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INJURY BIOMECHANICS RESEARCH
Proceedings of the Thirty-Second International Workshop

Neck Injury Mechanics In Lateral Bending

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ABSTRACT

This study examined the dynamic stiffness and failure tolerance of human adult lower cervical spine specimens subjected to lateral bending moments. A total of 9 cadaver cervical spines (65.0 ± 4.2 years) were dissected into 27 functional spinal units (C3-C4, C5-C6, and C7-T1) and tested to failure in a custom bending fixture within a MTS servohydraulic test frame. The average applied angular displacement rate was 10.8 ± 2.9 rads/sec. Average dynamic stiffness in lateral bending was 151 ± 44 N-m/rad, and the average failure moment was 26.3 ± 5.5 N-m. The lateral bending tolerance was similar to those reported by Nightingale et al. for the human adult lower cervical spine in flexion (17.4 N-m) and extension (21.2 N-m).

INTRODUCTION

Few data exist on the lateral (side-to-side) bending mechanics of the human adult cervical spine. Panjabi et al. (2001), Dickman et al. (1994), Liu et al. (1982) and others have reported lateral bending stiffness data for intact human cadaver cervical spines. However, tolerance of the cervical spine to lateral bending moments has been largely unexplored. In 1988, Moroney et al. performed a variety of mechanical tests on cervical functional spinal units and body-disc-body preparations and reported a single (n=1) lateral bending failure test. For this specimen, lateral bending stiffness was measured to be 39.2 N-m/rad and failure occurred at 8.2 N-m; however, the posterior spinal elements (facets and posterior ligament complex) were removed leaving only the body-disc-body intact for testing. To date, no lateral bending human tolerance data has been published for the intact cervical spine or functional spinal units. Hence, the objective of this project was to document the stiffness and failure tolerance data for human adult neck functional spinal units subjected to dynamic lateral bending moments.

METHODS

Nine, fresh (unembalmed) adult human cervical spines were obtained and dissected free of all musculature leaving the intact osteoligamentous cervical spine. The average age of the specimens was 65.0 ± 4.2 years old with 6 males and 3 females. Each specimen was further dissected into functional spinal units:

C3-4, C5-6, and C7-T1 (27 FSUs). Radiographic and visual inspections were used to exclude those FSUs with previous injury or spinal pathology. In preparation for testing, each vertebra were wired and embedded in poly-methylmethacrylate (Figure 1).

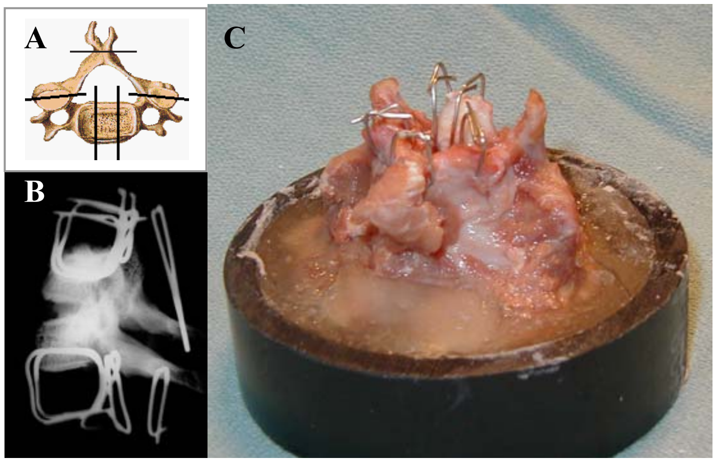

Figure 1: Wiring and potting of the vertebra for rigid fixation during mechanical testing. (A) Schematic diagram of the wiring procedure (transverse plane) with the black lines indicating where wires are passed through the bone of the vertebra. (B) X-ray of the wired 1-FSU specimen (sagittal plane) demonstrating the looping of the wires for fixation into PMMA. (C) Potted superior section of a functional spinal unit in PMMA cup with the inferior vertebra (wires shown) upward.

A custom bending apparatus (Nuckley et al., 2002, Figure 2), which converts the axial motion of an MTS 318 actuator to a force couple, was used to apply dynamic bending moments to each test specimen. Each specimen was subjected to dynamic lateral bending moments to failure at an angular displacement rate of approximately 10 to 12 rads/s. Sliding (lower) and free (upper) end conditions minimized shear while allowing for coupled motion in response to the lateral bending input. A six-axis load cell (Model 4526, Denton ATD, Rochester Hills MI), an angular accelerometer (Model 7302B, Endevco, San Juan Capistrano, CA), and a high-speed digital imaging system (FastCam 1280, Photron, San Diego, CA) were used to document the resultant loads, angular displacement rates, and angular displacements.

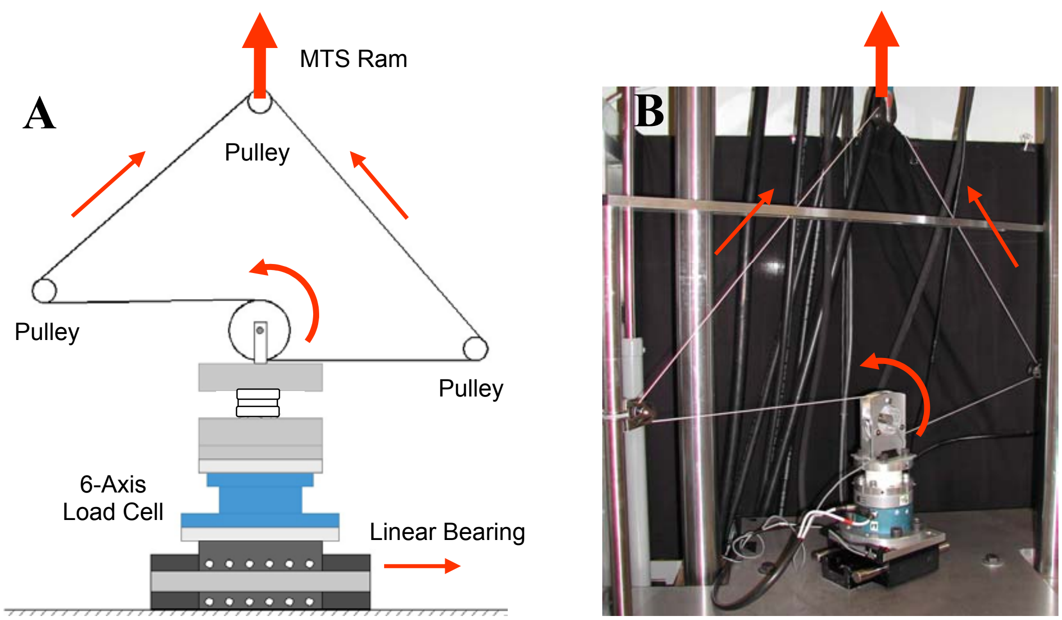

Figure 2: Schematic diagram (A), and photograph (B), of dynamic bending apparatus in the MTS.

RESULTS

A total of 27 functional spinal units were tested to failure in lateral bending at an average angular displacement rate of 10.8 ± 2.9 N-m/rad. Of these, we experienced two potting failures (i.e., the specimens failed at the bone-potting interface and not in the tissues) and two specimens that were found to have unilateral arthritic facet joints (during post-test inspection). The data for these four tests were excluded from our reported results.

Figure 3 provides the mean ± 1 standard deviation of the moment-angle curves by spinal level. Across all spinal levels, the average dynamic stiffness in lateral bending was 151 ± 44 N-m/rad (Figure 4), and the average failure moment was 26.3 ± 5.5 N-m (Figure 5). Statistical differences (though slight in magnitude) were observed between the C3-C4 and C7-T1 spinal levels for failure load, however no spinal level differences were observed for dynamic stiffness.

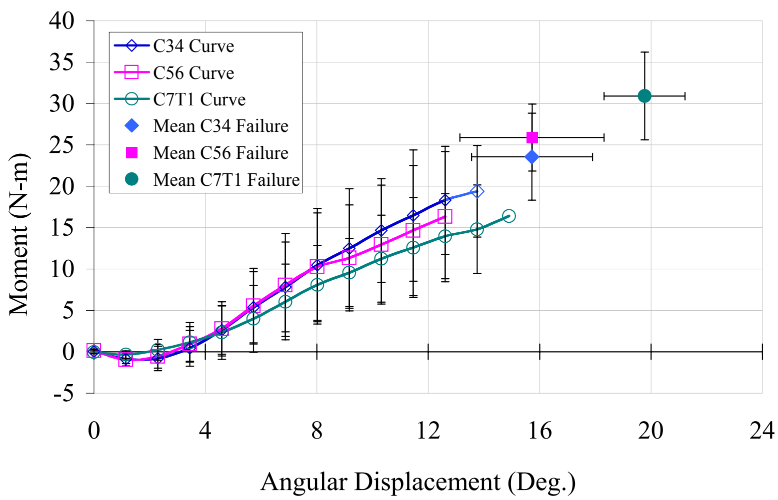

Figure 3: Moment-angle curves by spinal level. A slight negative moment was initially observed which corresponded to the break-away torque required to overcome the friction in the linear bearing track. The mean failure moments for each spinal level are also shown ± 1 SD of both the failure moment (vertical error bars) and angular displacement (horizontal error bars).

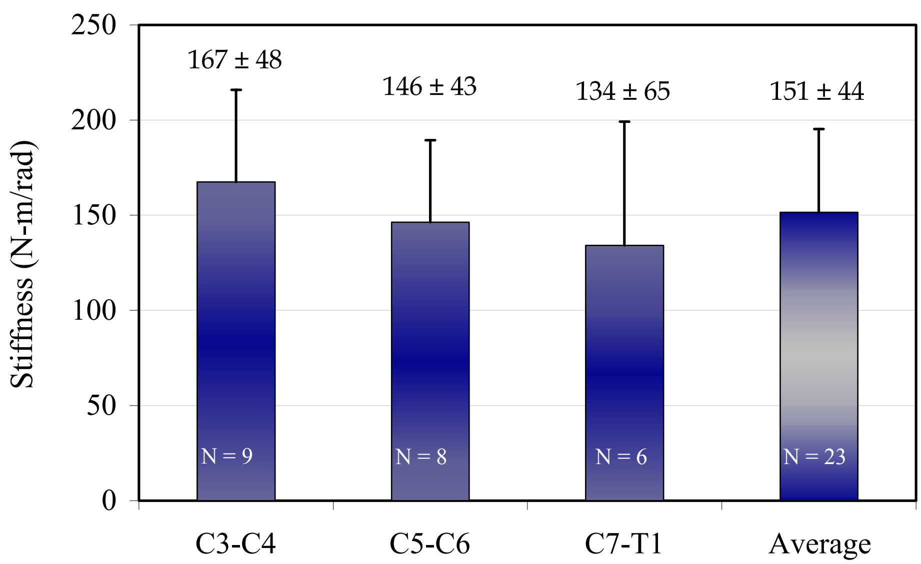

Figure 4: Average functional spinal unit stiffness by spinal level.

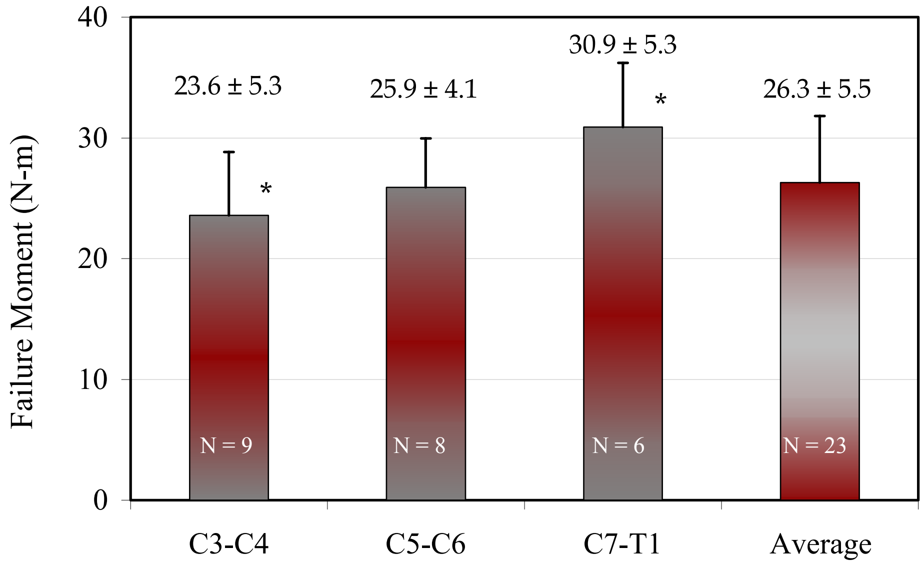

Figure 5: Average functional spinal unit failure moment by spinal level. A statistical difference ($p < 0.01$) in failure moment was observed between the C3-C4 and C7-T1 spinal levels.

CONCLUSIONS

The average dynamic stiffness (151 N-m/Rad) was much greater (nearly 4x) than that reported by Moroney et al. (1988) (39 N-m/rad) who had quasi-statically tested a single body-disc-body cervical preparation. The average lateral bending failure moment (26.3 N-m) was over three times higher than Moroney's body-disc-body specimen (8.2 N-m). Interestingly, the failure moments were in a similar range to that reported by Nightingale et al. (2002) for human adult lower cervical spine specimens failed in flexion (17.4 N-m) and extension (21.2 N-m). This suggests that adult cervical functional spinal units fail at similar bending moments in each of the principal loading directions (flexion, extension, and lateral bending).

ACKNOWLEDGEMENTS

This research study was supported by the U.S. Department of Transportation National Highway Transportation Safety Administration (Cooperative Agreement No. DTNH-22-99-27000).

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DISCUSSION

PAPER: **Neck Injury Mechanics In Lateral Bending**

PRESENTER: ***Randy Ching, Applied Biomechanics Lab, University of Washington - Seattle***

QUESTION: *Guy Nusholtz, DaimlerChrysler*
Why did it go negative? The moment angles go negative when you first put the load on.

A: Because that was the direction that we rotated the spine. The moment can be positive or negative depending on which way we loaded it. And, when I plotted the moment angle curves and I just inverted them and made them all positive just so that we could all see the curves going up.

Q: Oh okay. So you're loading in different direction —You've got two different rotations?

A: Well, if you apply left lateral bending or right lateral bending, one direction is going to be negative and one's going to be positive.

Q: Oh, I see. Okay.

A: And so, that just happened to be the way that we rotated it.

Q: But in the beginning of the curves up to 4°?

A: Oh, initially?

Q: Initially, it's opposite in sign.

A: Okay. That is due—I can go back to the slide. I think I know what you're talking about now. That's due to the inertial effect of the sled just starting to move.

Q: Okay.

A: But it happens before the momentum actually picks up.

Q: Oh, okay. So that's an artifact of the way you're doing the experiment.

A: Right. We are faced with either fixing the load cell at the base and then seeing really high shear forces in our specimen as it rotated over itself or decoupling, it by putting it on linear bearing track and allowing it to move out of the way… but it took a little bit of inertia to get out of the way.

Q: Very good. Thank you.

QUESTION: *Jason Foreman, University of Virginia*
This kind of has to do with Guy's question, but your moment angle plots showed some nonlinearity and I was just wondering how you calculated stiffness from that.

A: Okay. Sure. It'd probably be better for us to plot it, as a nonlinear function. But we went ahead and plotted stiffness so that we could make a comparison against the Marone paper, which is the only paper that's out there. What we did is basically truncate the upper 20%° and the lower 20%°, and then plot the stiffness for the middle range.

Q: Okay. Thank you.