KIN 380 – Occupational Biomechanics

Computerized biomechanical software programs and selection of biomechanical models

Lecturer: Andrew Laing
Office Hours:
Outline

■ Introduction
■ Review – Injury Mechanisms
■ OUBPS study – background for 4D Watbak
■ 4D - Watbak
  – Description of software
■ Biomechanical model selection
  – Univ. of Michigan model (3DSSPP)
  – University of Waterloo model (4D Watbak)
■ Software Demonstrations
Objectives of the Lecture

Learn:
- Proven back injury risk factors
- Back injury risk evaluation techniques
- The importance of understanding the assumptions / limitations of your model.
- Importance of assessing peak and cumulative loads
- Interpretation of results
- Intervention mock-up methods

Practice:
- Breaking jobs down into component actions
- Assessing real life jobs using 4D WATBAK
Workplace experience...
"and his knees were bent and his back was straight."
Q: At what point does a tissue get injured?

Applied Force > Tissue Tolerance
Peak Force Injury

Force

Injury

Tissue Tolerance

Margin of Safety

Applied Force

Time
Cumulative Force Injury

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<thead>
<tr>
<th>Injuries</th>
<th>Force</th>
<th>Time</th>
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<tr>
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Low, Constant Force Injury

Force

Tissue Tolerance

Applied Force

Injury

Time
To be most effective and comprehensive, an injury risk prediction model should incorporate these various injury mechanisms.
BIG QUESTIONS:

Is work-related biomechanical loading associated with risk of reporting an injury?

What variables are most important?
Science Behind 4D-Watbak

Biomechanical Risk Assessment Software
Goal – to determine risk factors for the reporting of low back pain

General Motors, Oshawa

10,000 possible subjects

Methodology:
- LBP matched with no LBP
- Interviews
- Peak, Cumulative load collected

Results – reported Norman et al. (1998) study, summarized in following slides
Biomechanical Spine Model

- Back muscles must produce a moment of force to counteract moment from hand force and weight of head+arms+tORSO.
- Otherwise person bends forward.

\[
\text{hat} = \frac{1}{2} \text{bw}
\]
Moment of Force

= the tendency of a force (the hanging weight) applied to an object (torque wrench handle) to cause the object to rotate about a point (nut)

- size of moment = force x distance
- units are Newton*meters
Moment of Force

\[ \text{Load Moment} = F \times d \]
Odds ratio for reporting low back pain: Peak L4/L5 Moment
Probability of reporting low back pain: 
Peak L4/L5 Moment
Biomechanical Spine Model
Internal Forces

Load Moment
Muscle Force
Compression
Shear
Odds ratio for reporting low back pain: Peak L4/L5 Compression
Probability of reporting low back pain: Peak L4/L5 Compression
Biomechanical Spine Model
Internal Forces

- Load Moment
- Muscle Force
- Compression
- Shear
Shear is defined as a force that acts parallel or tangent to a surface to create sliding of one object with respect to another.

With respect to the lumbar spine, the forces due to the mass of the upper body and the forces acting on the hands create shear forces at the L4-L5 joint. The resultant shear due to these two types of forces is displayed as the L4-L5 Reaction Shear.

A positive shear value indicates a tendency for L4 to shear forward on L5, while a negative value indicates a tendency for L4 to shear backward on L5.
In addition to the shear force created by the mass of the upper body and the forces acting on the hands (reaction shear), a shear force is produced by the supportive trunk tissues (muscles and ligaments).

The L4-L5 **Joint Shear** represents the resultant shear force due to the sum of the reaction shear and the muscle/ligament shear. It is this value, that includes the effect of muscle/ligament forces, which represents the actual shear experienced at the L4-L5 joint.
Joint Shear

- $F_m$ – muscle and ligament force
- $F_{ms}$ – component of muscle and ligament force in the shear direction
- $F_{mc}$ – component of muscle and ligament force in the compression direction
- Joint shear = reaction shear + $F_{ms}$
Joint Shear

- In cases of extreme spine flexion, soft tissue elements other than muscle significantly contribute to opposition of load moment.

- In these cases, the ligament force line of action is such that it ADDS to anterior joint shear.

- Thus, in cases of extreme spine flexion the magnitude of joint shear (and presumably risk of injury) increases dramatically.
Odds ratio for reporting low back pain: Peak L4/L5 Shear
Probability of reporting low back pain: Peak L4/L5 Shear
Summary: major biomechanical risk factors for reporting LBP

- Higher Peak Hand Forces
- Higher Peak Loads
  - Peak L4/L5 Reaction Shear
- Higher Cumulative Loads
  - Cumulative L4/L5 Moment
Cumulative Loading = Action 1 + Action 2 + Action 3...

Area 1 = 598 N * 5 s = 2990 N.s
Area 2 = 9965 N.s
Area 3 = 7404 N.s
Area 4 = 4266 N.s
Area 5 = ...

Lumbar Compression (N)

Time (s)
BIG QUESTIONS:
Is work-related biomechanical loading associated with risk of reporting an injury?  
YES

What variables are most important?  
*Both peak and cumulative low back loads should be evaluated.*
Overall: psychosocial and psychophysical risk factors for reporting LBP

- Poorer workplace social environment
- Higher perceived education (compared to peers)
- Lower job control
- Higher co-worker support
- Higher job satisfaction
- Higher perceived physical demands
Injury Risk Assessment - Physical Risk Factors

1. Estimate size of peak and cumulative loads on tissues
2. Compare to scientific literature findings
3. Reduce the tissue loads by changing the job and you reduce injury risk
1. Estimate size of peak and cumulative loads on tissues
   a) link segment analyses by hand
   b) biomechanical modeling software

   - Benefits?
     - decreased analysis time
     - decreased chance of calculation errors
Ergonomics Software Packages

- Snook Tables
- NIOSH Equations
- 4D WATBAK
- +
- PDD
- 3D Static Strength (Michigan State)
Assessment Methods - 4D WATBAK

- Experience with Watbak?
- What does Watbak allow the user to do?
- What is unique about the Watbak software?
- Has it been validated?
What does it do?

Biomechanical

- calculates acute loads on body joints based on posture and hand forces
- values compared to established limits and population strength data
- calculates cumulative loads on body joints

Epidemiological

- compares peak and cumulative values to OUBPS data
4D WATBAK

Use to Assess:

- variety of actions including lifting, lowering, pushing, pulling, carrying, holding a static posture, one-handed actions, actions involving unequal hand forces
4D WATBAK

■ Inputs:
  – Worker height, weight, gender, time associated with actions, posture associated with actions, force applied by hands for each action

■ Outputs:
  – Peak load on lumbar spine and other major body joints
  – Cumulative loads on lumbar spine and shoulder
  – Limits, strength data comparisons and LBP Index to help interpret values
What is unique about the outputs?

1. Computes cumulative loads
2. Compares loads to an epidemiological database. Provides indication of risk of reporting back pain.
Beer Quiz:

- Job A requires worker to bend over 10 times in a shift to pick up a beer keg (assume action takes one second). This creates 3000 N of peak L4/L5 compression.

- Job B requires worker to bend over 50 times in a shift to pick up a case of beer (assume action takes one second). This creates 1000 N of peak L4/L5 compression.

- Which job involved higher cumulative L4/L5 compression?
Job A involved 10 reps \( \times 1 \text{ s} \times 3000 \text{ N} \)
\[ = 30,000 \text{ N.s} \]

Job B involved 50 reps \( \times 1 \text{ s} \times 1000 \text{ N} \)
\[ = 50,000 \text{ N.s} \]

Lifting beer cases involved higher cumulative load, so go for the kegs (if you’re not concerned about a 3000 N peak load!!).
Injury Risk Assessment - Physical Risk Factors

1. Estimate size of peak and cumulative loads on tissues
2. Compare to scientific literature findings
3. Reduce the tissue loads by changing the job and you reduce injury risk
L4/L5 Loading Threshold Guidelines

L4/L5 Compression:
  - NIOSH
    - Action Limit (AL): 3433 N
      - protects 90% of population (99% males, 75% females)
    - Maximum Permissible Limit (MPL): 6376 N
      - hazardous for a majority of the population
L4/L5 Loading Threshold Guidelines

L4/L5 Compression:

- Genaidy et al. (1993)
  - gender- and age-specific regression equations that predict compressive strength values for a given population percentile.
  - damage load, defined as the load that causes the first gross signs of damage to the vertebrae, and is approximately 60% of the compressive strength.
  - It is the damage load, specific to the age and gender of the worker and the population percentile selected by the user, that is displayed in 4D WATBAK output.
L4/L5 Loading Threshold Guidelines

L4/L5 Compression:

- Jager et al. (1991)
  - gender- and age- specific regression equations that predict average compressive strength.
  - they suggest that one standard deviation be subtracted from each average compressive strength value to derive upper limit compression values
  - these are the values displayed by 4D WATBAK
**L4/L5 Loading Threshold Guidelines**

**L4/L5 Shear:**
- McGill et al., 1998:
  - Action Limit (AL):
    - Males: 500 N
    - Females: 330 N
  - Maximum Permissible Limit (MPL):
    - Males: 1000 N
    - Females: 660 N
L4/L5 Loading Threshold Guidelines

Low Back Pain Reporting Index (LBPRI):

- The LBPRI scores were formulated based upon the results of the OUBPS epidemiological case-control study performed in an industrial setting (Norman et al., 1998).
- A value of 0.52 suggests that there is a 52% chance that the worker performing this job would be classified as a low back pain case (would have reported low back pain).
L4/L5 Loading Threshold Guidelines

LBPR1 - Combined vs. Univariate:

- **Univariate**
  - prob. of reporting LBP based on one specific measure. e.g. peak compression

- **Combined**
  - Equation based on:
    - Cumulative Moment
    - Peak Hand Load
    - Peak Reaction Shear

All were independent predictors of LBP from OUBPS study.
L4/L5 Loading Threshold Guidelines

Low Back Pain Reporting Index

- Combined
- Peak Hand Load
  (Demould: Pull Foam: Pull Close Bowl Foam)
  0.35
- Peak L4-L5 Moment
  (Demould: Pull Foam: Pull Far Bowl Foam)
  0.37
- Peak L4-L5 Compression
  (Demould: Pull Foam: Pull Far Bowl Foam)
  0.35
- Peak L4-L5 Reaction Shear
  (Demould: Pull Foam: Pull Far Bowl Foam)
  0.33
- Cumulative L4-L5 Moment
  0.70
- Cumulative L4-L5 Compression
  0.52
- Cumulative L4-L5 Reaction Shear
  0.60
Loading Threshold Guidelines

Joint Strength:

- Elbow, shoulder, lumbar moments from literature.
- Gender specific
- Watbak calculates % of gender specific population not capable
Assumptions in 4D Watbak

- Intra-abdominal pressure (IAP) effects are negligible. Rationale: IAP is due to abdominal contraction. Thus benefits of IAP cancelled out by added low back compressional force from abdominal contraction.
- Pin joints
- Segment mass calculation
- Segment lengths/COM calculations
Assumptions in 4D Watbak

- Rigid body model assumed (kinematics of body not taken into account)
- Errors in moment/reaction force calculations are small
- Single muscle force vectors accurate
- Angle of force application can be estimated.
- Work postures can be reasonably depicted.
Limitations with 4D Watbak

- 2D model currently. Evidence?
- Lower body postures don’t influence L4/L5 loads. Influences of leans, seated postures, kneeling?
- Can’t model shrugged shoulders
- LBPRI results based on:
  - predominantly males
  - over eight hour shift
Are there differences between models?
Biomechanical Model Selection

- Not all models are the same
- Some models more suited to particular loading situations
- To protect yourself, you need to know model details, assumptions, limitations
UM model details (3DSSPP)

- 3 dimensional model
- Quasi-dynamic
- Intra-abdominal pressure (IAP) effects are considered. Rationale: IAP is partly a function of posture. IAP forces assist in resisting the load moment, reducing back extensor muscle force, and reducing L4/L5 compression force.
- Four separate back extensor muscle employed
UM model details (3DSSPP)

- Six separate abdominal muscles employed
- Does not adjust for flexed or lordotic pelvic postures.
UW model details (4D Watbak)

- 2 dimensional model
- Quasi-dynamic
- Intra-abdominal pressure (IAP) effects are negligible. Rationale: IAP is due to abdominal contraction. Thus benefits of IAP cancelled out by added low back compressional force from abdominal contraction.
- Single equivalent back extensor muscle used, moment arm length = 6 cm
UW model details (4D Watbak)

- Back extensor muscle does not run parallel to the line of compression. A proportion of the extensor muscles are considered to pull at an angle from the line of compression (e.g. pars lumborum fibres of the longissimus thoracis). This influences joint shear values.

- Single equivalent abdominal muscle used, moment arm length = 4.5 cm

- Includes ligament anterior shear forces contributions at high degrees of pelvic flexion

- Allows computation of cumulative loads
Biomechanical Models Differ!!!

- Thus, output may differ across models
- These differences may be greater in some loading / postural situations
- Your choice of model should reflect a match between the strengths of the model and the situation to be studied
Let’s Practice!!!
Software
Examples
Single Action Posture - Before

- Input Posture
- Determine Loads
  - L4/L5 Comp and Joint Shear
- Compare to Limits in Literature
- Intervene? Redesign?
Single Action Posture – After Platform

- Input Posture
- Determine Loads
  - L4/L5 Comp and Joint Shear
- Compare to Original Design
- Compare to Limits in Literature
- Try in 3DSSPP
Cumulative Evaluation Postures
Cumulative Evaluation Postures
# Cumulative Eval Job Breakdown

## Job Breakdown and Time Sheet

<table>
<thead>
<tr>
<th>Task Group / Task / Action Name</th>
<th>Action Reps (# / 30s)</th>
<th>Action Reps (# / shift)</th>
<th>Action Duration (time / rep)</th>
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