Musculoskeletal Biomechanics
BIOEN 520 | ME 599R

Session 12B
Biomechanics of the Spine
Review: Session 12A...

- Reviewed the types and function of joints...
- Discussed common features of synovial (diarthrodial) joints
- Discussed which mechanical properties of joints are generally of interest and why
- Examined the #1 joint disease and how abnormal mechanics might play a role
- Discussed joint replacement systems
Session 12B Discussion Questions...

[Q]: What are the anatomical regions and basic structures of the spine?

[Q]: What are the primary functions of the spine?

[Q]: How would we test the mechanical properties of the spine?

[Q]: What mechanical properties might we expect?

[Q]: Why would we care about these properties?
[Q]: What are the basic anatomical regions of the spine?

- Cervical Spine [7]
- Thoracic Spine [12]
- Lumbar Spine [5]
- Sacrum [5 fused]
- Coccyx [4 fused]
Structures of the Spine...

- Spinous Process
- Facet
- Transverse Process
- Posterior Longitudinal Ligament
- Vertebral Body
- Pedicle
- Disc
- Spinal Canal
- Anterior Longitudinal Ligament
- Posterior Longitudinal Ligament
- Ligamentum Flavum
- Interspinous Ligament
- Supraspinous Ligament

FSU = Functional Spinal Unit

Tri-Joint Complex
Function of the Spine...

[Q]: What are three primary functions of the spine?

• Support Physiologic Loads (while maintaining stability)...
• Facilitate Movement...
• Protect Neurological Tissues...
Movement of the Spine...

Adapted from Accidental Injury edited by Nahum and Melvin
Biomechanical Testing...

[Q]: How would we test the mechanical properties of the spine?

- Establish mode of testing... [Tension, bending, etc.]
- Obtain tissue samples... [Type, age, gender, samples]
- Prepare test specimens... [Dissect, wire, potting]
- Set up testing apparatus and fixturing... [Test frame, fixtures, measurement devices, DAQ]
- Choose test parameters... [Preconditioning, loading rate, sampling rate, filtering]
- Run tests...
Biomechanical Testing...

Traditional metrics

Panjabi (1975)
Biomechanical Testing...

Zdeblick (1992); Nightingale (1997)
Properties of the Spine...

[Q]: What mechanical properties would we expect?

<table>
<thead>
<tr>
<th>Stiff / Failure</th>
<th>Cervical</th>
<th>Thoracic</th>
<th>Lumbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexion</td>
<td>.3-.5 / 15-20</td>
<td>1-3 / 30-40</td>
<td>2-3 / 75-200</td>
</tr>
<tr>
<td>Extension</td>
<td>.5-1 / 16-21</td>
<td>2-3</td>
<td>2-3</td>
</tr>
<tr>
<td>Lat. Bending</td>
<td>.5-1 / 24-28</td>
<td>2-3</td>
<td>2-3</td>
</tr>
<tr>
<td>Torsion</td>
<td>1-2</td>
<td>2-3</td>
<td>3-5</td>
</tr>
</tbody>
</table>

Stiffness: N-m/deg / Failure Load: N-m

Biomechanical Testing...

ABL Spine Simulator / Shear testing
Biomechanical Testing...

ABL Spine Simulator
Biomechanical Testing...

Our metrics

![Graph showing biomechanical testing metrics: ROM, NZ, S0, S1, S2, and hysteresis curve.](image)
Properties of the Spine...

Typical plots...
Properties of the Spine...

Non-traditional plots...
Properties of the Spine...

**[Q]**: Why would we care about their properties?

Stability ➔ Treatment

- Design of spinal implants
- Evaluate effectiveness of surgical procedures
- Prevention of spinal injuries
Case Study #1: Pediatric Spine Biomechanics

• Assist in development of child crash test dummies...

• Develop pediatric FE models to evaluate neck injury risk...

Greatest Challenge???
> Human Pediatric Tissues...
Case Study #1: Pediatric Spine Biomechanics

- Papio Anubis...
  - Similar vertebral architecture
  - Upright cervical alignment
  - Available across wide age range

- Human equivalent age...

3-HE Years

12-HE Years

Case Study #1: Pediatric Spine Biomechanics

Strategy: Baboon Data to Estimate Human Child
Case Study #1: Pediatric Spine Biomechanics

Specimen Preparation:
Case Study #1: Pediatric Spine Biomechanics

Test Apparatuses
Case Study #1: Pediatric Spine Biomechanics

Tension: C5-C6
Case Study #1: Pediatric Spine Biomechanics

Tensile Rate Effects

\[ y = 492.25x^{0.1532} \]

\[ R^2 = 0.9832 \]

Failure Load (N)

Loading Rate (mm/sec)

J. Biomechanics (2005)
Case Study #1: Pediatric Spine Biomechanics

Lat Bending:
C5-C6, 10 rad/s
Case Study #1: Pediatric Spine Biomechanics
Case Study #1: Pediatric Spine Biomechanics

Bending Failure Tolerance

Developmental Age (H.E. Years)

Failure Moment (N-m)

Extension

Flexion

y = 0.5175x + 2.7728

R² = 0.9826

y = 0.4007x + 2.313

R² = 0.9105

n = 16

Human Subjects Biomechanics Workshop (2002)
Case Study #1: Pediatric Spine Biomechanics

Compression: C6-T1, 500 mm/s
Case Study #1: Pediatric Spine Biomechanics

Compressive Rate Effects

- 1000 mm/sec
- 1 mm/sec
- Series 1

J. Biomech Engr (2006)
Case Study #1: Pediatric Spine Biomechanics

Validation: Compressive Stiffness

Stiffness = -0.16(age)^2 + 17.13(age) + 369.28

H.E. Age (Years)

C3-C5 Compressive Stiffness (N/mm)

Baboon Data
Baboon Data Fit
Baboon Fit Shifted
Human Data

Human Adults

Stiffness = -0.16(age)^2 + 17.13(age) + 188.53
Case Study #2: Spinal Arthroplasty

Spinal Fusion

- Standard of care (1950s)...
- 430,000 fusions in 2009...
- ~1/2 in cervical spine...
- Limits motion...
- Adjacent-disc disease...
Case Study #2: Spinal Arthroplasty

Spinal Dynamics Corp.

- Vince & Alex (1997)...
- Bryan Cervical Disc...
- Testing and development...
Case Study #2: Spinal Arthroplasty

Test Results

Dynamic Stiffness (C5-C6) Mean and Stdv. (400 N)

Viscous Damping Ratio Mean and Stdv.

Case Study #2: Spinal Arthroplasty

http://www.carolinaneurosurgery.com/spine/bryandisc.html