Mechanics of the Human Spine
Lifting and Spinal Compression

Hamill and Knutzen: Chapter 7
Nordin and Frankel: Ch. 10 by Margareta Lindh
Hall: Ch. 9 (more muscle anatomy detail than required)

Low Back Pain (LBP)

- Lifetime prevalence of LBP is very high (80+%)
- MMH is a major cause of work related LBP and other musculoskeletal injuries.
- However, LBP is common in work environments where no MMH occur, such as seated work.
- Work-related psychological stress and lifestyle factors may also increase LBP risk.
- Possibly only 33% of work-related LBP is due to lifting and bending tasks (Brown, 1973 & Magora, 1974)

Review terms: tension, compression, shear, bending, torsion.

Most flexion in these regions
Relative loads on the third lumbar disk for living subjects

Upright standing depicted as 100%

Many subjects report the position below gives them the most relief from back pain as this relaxes the psoas muscle.

The line of gravity shifts further ventrally during relaxed unsupported sitting (B) as the pelvis is tilted backward and the lumbar lordosis flattens (this creates a longer lever arm). When sitting erect (C) the pelvic backward tilt is reduced and the lever arm shortens (still longer than when standing (A)).
Decrease is seen in all spinal regions

Another use of EMG

Compressive Disk Force vs. different backrest inclination and size of lumbar support
Causes of LBP

LBP is a big industrial problem (low back injury claims account for 40-50% of compensation claims in some industries) but it is not only caused by lifting.

Personal Risk Factors

- Physique / anthropometry / strength (static / dynamic endurance)
- Physical fitness / health history / spinal abnormalities / spinal mobility
- Age / gender
- Psychophysical factors / motivation
- Training and selection (experience)

Workplace Risk Factors

- Load characteristics (weight, size, shape, handles, other couplings)
- Posture / handling techniques (stretching, reaching, twisting)
- Confined environments / spatial restraints
- Safety aspects / protective equipment
- Duration / repetition
- Work organization (spacing tasks out)
- Environment (heat, humidity, noise, glare, etc.)

Causes of Reportable Injuries

- Handling: 33%
- Fall: 8%
- Struck by: 15%
- Trip: 19%
- Other: 21%
- Machinery: 5%
Manual Handling Injuries

- Approximate 33% of the U.S. workforce is presently required to exert significant force as part of their jobs (NIOSH, 1981).
- This figure has not changed much in recent years.
- This can lead to external injuries (cuts, bruises, crush injuries, lacerations of fingers, hands, forearms, ankles and feet), internal injuries (muscle and ligament tears, hernias, knee ankle and shoulder injuries, slipped disc).

Types of Handling Accidents

- Sprain/Strain: 63%
- Fractures: 5%
- Contusion: 7%
- Laceration: 8%
- Other: 8%
- Superficial: 9%

Analysing Lifting Tasks

More detail in specialized ergonomics courses

Epidemiological Analysis

The approach is concerned with identifying the incidence, distribution and type of injury in the workforce. It is hoped that by studying comparative data, conclusions can be drawn about injury type, contributing factors and probability of occurrence.
Lifting task evaluation criteria

- **Biomechanical**
  - maximum disc compressive force
  - limits lumbosacral stress
  - NIOSH cut-off value of 3.4 kN (~350 kg)
  - most important for infrequent lifting tasks

- **Physiological**
  - maximum energy expenditure
  - limits metabolic stress and fatigue
  - NIOSH cut-off value of 2.2-4.7 kcal/min (varies with specific task variables)
  - most important in repetitive lifting tasks

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 \([F_{\text{comp}}]\)?
  - 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? \[\text{[Herrin+}, 1986\]\)
- 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?
Calculate the forward (clockwise) bending moment about L5/S1 (red square)  
Lw = 0.25 m  
Lp = 0.4 m  
Answer =  
If the erector spinae moment arm is estimated at 0.05 m. What is the magnitude of the muscle force?  
Answer =
Compression and Shear

- Once you have calculated the muscle force, you can calculate the compressive and shear forces across L5/S1.
- However, you cannot do this for the questions just given. Why? Think about what information you would need and how you would go about calculating these values.
- You need to know the alignment of the segment in question (i.e. trunk).
Compression & Shear Solution

- In this simple model, three main forces act on the lumbar spine at the lumbosacral (L5/S1) level:
  - The force produced by the weight of the upper body (body mass above L5/S1).
  - The force produced by the weight of the object.
  - The force produced by the erector spinae muscles (which acts approximately at right angles to the disc inclination).

Free Body Diagrams

- \[ \Sigma F_y = 0 \]
- 200 N
- 450 N
- \( \theta \)

Compression and Shear

- Shear force components in blue
- Compressive force components in pink

The solution to this diagram is in the Nordin and Frankel text

- Same diagram as used earlier
- As the other examples calculate the total forward bending moment produced by these two forces and the resultant muscle force required to maintain stable equilibrium.
- Assuming the trunk is aligned 55\(^\circ\) to the horizontal (forward bend of 35\(^\circ\)) find the compressive and shear forces acting on L5/S1.
Buckling

- If the work done on the spine (energy applied) is greater than the work the muscles can do to stiffen the spine, then the spine will buckle.

Chaffin & Park, 1973

LBP incidence

(freq. rates per 200,000 man-hours worked)

Predicted compressive forces on L5/S1 disc (kg)

Inverted Pendulum

Chaffin & Park, 1973

Torque and forces acting on the lumbar spine

- Torque due to Load and Upper Body Mass
- Muscle Force
- Compression
- Shear
Force from interspinous ligaments adds to anterior joint shear in the lumbar spine

Muscles engaged (active) versus load carried by ligaments

Good (left) and Bad (right) Deadlift Form
Fully flexed spine inactivates back extensors, loads the posterior passive tissues and results in high shearing forces. Neutral spine posture disables interspinous ligaments reducing shear.

4D WATBAK

- 4D WATBAK is an easy to use biomechanical modelling 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