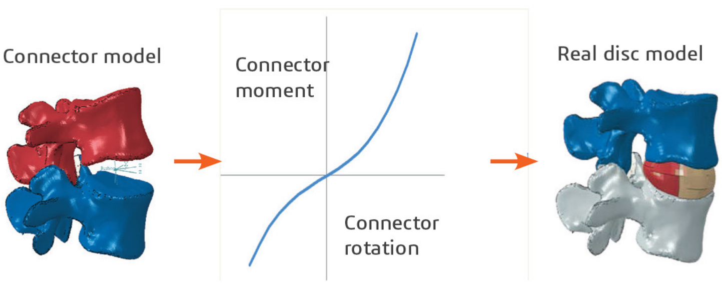
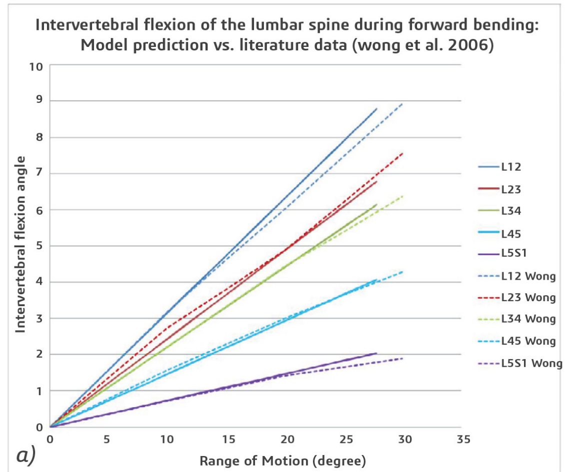


Fig 3. Calibration of the material properties of the detailed FE model of L23 using the connector model.

Lumbar Spine	L12	L23	L34	L45*	L5S1
Flexion stiffness (Nm/radians)	37	48	53	80	160

Table 2: Flexion stiffnesses of connector elements used in modeling the lumbar joints.



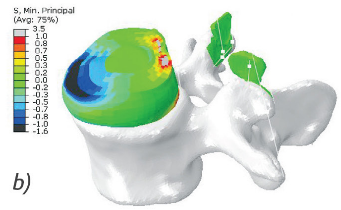


Fig 4. (a) Comparison of model prediction vs. literature data [7] on interverte- bral flexion of the lumbar spine during forward bending, (b) Contour plot of the stresses in the intervertebral disc.

CONCLUSION

- Connector model significantly improved computational efficiency while enabling more realistic motion simulation.
- Detailed FE model of L23 helped understand load distribution among soft tissues.
- Results illustrate the importance of accounting for stiffness variation across lumbar FSUs.

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