Spinal Mechanics

Readings:
Chapter 7 [course text]
Nordin & Frankel, Chapter 10 [on reserve]
Hall, Chapter 9 [on reserve]

Learning Objectives
By the end of this lecture, you should be able to:
• Identify risk factors for low back pain
• Identify the most common location of back pain, and use mechanical concepts to explain why pain at this location is more common than in other parts of the spine
• Use mechanical concepts such as force, moment, and stress to predict postures at higher risk for low back pain
• Calculate moments, muscle forces, and stresses (compressive and shear stress) in the spine during different postures
• Use calculated compressive force values to determine whether tasks are likely to cause back pain
• Explain the relationships between spinal ligaments, muscle activity, and posture
• Discuss how these relationships affect the risk of spinal injury

Prevalence of Low Back Pain
>80% of people will experience low back pain at some point in their lives
Low back pain commonly occurs in work environments
40-50% of Workers’ Compensation claims in some industries are due to low back pain
Low back pain is especially common in work environments that involve:
• seated work
• manual materials handling – 1/3 of work-related low back pain is due to lifting and bending tasks [Brown, 1973; Magora, 1974]

Why Low Back Pain?
Stresses on the lumbar spine often limit lifting more than strength [studies have shown this].
Large moments are created in the trunk during lifting, especially if the load cannot be held close to the body [biomechanical models have shown this].
The disk between L5/S1 has the potential to incur the greatest moment, and is one of the most vulnerable tissues to force-induced injuries.
85-95% of all disk herniations occur relatively equally at the L4/L5 & L5/S1 levels.
Low Back Pain – Personal Risk factors

- anthropometry
- fitness and strength (static and dynamic endurance)
- health history
- age and gender
- psychophysical factors
- training and experience

Low Back Pain – Workplace Risk Factors

- load characteristics (weight, size, shape, handles)
- posture (stretching, reaching, twisting)
- spatial constraints (confined environments)
- protective equipment
- duration and frequency
- environment (heat, humidity, noise, etc.)

Posture Affects Compressive Stress

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<tr>
<th>Posture Affects Compressive Stress</th>
<th>Posture Affects Compressive Stress</th>
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<tbody>
<tr>
<td><em>relative loads on L3 disk</em> (% of standing)</td>
<td><em>standing at ease</em></td>
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<tr>
<td>200</td>
<td>300</td>
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<td>150</td>
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*Posture Affects Compressive Stress*
Posture Affects Moment Arm

Postural changes affect the moment arm of torso weight.

Lumbar support and backrest inclination affect compressive stress

Backrest Inclination Affects Muscle Activity

this trend is seen in all spinal regions
Muscle Activity Affects Back Pain

Analyzing Lifting Tasks

The National Institute for Occupational Safety and Health (NIOSH) conducted studies to examine the relationship between risk factors and injury. The results of these studies were used to generate criteria to evaluate whether a given lifting task was likely to cause injury.

Analyzing Lifting Tasks

NIOSH identified three categories of criteria:

- **Biomechanical** – limit lumbosacral stress
  - maximum disk compressive force of 3.4 kN
  - (most important for infrequent lifting tasks)

- **Physiological** – limit energy expenditure and fatigue
  - (most important in repetitive lifting tasks)

- **Psychophysical** – limit load based on workers’ perception
  - (important for all lifting tasks except very high-frequency)

Justification for the Criteria

Our focus is the biomechanical criteria

Questions regarding the Biomechanical criteria in the revised NIOSH equation (1991):

- why choose L5/S1?
- why compressive force [Fcomp]?
- why 3.4 kN?
L5 / S1?

Studies have confirmed that lifting under certain conditions is limited more by the stresses on the lumbar spine than by limitations of strength.

Biomechanical models of lifting show that large moments are created in the trunk (especially if the load cannot be held close).

The disk between L5/S1 has the potential to incur the greatest moment and is one of the most vulnerable tissues to force-induced injuries.

Between 85-95% of all disk herniations occur relatively equally at the L4/L5 & L5/S1 levels.

Compressive Force Vector?

The relative importance of compressive, shear and torsional forces is not well understood.

Disc compression is thought to be largely responsible for vertebral end-plate fracture, disc herniation, and resulting nerve root irritation.

Back compression is a good predictor of low-back and other overexertion injuries? [Herrin+, 1986]

Due to clinical interest in this area data exists on the compressive strength of the lumbar vertebral bodies and intervertebral disks.

3.4 kN = maximum compression

NIOSH reviewed data from cross-sectional field studies that provided estimates (from biomechanical modeling) of $F_{\text{comp}}$ generated by lifting tasks and subsequent injuries.

Herrin et. al. 1986 studied 55 jobs (2934 potentially stressful MMH tasks) and traced medical records (6912 workers).

For jobs with $F_{\text{comp}}$ between 4.5-6.8 kN the rate of back problems was 1.5 times greater than for jobs with $F_{\text{comp}}$ less than 4.5 kN.

Cadaver Data

Jager & Luttman (1989) found the mean compressive strength of lumbar segments to be 4.4 kN with a SD of 1.88 kN.

If normally distributed, 30% of segments had a lumbar strength less than 3.4 kN.

Brinckmann et. al. (1988) found compressive strength ranged 2.1 to 9.6 kN. <21% fractured (or suffered end-plate failure) below 3.4 kN.

How relevant are cadaver results to LBP?
Biomechanical Models

Models can predict bending moments, which in turn can be used to predict muscle force, compressive stress, and shear stress.

Load Characteristics Affect Moment

Lifting Technique Affects Moment

Calculating Moments

Example: Calculate the muscle moment.

\[ L_w = 0.18 \text{ m} \]
\[ L_p = 0.35 \text{ m} \]

\[ L_w = 0.25 \text{ m} \]
\[ L_p = 0.5 \text{ m} \]
Calculating Moments

Answer:
\[ \Sigma M = 0 \]
\[ M_{\text{musc}} + M_w + M_p = 0 \]
\[ M_{\text{musc}} + (0.18 \, \text{m})(450 \, \text{N}) + 
- (0.35 \, \text{m})(200 \, \text{N}) = 0 \]
\[ M_{\text{musc}} = 81 \, \text{Nm} - 70 \, \text{Nm} = 0 \]
\[ M_{\text{musc}} = +151 \, \text{Nm} \]

Calculating Muscle Forces

The erector spinae are the main spinal column extensors.

The moment arm of the erector spinae is usually about 5–6 cm.

Example: Calculate the muscle force if the moment arm of the erector spinae is 0.05m.

\[ M_{\text{musc}} = +151 \, \text{Nm} \]

Answer:
\[ M_{\text{musc}} = F_{\text{musc}} \, d_{\text{musc}} \]
\[ +151 \, \text{Nm} = (F_{\text{musc}})(0.05 \, \text{m}) \]
\[ F_{\text{musc}} = (151 \, \text{Nm}) / (0.05 \, \text{m}) \]
\[ F_{\text{musc}} = 3,020 \, \text{N} \]

4,250 N
Calculating Compressive and Shear Forces

In our simple model of the lumbosacral spine, three main forces act at L5/S1, and are balanced by the joint reaction force.

The force produced by the erector spinae muscles acts approximately at right angles to the intervertebral disks.

If you know the muscle force, as well as trunk alignment, you can calculate the components of force acting to create compressive and shear stress on the spine.

Compressive forces act perpendicular to the intervertebral disks (parallel to the spinal column).

Shear forces act parallel to the intervertebral disks (perpendicular to the spinal column).
Calculating Compressive and Shear Forces

**Example:** Calculate the compressive and shear forces at L5/S1

\[ F_\text{musc} = 3,020 \text{ N} \]

\[ \text{trunk angle} = 80° \]

\[ F_\text{musc} = 4,250 \text{ N} \]

\[ \text{trunk angle} = 65° \]

**Answer:**

**Compressive force:**

\[ F_\text{comp} = F_\text{musc} + F_\text{w,comp} + F_\text{p,comp} \]

\[ = 3020 + 450\sin80 + 200\sin80 \]

\[ = 3020 + 443.16 + 196.96 \]

\[ = 3660 \text{ N} \]

**Shear force:**

\[ (F_\text{musc} \text{ does not act in shear direction}) \]

\[ F_\text{shear} = F_\text{w,shear} + F_\text{p,shear} \]

\[ = 450\cos80 + 200\cos80 \]

\[ = 78.142 + 34.730 \]

\[ = 113 \text{ N} \]

Sample problem: a) Calculate the total forward bending moment produced by the two forces (weight of upper body and weight of load).

b) What is the resultant muscle force required to maintain static equilibrium?

c) Assuming the trunk is aligned at 55° to the horizontal (i.e. a forward bend of 35°), find the compressive and shear forces acting on L5/S1.

The answer is in the Nordin and Frankel text

Moments and Forces on the Lumbosacral Spine
Spinal Muscles and Ligaments
If the work done on the spine is greater than the work done to stiffen the spine, the spine will buckle.

Interspinous ligaments help to limit flexion of the spine, and can also help carry some of the load. Unlike muscles, ligaments do not help to reduce joint shear, and may even increase shear forces.

Muscle activity helps protect the spine against shear forces.

Stuart McGill, Ph.D., Low Back Disorders, 2002
Muscle Activity

Good and poor deadlift form:

Spinal Ligaments and Muscle Activity

**Fully flexed spine:** extensor muscles inactive, high shear forces

**Neutral spine:** interspinous ligaments inactive, lower shear forces

4D WATBAK

- 4D WATBAK is an easy to use biomechanical modeling tool that calculates acute and cumulative loads at the major body joints, particularly the lumbar spine region.
- It can be used to estimate the risk of injury associated with a variety of occupational actions including pushing, pulling, lifting, lowering, holding, carrying, etc.

WATBAK manikin model of two deadlift lifting positions
Spinal Exercises / Core Strength

- Know the neutral spine position
  - Proper lordosis
  - Blood pressure cuff tests
- Check posture during lifting / work
  - Avoid trunk flexion
  - At full flexion spinal erector muscles are inactive