Doctoral Dissertation Public Defense Announcement

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With a concentration in Biomechanics

Joint Department of Biomedical Engineering
Medical College of Wisconsin and Marquette University

The Effect of Bending Posture on the Tensile Response of the Lumbar Spine

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Link to Panopto Livestream:
https://mcw.hosted.panopto.com/Panopto/Pages/Viewer.aspx?id=8aacca5f-fa10-4b31-ae03-adb0013ce3a4

Committee in Charge:
Frank Pintar, PhD (Chair)
Brian Stemper, PhD
Carolyn Hampton, PhD
Jamie Baisden, MD
Mei Wang, PhD
Graduate Studies

Biomedical Instrumentation Design
Systems Physiology
Biomechanics of Sport and Injury
Intermediate Dynamics
Biomaterials in Science and Engineering
Statistical Methods
Human Gross Anatomy
Intro to Finite Element Method
Biomedical Signal Processing
Biomedical Engineering Analysis of Trauma
Applied Finite Element Analysis
Advanced Engineering Analysis
Seminar in Biomedical Engineering
Ethics and Integrity in Science
Research Ethics Discussion Seminar
Reading and Research
Doctoral Dissertation
Dissertation Abstract

As aircraft and automotive technologies have evolved over the last several decades, so have the safety standards used to protect occupants. Essential to this is an understanding of how new loading scenarios impact the injury potential of the human body. Changes to future automotive and aircraft interiors where occupants are seated at oblique angles to the direction of travel may lead to complex loading of the spine in high-G loading scenarios. However, the injury potential of non-planar loading to the spine is largely unknown. Previous Postmortem Human Subject (PMHS) tests were conducted to investigate gross occupant kinematics in an oblique seating posture using the FAA emergency landing test conditions. From this testing, severe lumbar spine injuries were produced through a combination of multi-axis bending and distraction. It was hypothesized that this oblique loading mechanism significantly altered the lumbar spine response to tensile loading and decreased injury tolerance compared to a traditional forward-facing seat. The current work provides a more thorough understanding of the effects of combined tension and multi-axis (oblique) bending on the lumbar spine through experimentation and computational modeling.

An experimental isolated PMHS spine study was conducted to investigate loading differences between a flexed and obliquely bent posture at both sub-maximal and failure inducing loads. 12 PMHS isolated lumbosacral spines were tested in tension using an electrohydraulic piston while positioned in three separate postures: the spines naturally unloaded posture (neutral), flexed forward (flexed), and flexed and laterally bent 15° (oblique). A novel positioning table was designed and assembled to accurately position the spines with the required combination of flexion and lateral bending in a repeatable way that minimized axial preload. With the sacrum fixed, a sub-failure tensile test to 4 mm of T12 displacement was conducted in each of the three sub-failure postures, followed by a tensile test to failure in either the oblique (n=5) or flexed posture (n=8). Anatomic loads at the center of the sacral end plate were calculated from the inferior load cell using rigid body transformations.

Statistically significant changes were seen across several metrics between the three sub-failure test postures. Significant increases in tensile stiffness, peak tensile force, and peak flexion moment were seen when comparing both the flexed and oblique postures to the neutral posture. Peak tensile force increased from an average of 275 N in the neutral posture to 814 N in the flexed, and 874 N in the oblique. However, minimal changes were observed between the flexed and oblique postures at this low level of loading.

Substantial differences were found between the load response to failure between the flexed and oblique postures. The spine demonstrated a greatly reduced tolerance for tensile injury in both loads and total column displacement at failure in an obliquely bent posture compared to a flexed posture. This is thought to be a product of the asymmetrical nature of loading in the presence of oblique bending. Lateral bending moment response appeared to be an
indication of early signs of failure. Load response corridors were created as novel validation data used in finite element (FE) modeling.

With the rise in the use of computational FE models for injury prevention, it is important they are evaluated against experimental data to assess their validity in predicting human body behavior to new loading scenarios. The commercially available Global Human Body Model Consortium 50th Percentile Male Occupant (GHBMC M50-O) finite element model was evaluated using the novel experimental data. The lumbar spine FE model was extracted from the full-body model and run through five simulations that closely approximated the experimental testing protocol.

Results from the sub-failure simulations demonstrated good overall agreement with experiments, with the exception of an overestimation of tensile force in the neutral position. For the failure level simulations, agreement with experimental results was achieved by the tensile force of the two test conditions. However, both the flexion and lateral bending moments demonstrated a considerably decreased response from what was observed experimentally.

Following validation of the model for sub-failure loading scenarios, a series of seven simulations were conducted to investigate the effect of oblique bending angle on the loads experienced by the spine from a bending-tension loading mechanism. In the plane of the sacral endplate, vectors were created at 7 equally spaced angles from 0° (mediolateral axis or pure flexion) to 90° (anteroposterior axis or pure lateral bending). The sacrum was fixed about all degrees of freedom and T12 was bent 26.4° about the described vectors in the same manner utilized in the validation study.

From a force standpoint, the angles where T12 was bent towards lateral bending (more obliquity) demonstrated larger peak tensile loads, and low oblique angles (more towards flexion) produced larger initial compressive loads. A 67° oblique bending angle was estimated to produce the largest tensile force in this loading scenario. In contrast, moments showed the greatest changes at low oblique angles. At 22°, it was predicted that the lateral bending moment would overtake the flexion moment in magnitude and become the predominant moment affecting the spine.

In summary, the physical experiments revealed that for physiologic, sub-failure displacements, while initial deviations from a neutral posture produced a significantly altered load response, significant changes were not found between different bending postures. Large differences were seen in the failure response between flexed and oblique postures, where the oblique posture demonstrated a greatly reduced injury tolerance as compared to the flexed posture. The GHBMC lumbar spine model was sufficiently validated for sub-failure oblique loading scenarios, but may need further development to achieve the appropriate response at failure levels of loading. Parametric modeling revealed a force and moment response that is highly dependent on the oblique bending angle.
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CURRICULUM VITAE

EDUCATION

Ph.D., Biomedical Engineering  
Aug 2017 – Dec 2021 (Expected)  
Medical College of Wisconsin and Marquette University  
Concentration: Injury Biomechanics  
Dissertation: The Effect of Bending Posture on the Tensile Response of the Lumbar Spine  
Dissertation Advisor: Frank Pintar, PhD

B.S., Mechanical Engineering w/certificate in Leadership Studies  
Gonzaga University

TEACHING EXPERIENCE

Guest Lecturer, Marquette University, 2018-Current  
Course: Biomechanics Design Lab  
- Provide select lectures in the field of biomechanics.  
- Improve existing lecture materials using a variety of sources including textbooks and literature.

Graduate Teaching Assistant, Marquette University, 2017-2018  
Course: Biomechanics Design Lab  
- Lab Instructor for Biomechanics Design Lab, a year-long senior level biomedical engineering capstone class and lab.  
- Prepared prescribed laboratory experiments that assist students in translating their knowledge to real world applications.  
- Improved existing lab curriculum to provide students with exposure to up-to-date research and technology.

Adjunct Instructor, Gonzaga University, 2016-2017  
Course: Manufacturing Processes Lab  
- Instructor for Manufacturing Processes Lab, a junior level mechanical engineering lab course.  
- Instructed students on how to properly use manufacturing equipment such as lathes, mills, and welding devices.  
- Provided guidance on independently completed projects, assisting students with translating knowledge from the classroom to hands on experience.

RESEARCH EXPERIENCE

Graduate Research Assistant, Medical College of Wisconsin, 2018-Present  
- Assist in the preparation and execution of complex test setups studying injury biomechanics.
- Conduct analysis of experimental data by integrating load transducer, motion capture, and imaging data.
- Drive the progress of a project by coordinating internal resources and leading communications with the funding agency.

**PEER-REVIEWED PUBLICATIONS**


**PRESENTATIONS**


**AWARDS AND HONORS**

Induction into Alpha Sigma Nu – Jesuit Honor Society, 2019
Outstanding Biomedical Department Teaching Assistant, 2018

**PROFESSIONAL MEMBERSHIPS**

Biomedical Engineering Society