Biomechanics of Lifting and Lower Back Pain
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Outline

• Epidemiology of lower back pain
• Strength of spinal segments
• Lifting models:
  • muscle and intervertebral joint forces (compression and shear)
  • effect of abdominal pressure on lifting mechanics
Required Reading from Custom Courseware


Also recommended:

Epidemiology of lower back pain
Lower back pain: true or false?

• I will probably experience at least one episode of back pain during my lifetime
• slouching is bad for my back (i.e., increases spinal forces)
• sitting is harder on my back than standing
• chairs should have lumbar supports
• I should lift by flexing my knees instead of my trunk
• I should use a back belt when lifting heavy objects
Epidemiology of lower back pain

- Lower back pain (LBP) is the most costly musculoskeletal disorder in industrial nations.
- 80% of individuals will suffer from LBP in their lifetimes.
- Severity ranges from completely debilitating to temporary annoyance.
- 10-17% of adults in the U.S. have an episode of LBP in a given year.
- Annual cost in the U.S. of back-pain-related care and disability compensation is $50 billion.
In Canada, LBP accounts for 18% of all injuries, and more than 21 million disability days annually.

- average sickness absence period is 21 days
- 80% to 90% of patients recover completely within seven weeks
- others require special treatments such as traction, chemonucleolysis, or disk surgery
- 7% are left with permanent disability, which in about 50% of cases permanently prevents the patient from doing strenuous work
Cause and prevention of LBP

- LBP is caused by chemical or mechanical irritation of pain-sensitive nerve endings in structures of the lumbar spine
- exact cause of pain in 85% of cases is undiagnosed
- therefore, considerable guesswork is often involved in selecting between treatment options (e.g., ice, rest, gentle activity, manipulative therapies, therapeutic exercise, surgery)
Work-related risk factors for LBP

• heavy physical work
• static work postures
• frequent bending or twisting
• lifting, pushing and pulling
• repetitive work
• vibrations
• psychological/psychosocial
Probability of case-group members reporting LBP increases with peak load during work (Norman et al. 1998)
Spinal loads during daily activities: the problem with slouched sitting

- The graph on the right shows compressive forces between the L3/L4 vertebrae for various activities, as a percent of the L3/L4 load during standing (shaded bar).

- Lying creates the least force, while slouched sitting creates the greatest force.
Muscle forces augment spinal loads during standing

- during standing, the COG of the trunk is located ventral to the spine
- this creates the need for the erector spinae muscles to be active
- this, in turn, creates the need for compressive forces in individual vertebrae that equal ~twice the weight of the body above the measured level (e.g., 700 N in L3/L4 for a 70 kg individual)
Pelvis tilt, reduced lordosis cause lumbar loads to be higher in sitting than standing

- when compared to standing, sitting involves backward tilting of the pelvis and straightening of the lumbar lordosis
- these both act to increase the moment arm ($L_w$) of the trunk weight with respect to the lumbar spine
Backrests and lumbar supports reduce spinal loads during sitting

- Backrests reduce spinal loads by supporting a portion of the weight of the trunk.
- The farther back the inclination, the smaller the load.
- Lumbar supports (but not thoracic supports) reduce $L_w$ and spinal loads.
Load geometry and body posture affect vertebral loads during carrying

Moments at L5/S1 during lifting (shown on the top of the figure) are affected by (a) geometry of the load, (b) trunk angle, and (c) knee flexion

- 60 Nm
- 80 Nm
- 69 Nm
- 193 Nm
- 151 Nm
- 213 Nm
Review Questions

• Why are spinal forces non-zero during standing?
• Why are spinal forces higher during sitting than standing?
• What factors affect spinal forces during lifting?
• What lifting techniques should be used to minimize spinal loads?
Strength of spinal segments
The L4/L5 and L5/S1 disks are most vulnerable to herniation

- 85-95% of all disk hernias occur at the L4/L5 & L5/S1 levels
- The frequency of hernias is similar at each site
- Some lifting models use L4/L5, some L5/S1.
Disk compression forces are thought to affect risk for LBP

- disk compression is thought to be largely responsible for vertebral end-plate fracture, disk herniation, and resulting nerve root irritation
- data exists on the compressive strength of the lumbar vertebral bodies and intervertebral disks
- however, the relative importance to LBP of disk shear forces and torsional moments (versus compressive forces) is not well understood
NIOSH suggests a maximum disk compressive force of 3.4 kN

- In arriving at this estimate, NIOSH reviewed data from cross-sectional field studies, and used biomechanical models to estimate $F_{comp}$ in lifting tasks associated with lower back injury.
- Herrin et al. 1986 studied 55 jobs (2934 potentially stressful MMH tasks), and traced medical records for 6912 workers. Jobs involving a peak $F_{comp}$ between 4.5-6.8 kN had a 1.5-fold greater risk for back problems than jobs where $F_{comp}$ was less than 4.5 kN.
LBP incidence (freq. rate per 200,000 man-hours worked)

Chaffin & Park, 1973
Cadaver studies show that 3.4 kN is a conservative estimate of lumbar compressive strength

- Jager & Luttman (1989) found that the mean compressive strength of lumbar segments was 4.4 ± 1.9 (SD) kN
- 30% of segments had a strength less than 3.4 kN
- Brinckmann et. al. (1988) found compressive strength ranged from 2.1-9.6 kN, with less than 21% of specimens failing below 3.4 kN
- Porter, Hutton and Adams (1982, 89) found an average compressive strength of approx. 10 kN for males specimens aged 20-40 yrs
Cadaver strength data: best estimates, which should be interpreted with care

- strength estimates vary widely between studies
- depend on donor age, gender, occupation, history of injury and disease
- also depend on method of testing:
  - Method of specimen support
  - Method of load application
- spinal unit is usually stripped of supporting muscles and ligaments (reducing strength)
Lifting models
Lifting Models

- Analytic models:
  - HAT model of lifting
  - Cantilever low back model of lifting
  - Link segment static models

- Computer models:
  - 4D WATBAK computer program
    (University of Waterloo)
  - 3D Static Strength Prediction Program
    (University of Michigan)
HAT Model of lifting

- upper torso is modeled as a single mass representing the combined mass of the head, arms, and trunk
- referred to as the “HAT model”
- simple to analyze, but of limited accuracy

\[ W_{\text{HAT}} \approx 1/2 \ BW \]
HAT Model of lifting (continued)

- back muscles must produce a moment ($M_M$) to counteract moments due to hand force ($F_{hand}$) and weight of HAT ($W_{HAT}$)
- Otherwise person would bend or fall forwards.
Moment is force times distance

the moment that a force $F$ produces about a fixed point $O$ is equal to the force times the perpendicular distance from $O$ to the line of action of the force

$MO = Fd$

$d = "moment\ arm"$
Muscle force can be estimated from muscle moment and moment arm

- Once the muscle moment ($M_M$) has been calculated, the muscle force ($F_M$) can be estimated by dividing $M_M$ by the moment arm of the erector spinae muscle.

- This force contributes to the resultant joint compressive force.
Single Equivalent Muscles

- In most joints (other than the spine), more than one muscle or muscle group contributes to $M_M$
- In shoulder flexion, there are two prime movers and two assistors
- In forearm flexion, there are three prime movers
- We often lump such muscle groups together and refer to the lumped muscle as a “single equivalent muscle”
Examples: Vertebral moments due to load only.
Examples: Vertebral moments due to load and weight of HAT.
Sample problem

- Calculate the required muscle moment ($M_M$) to stabilize L5/S1 (red square) when $L_w = 0.25$ m and $L_P = 0.4$ m
- Answer: $M_M = 192.5$ Nm
- If the erector spinae moment arm is 5 cm, what is the magnitude of the muscle force $F_M$?
- Answer: $F_M = 3850$ N
Sample problem

1. **$L_w = 0.18 \text{ m}$**
   **$L_p = 0.35 \text{ m}$**

2. **$L_w = 0.25 \text{ m}$**
   **$L_p = 0.5 \text{ m}$**

Find the muscle moment ($M_M$) and the muscle force ($F_M$), assuming the erector spinae moment arm is 5 cm.
Need to consider trunk angle to determine disc compressive and shear forces

• 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).
Sample problem

For the loading condition shown, calculate the erector spinae muscle force $F_M$ and the compressive and shear components of joint reaction force ($F_{JC}$ and $F_{JS}$) at the L5/S1 vertebrae (red square).

Is $F_{JC}$ greater than the maximum safe value of 3.4 kN recommended by the U.S. National Institute for Occupational Safety and Health (NIOSH)?
Effect of intra-abdominal pressure and back belts on lifting mechanics

Compare the stiffness of a full drink can with that of an empty one. We similarly can stiffen the trunk by contracting the abdominal muscles to increase “intra-abdominal pressure” (IAP).

Back belts claim to increase IAP and reduce risk for injury during lifting. But are they really protective? In 1992, NIOSH concluded that “the effectiveness of using back belts to lessen the risk of back injury among uninjured workers remains unproven.”