The Working Back: A Systems View

William S. Marras, Ph.D., CPE
Honda Professor and Director
Biodynamics Laboratory
Spine Research Institute
The Ohio State University
Columbus, Ohio
http://biodynamics.osu.edu

Background on Back Pain
- Up to 80% of the population will suffer from low back pain at least some time during their life (Luo, 2004)
- Low back pain is the 2nd most common symptom-related reason for physician visits (Deyo and Weinstein, 2001)
- Low back pain is 2nd greatest cause of disability in U.S. (Bagnall, 2010)
- 15-20% of Americans report back pain yearly (Deyo and Weinstein, 2001)
- Results in over 100 million lost work days per year (Atlas, 2004)
- Health care expenditures are 60% higher for those with back pain (Deyo and Weinstein, 2001)

Current State of LBP Treatment
- A precise diagnosis is unknown in 80% to 90% of patients with low back pain (Deyo & Weinstein, 2001)
- Few diagnosed through imaging (10-15%)
- Spend $90 Billion per year treating back problems in the U.S. (about the same as we spend on cancer) (JAMA, 2011)
- Cost of treatment increased 65% in 8 years (Martin, et al., 2008)
- Less than 50% of surgeries are successful (Weinstein, 2006)

Increases in Use of Various Services for LBP Treatment (Deyo et al., 2009)

- Surgical success rates for discectomy = 42.6% (vs. 32.4% non-operative) (Weinstein et al., 2006)
- Increase in complex fusion surgeries increased 15x from 2002 to 2007 with life threatening complications increasing 3x (Deyo et al, 2010)
- Source of pain often unknown (van Tudler, et al, 2006)
- Surgical effect size small (Keller, 2007; Deyo, 2004)
- Value of prevention

Low Back Surgery
- "No operation in any field of surgery leaves in its wake more human wreckage than surgery on the lumbar disc" (DePalma and Rothman, 1970)
- Surgical success rates for discectomy = 42.6% (vs. 32.4% non-operative) (Weinstein et al., 2006)
- Increase in complex fusion surgeries increased 15x from 2002 to 2007 with life threatening complications increasing 3x (Deyo et al, 2010)
- Source of pain often unknown (van Tudler, et al, 2006)
- Surgical effect size small (Keller, 2007; Deyo, 2004)
- Value of prevention
Presentation Topics

- Does our current approach to understand and controlling LBP make sense?
- Potential "pathways" to low back pain
- State-of-the art biomechanical assessment’s potential to assess the body’s response to low back pain risk factors
- How might various work and non-work factors contribute to spine loading and low back pain development?

Low Back Pain Risk Factor Environment

Social & Org. Factors

Individual Factors

Physical Factors

(NRC/IOM, 2001)

Risk Factor Exposure Surveillance at the Workplace

- Spine Motion
- Dynamic Moment Assessment

Assessment of Causal Relationships

Workplace

Surveillance (Risk Factors)

Biomechanics

Lumbar Motion Monitor (LMM)
Low Risk Physical Environment

High Risk Physical Environment

Analysis: LMM Output
How much is too much exposure?

Comparison of Back Injury Rates and Risk Predictions Before and After Interventions (Marras et al. 2000)

Prospective Study Design

- Health Effects Measurements (all workers on job)
  - Background
  - Health History
  - Questionnaire
  - Health
  - Psychosocial
  - Perception
  - Kinematic Back Function

- Work Exposure Measurements (subset of workers (3-7) from each job)
  - 390 continuous measurements per lift monitored over ½ day

Health Effects Measurements (all workers on job)

- Health Questionnaire
- Health
- Psychosocial
- Perception
- Kinematic Back Function

Time

Baseline

Follow-up (after 6 mo.)

Exposure Assessment:
Laboratory in a backpack (3.4 kg)
390 measures recorded continuously

Categories of Measures
- Load weight, force, acceleration, etc.
- Load direction (lift, push, pull, etc.)
- Load 3-D path and motion (position, velocity, and acceleration)
- Trunk position, velocity, and acceleration
- Timing (cycle times, peak loads, cumulative measures, etc.)

(Marras et al., 2009)

Exposure Assessment:
Force Measurement
Directional force, acceleration, etc. to derive static/dynamic load moments, push/pull force, etc.

Accuracy: +/- 0.5 Kg

(Marras et al., 2009)

Dynamic Exposure Measurements:
Position and Movement of loads and Spine

Measurement Categories
- 3D Position, distances, velocity, acceleration, heights, reaches
- Timing, frequency, cumulative loading

Accuracy: position AAE = 3.8 cm; motion $R^2 = .98$

(Marras et al., 2009)

Data Acquisition System

Continuous Recording of 390 variables:
- 3-D Positions
- Load Characteristics
- Trunk Kinematics
- Timing Features

Health Effects Worker Sampling

Baseline Evaluation N=888 workers (19 facilities / 50 jobs)

Follow-Up Evaluation N=522

Drop Out N=366 Unavailable for follow-up

Follow-Up On Same Job N=450

Follow-Up Changed Jobs N=72
**Load (Force): Univariate (continuous) Odds Ratios (with 95% Confidence Interval)**

<table>
<thead>
<tr>
<th>Odds Ratio</th>
<th>Max Static Transverse Plane Load Moment*</th>
<th>Max Static Sagittal Load Moment*</th>
<th>Max Dynamic Sagittal Load Moment*</th>
<th>Max Dynamic Lateral Load Moment*</th>
<th>Max Dynamic Twisting Side Moment*</th>
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<tbody>
<tr>
<td>0.00</td>
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* Statistically significant (Marras, et al., Spine, 2010)

**Temporal Measures: Univariate (continuous) Odds Ratios (95% Confidence Interval)**

<table>
<thead>
<tr>
<th>Odds Ratio</th>
<th>Duration of Carry*</th>
<th>Duration</th>
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<td>14.00</td>
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</table>


**Multivariate Risk Models: Individual Worker**

<table>
<thead>
<tr>
<th>Multivariate Model Variables</th>
<th>Daily Odds (95% CI)</th>
<th>Weekly Odds (95% CI)</th>
<th>Job Tenure Odds (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline lumbar function (mmHg)</td>
<td>6.64 (3.84-11.5)</td>
<td>6.64 (3.84-11.5)</td>
<td>7.84 (4.27-14.0)</td>
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<tr>
<td>Cumulative daily rest time</td>
<td>2.83 (1.41-5.7)</td>
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<tr>
<td>Cumulative weekly rest time</td>
<td>2.74 (1.59-4.72)</td>
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<tr>
<td>Cumulative job tenure rest time</td>
<td>2.83 (1.41-5.7)</td>
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<tr>
<td>Cumulative Coronal dynamic load moment exposure</td>
<td>1.85 (1.03-3.39)</td>
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<td>Peak duration weekly sagittal trunk acceleration</td>
<td>3.66 (1.5-10.22)</td>
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<td>Cumulative sagittal static load moment</td>
<td>6.77 (1.43-32.14)</td>
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<tr>
<td>Job satisfaction</td>
<td>2.84 (1.7-3.77)</td>
<td>2.10 (1.20-3.79)</td>
<td>2.11 (1.20-3.68)</td>
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<tr>
<td>Age of baseline</td>
<td>2.70 (1.84-4.03)</td>
<td>2.77 (1.97-3.77)</td>
<td>2.98 (1.97-3.77)</td>
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</tbody>
</table>

| Sensitivity/Specificity (%) | 74%/74% | 75%/72% | 66%/78% |

**Assessment of Causal Relationships**

**Intervertebral Disc**

- The primary source of low back pain is suspected to be the disc (Nachemson, 1976; Videman and Battie, 1996; An, 2004)
- Noxious stimulation of the disc produces symptoms of low back pain
- Anular tears and reduced disc height are associated with low back pain (Videman et al., 2003)
- Mechanical load can be the stimulus (Marras, 2008)

**Traditional Biomechanical Logic**

**Load — Tolerance Relationship and Risk**

- Risk of Injury
- Tolerance
- Loading Pattern

(McGill, 1997)
**Spine Anatomy**

- Cervical vertebrae
- Thoracic vertebrae
- Lumbar vertebrae
- Neural roots
- Intervertebral disc
- Vertebral body
- Vertebral endplate
- Nerve root

**Intervertebral Disc**

- Nucleus pulposus
- Anulus fibrosus
- Intervertebral disc
- Endplate
- Anterior
- Posterior

**Pain Sensitive Tissues** *

- Ligamentum flavum
- Interpedicular ligament
- Neural arch
- Nucleus
- Intervertebral disc
- Vertebral endplate
- Nerve root

* indicates pain-sending trabecular

**Disc Degeneration**

A, B, C, D

**How Cumulative Trauma Develops in the Spine**

- Vertebral endplate

**Disc Nutrition Pathways**

- Vertebral body
- Vertebral endplate
- Disc
Compression Leads to Increased Disc Pressure and Endplate Deformation

How Cumulative Trauma Develops in the Spine

Vertebral Endplate

Scar Tissue Development

How Cumulative Trauma Develops in the Spine

Disc Degeneration and Cumulative Trauma

Vertebral Body

Vertebral Endplate

Disc

Effects of Shear on the Annulus Fibrosis

Disc Degeneration Sequence of Events

Excessive or highly repetitive forces

End-plate microfracture

Scar tissue

Reduced nutrients

Degeneration (annulus fibrosis)

(From White AA III, Panjabi MM, 1990.)

(From Adams MA, Bogduk N, Burton AK, et al. 2006)
Biomechanics is More than Strength

Can we assess specific spine tissue loads *in-vivo*?

Spine Loads Results from the Reaction of Internal Forces to External Forces

Trunk Muscle Coactivity

(Maras et al., 2005)
### Biologically-Assisted Models

<table>
<thead>
<tr>
<th>Spine Model Group</th>
<th>Location</th>
<th>Model Type</th>
<th>Static/Dynamic</th>
<th>Spine Geometry</th>
<th>Muscle Geometry</th>
<th>Muscle Function</th>
<th>Validation</th>
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<tr>
<td>McGill et al.</td>
<td>Lumbar</td>
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<td>Shirazi-Adl et al.</td>
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<td>van Dieen et al.</td>
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<td>Data, Literature, EMG</td>
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<tr>
<td>Marras et al.</td>
<td>Hybrid FEM and Rigid Linked Segment</td>
<td>Dynamic</td>
<td>Literature Data</td>
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<td>Literature Data</td>
<td>Literature Data</td>
<td>Literature, EMG</td>
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### Towards the Development of a Personalized Biomechanical Model: Our Vision

- Unique to the subject/patient (muscle control, imaging, structure characteristics)
- Driven by muscle activities characteristic of pathology
- Show tissue compromise
- Predict tissue breakdown
- Use to understand biochemical triggering
- Can assist in understanding impact of interventions (surgical vs. conservative)

### Spine Loading Model Development

- **Sagittal Plane**
  - Marras and Reilly, 1988; Reilly and Marras, 1989; Marras and Sommerich, 1991a; 1991b; Marras and Hinko, 1993; Granata and Marras, 1993; Davis et al., 1998; Marras et al., 1999, 2001, Marras and Granata, 1997
- **Asymmetric Lifting**
  - Marras et al., 1999, 2001
  - Fathallah et al., 1998
- **Lateral Flexion**
  - Marras and Granata, 1997
- **Axial Twist**
  - Marras and Granata, 1999
- **Gender Adjustment**
  - Marras et al., 2001
  - Jorgensen et al., 2001
- **Complex Movements**
  - Theado et al., 2007 (entire lumbar spine)
  - Marras et al., 2009 (complex control)
  - Vanden et al., 2011 (facet forces)

### Personalized Biodynamic Model Structure (2011)

![Model Diagram]

- **Inputs**
  - Force
  - EMG
  - Gigahertz
  - Motion
  - Reaction
  - Load
  - Contact

- **Model**
  - Muscle
  - Spine
  - Joint
  - Tissue
  - Forces

- **Outputs**
  - Force
  - EMG
  - Gigahertz
  - Motion
  - Reaction
  - Load
  - Contact

*Note: The model structure diagram includes various components such as muscles, spines, joints, and tissues, with arrows indicating the flow of forces and interactions.*
Personalized Biodynamic Model Structure (2012)

Underlying Model Mechanics

Trunk Muscle Lines of Action, Area, and Mechanical Advantage determined via MRI

The Control System

Instrumentation Needed for Muscle Force Interpretation

- Instrumentation
  - EMG
  - Lumbar Motion Monitor (LMM)
  - Body part position sensors (gyros/accelerometers/goniometers)

- Muscle Information
  - Activity Level
  - Muscle Length/Orientation
  - Muscle Velocity

Instrumentation
Laboratory Assessment of Push-Pull

Assessment of Spine Forces Based Upon Task

Spine Loads at Different Levels

Disc Wear at Different Levels (EMG-Driven/FEM Hybrid Model) (2006)

Load Distribution of Specific Structures and Tissues (2007)

Concept Model: Import Specific Subject Anatomy

Finite Element Modeling of Specific Patient’s Disc (2009)

Facet Contact Force Distribution (2011)

Personalized Dynamic Biomechanical Model of the Lumbar Spine (2011)

(Vandlen, K.A., Marras, W.S., and Mendelsohn, D. 2011)

Personalized Model Applications
- Assist in understanding causality
  - Distribution of loads on spine
  - How does load distribution change with LBD?
  - Influence of non-physical factors
- Biomechanical Impact of Surgical Intervention
  - Adjacent Level Disease Risk
  - Fusion
  - TDR
  - Metastatic Cancer

Surgical Interventions
Personalized Biodynamic Model Structure (2011)

Adjacent Level Evaluation of Surgical Alternatives

Biomechanical Load Implications for an Intact Spine vs. TDR @ L5/S1

European Spine J. (2012)

Surgical Option Effects on Entire Lumbar Spine

Motion Quality
Spine Loading and Dynamic Moment Exposure
(Trunk Motion)

Spinal Loading vs. Sagittal Velocity
Spinal Load per Unit Extension Moment

Spinal Loads Significantly Influenced by Lateral Velocity

Granata and Marras, J. Biomech. 28(11): 1309-1317, 1995

Marras and Granata, J. Biomechanics 30(7): 697-703, 1997
Biomechanical Validation of LMM Risk Factors

LBD Risk Model | Biomechanical Validation
--- | ---
Lift Rate | Spine, 1997
Twisting Velocity | Spine, 1995
Moment | Spine, 1988, 1989
Sagittal Flexion | Human Factors, 1991a, 1991b

Spine Loading Due to Physical Work Factors

Spine Compression Force as a Function of Weight Lifted

<table>
<thead>
<tr>
<th>Weight (Kgs)</th>
<th>Maximum Compression Force (N)</th>
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<tr>
<td>18.1</td>
<td>2925</td>
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<tr>
<td>22.6</td>
<td>3399</td>
</tr>
<tr>
<td>27.2</td>
<td>3866</td>
</tr>
</tbody>
</table>

Spine Compression Force as a Function of Lift Height

<table>
<thead>
<tr>
<th>Lift Height</th>
<th>Maximum Compression Force (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1822</td>
</tr>
<tr>
<td>Middle</td>
<td>2353</td>
</tr>
<tr>
<td>Low</td>
<td>4337</td>
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</tbody>
</table>
Compressive Loading Changes Over Repeated Exertions throughout a Workday

(Marras et al., 2006)

Co-Activity Significance
- Increased trunk velocity requires increased muscle control = incr. co-activity
- Working in confined spaces requires increased control = incr. co-activity
- Increased co-activity increases spine loading
  \[ \text{control} \rightarrow \text{co-activity} \rightarrow \text{spine load} \]

Musculoskeletal Disorder Risk Factor Environment

(IOM/NRC, 2001)

Non – Physical Work Factors Affecting Spine Loading

The Influence of Psychosocial Stress, Gender, and Personality on Mechanical Loading of the Lumbar Spine (Marras et al., 2000)

Study Procedure
1. **Un-Stressed Session** - Perform Lift Tasks
2. Experiment Interruption / Experimenters Called Out of Room
3. **Stressed Session** - Perform Same Lift Tasks

Variability of Biomechanical Responses to Psychosocial Stress (Marras et al.2000)
Differences in Spinal Loads Between Personality Traits in Response to Psychosocial Stress (Marras et al., 2000)

Low Back Pain

Musculoskeletal Control and Tissue Load

Pain From the Brain: Central Sensitization

Working with Back Pain

Functional MRI scans show brain response in pain-sensitive (left) and nonsensitive (right) patients.

http://www.pnas.org/misc/archive062303.shtml
Normalized Spine Loading

Coactivity

Role of Wellness in Occupational Low Back Disorders

Five Core Interconnected Dimensions of Wellbeing

Wellbeing can offset the effects of age in health-related costs

Thriving Employees have 62% Lower Health-Related Costs Compared to those Who are Suffering
Turnover Costs: 35-52% Lower for Thriving Employees

Health Care Costs are Directly Related to the Number of Thriving Dimensions

Pathways to Spine Tissue Force Generation

Balance your life & Control your back pain

Conclusions

- Low back forces (and probably pain) are initiated by spine loading due to a mix of:
  - Physical Exertions
  - Psychosocial and Organizational Influences
  - Individual Factors
- Co-contraction can initiate greater tissue loads due to many of these factors (via co-contraction mechanisms)
- Working with back pain means tissue loading is even greater
- Possible to quantify the effects of surgical interventions on tissue load distribution and spine motion
Thank You!

http://biodynamics.osu.edu

e-mail: marras.1@osu.edu