Mechanics of the Human Spine
Lifting and Spinal Compression

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

Manual Handling Injuries
- Approximately 33% of the U.S. workforce is presently required to exert significant force as part of their jobs (NIOSH, 1981).
- 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) and cumulative back injuries (slipped disc).

Causes of Reportable Injuries

Types of Handling Accidents
Most flexion in these regions

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

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)

Relative loads on the third lumbar disk for living subjects

- Upright standing depicted as 100%
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.

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, as stated, 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.)

Analysing Lifting Tasks

More detail in Kin 380

Analysing Lifting Tasks

More detail in Kin 380

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
Lifting task evaluation criteria

Psychophysical
- limits loads based on workers perception
- uses the concept of a maximum acceptable weight
- applicable to nearly all lifting tasks (except high-frequency lifting above 6 lifts per min)
- NIOSH cut-off acceptable to 75% of female workers and 99% of male workers.
- other researchers (Snook, Mital et.al. provide different tables for males and females).

Justification for the Criteria
- 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_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_comp between 4.5-6.8 kN the rate of back problems was 1.5 times greater than for jobs with F_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?

Find the muscle moment and muscle force

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

Compression and Shear

Muscle force = 3020
3020 + (450 x sin 80) + (200 x sin 80) - C = 0
3020 + 443.16 + 196.96 - C = 0
C = 3660.12 = 3660 N

Muscle force = 4250
4250 + (450 x sin 65) + (200 x sin 65) - C = 0
4250 + 407.84 + 181.26 - C = 0
C = 4839.10 = 4839 N

Shear Calculations

1. Muscle force does not act in shear direction
   
   (450 x cos 80) + (200 x cos 80) - S = 0
   78.142 + 34.730 - S = 0
   S = 112.87 = 113 N

2. 
   (450 x cos 65) + (200 x cos 65) - S = 0
   190.18 + 84.52 - S = 0
   S = 274.70 = 274 N

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° to the horizontal (forward bend of 35°) find the compressive and shear forces acting on L5/S1.
Problem?
- How do you actually know where the centre of gravity of the segments above L5/S1 are located?
- You can calculate it knowing the segment centre of mass locations...BUT...
- This is time consuming and you will miss additional information that can be calculated just as easily.

Forces Acting on the Link Segment Model
- Gravitational forces.
- Ground reaction forces and other external forces.
- Muscle forces and joint reaction forces.

Remember this is really what it looks like.

So if you are calculating NET joint forces remember that they are just that "NET". They bear no relationship to the true joint reaction force!

Limitations of this Method
- Any force which is calculated at a joint will be the vector sum of the muscle forces (note plural, usually there is more than one common tendon for muscles crossing that joint) and the true joint reaction force (bone-on-bone force).
- Unfortunately this net joint force cannot be separated into its muscular and joint reaction components.
Advantages

- The advantage of this method is that net muscle moments can be calculated for all the joints (with the models shown in the lecture on lifting, we are calculating the moment only about one joint).
- If you calculate a moment across a joint system where you can accurately model the muscle as a single equivalent muscle (e.g. erector spinae), then you can determine muscle force and joint reaction force as we have done in many of our problems already.

Predicted Strength

- There are tables suggesting safe limits for muscle moments for various joints.
- Other tables provide maximal strength muscle moments. It is for the ergonomist, designer, etc, to decide if task is suitable.
- Still other tables provide equations to predict strength. These generally factor in joint angles.

Mean Isometric Joint Moments of Force (Nm) [strength values]  Stobbe'82

<table>
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<tr>
<th>Joint</th>
<th>Male %var</th>
<th>Female %var</th>
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<tr>
<td>Hip</td>
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<td>Extension</td>
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<td>Extension</td>
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<tr>
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<td>301</td>
<td>19</td>
</tr>
<tr>
<td>Extension</td>
<td>391</td>
<td>19</td>
</tr>
</tbody>
</table>

% var. = % variability = (S.D./mean) x 100

Link Segment Models Assumptions

- Each segment has a fixed mass located as a point mass at its centre of gravity.
- The location of the centre of gravity remains fixed during movement.
- The joints are considered to be hinge (pin) joints (2 dimensional models).
- The moment of inertia of each segment about its mass centre (or distal and proximal joint centres) is constant during movement.

Inverted Pendulum
**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.

**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.**

**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

**Muscle Force**

**Ligament Force**

**Joint Shear**