BIOMECHANICS OF LOW BACK PAIN: A COMPUTATIONAL PERSPECTIVE

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Overview

• Low back pain (LBP)
• Research focus
• Computational approaches
  – Spinal loads
  – Cumulative effects of abnormal spinal loads
Low Back Pain (LBP)
LBP Significance

- **Prevalence**
  - ~ 20% of world population have LBP at any given time
  - Up to 80% of US population will experience LBP during their lifetime
  - Annual prevalence in old versus young individuals: 38% vs. 12%
  - Annual prevalence in person with and without lower limb amputation: 52-71% vs. 6-31%

- **Impact**
  - Chronic LBP is the leading cause of disability in the world
  - Chronic LBP force older workers to retire prematurely
  - Half of opioid users report LBP
  - Total cost associated with LBP has been reported to be >$100 billion per year
LBP Management

>90% LBP cases are categorized as non-specific LBP
Prevention: Risk Factor Management

Risk Factors

Non-occupational
- Age
- Gender
- Obesity
- Pregnancy
- Physical Fitness

Occupational
- Physical
  - Manual material handling
  - Motion and fatigue
  - Whole body vibration
  - Awkward posture
  - Static posture
- Psychosocial
  - Job satisfaction
  - Social support
  - Stress
  - Job clarity
Treatment: Trial and Error Efforts

**Chou et al (2007): Diagnosis and Treatment of Low Back Pain: A Joint Clinical Practice Guideline from the American College of Physicians and the American Pain Society**

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**Treatment Algorithm**

1. **History and Physical Exam**
   - List of symptoms
   - Medical history
   - Past medical history
   - Family history

2. **Diagnostic Workup**
   - Imaging (X-ray, MRI, CT) based on clinical findings
   - Laboratory tests
   - Electromyography (EMG)
   - Nerve conduction studies (NCS)

3. **Treatment Plan**
   - Acute phase (≤ 4 weeks)
   - Chronic phase (> 4 weeks)
   - Adjunctive therapies
   - Surgery

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**Evidence-Based Medicine**

- **Level of Evidence:** Evidence-based practice guidelines are referenced throughout.
- **Strength of Recommendation:** Ranges from weak (W) to strong (S) evidence.
- **Consensus:** Consensus statements are noted where evidence is lacking.

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**Key Points**

- **Low Back Pain:** Acute (< 4 weeks), Chronic (> 4 weeks)
- **Acute Pain Management:** Consider pharmacological and non-pharmacological treatments (Recommendations 4, 7)
- **Chronic Pain Management:** Ongoing evaluation and reassessment (Recommendations 4, 10)
- **Adjunctive Therapies:** Physical therapy, cognitive-behavioral therapy, acupuncture, yoga, etc.

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**Key References**

Research Focus
Research Need

Determine the root cause(s) of LBP for a given patient
Research Focus

• Mechanical loading can cause LBP

White and Panjabi 1990
Spinal Loads

- Loads experienced in the spinal tissues are determined by the state of spine equilibrium and stability.

- **Spine equilibrium**: A delicate balance between the physical demands of an activity and the active and passive responses of the spine tissues.

- **Spine stability**: The capacity to regulate and sustain spine equilibrium within an optimal range that provides the spine both its rigidity and flexibility under diverse conditions.
Research Design

- Task demand
- CNS
  - Active tissues responses
  - Work method (posture and motion)
  - Passive tissues responses
- Equilibrium and stability of spine
- Spinal loads
- Exposure to risk factor or receiving a treatment
- Stimulation threshold
- LBP

For example: Lifting
Evaluation of Spinal Loads
Spinal loads
Modeling Approaches

• **Modeling Approaches**
  – Rigid-body models
  – Rigid-body + muscle models (EMG-driven or Optimization-based)
  – Rigid-body + muscle + deformable-body models (finite element methods)
  – Equilibrium vs. stability-based models

• **Measures**
  – Mechanical demand of the task at lower back
  – Active and passive muscle forces
  – Passive mechanical response of ligamentous spine
  – Spinal loads (compression and shearing forces)
Finite Element (FE) Model

Arm and hand masses

Distribution of trunk mass anterior to vertebral column

Nonlinear Compression only

Disc Damping Axial-Rotational

Beam Elements with nonlinear: Load-Displacement Moment-Curvature

T1

T12

L5

Sacrum
Passive Tissue Contribution

![Graph showing relationships between segmental rotation, flexion moment, axial compression, and strain.](image-url)
Active Tissue Contribution
Kinematics-Driven Method

- External loads
- Kinematics \((in\ vivo)\)
  - Nonlinear transient FE model
    - Temporal variation of joint loads
      - Calculation of muscle forces
        - Effects of muscle forces
          - Convergence?
            - NO
            - YES
              - Post processing

T12
S1
Squat vs. Stoop Lifting

- Moment arm of load
- Energy consumption
- Balance
Experiments
Trunk Kinematics
Net moment @ S1 = Passive moment + Muscle moment

Moment (N-m)

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Stoop
Squat

Load

F

F_{\text{Trunk}}

F_{\text{Load}}

S1

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Trunk

F

Net moment @ S1

Passive moment

Muscle moment

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Moment (N-m)

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Moment (N-m)

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Moment (N-m)
Spinal Loads

L5-S1

Compression
Shear force

Compression Force (kN)

Shear Force (kN)

Stoop
Squat
Alteration in Passive Properties

![Graph showing the alteration in passive properties](image-url)

- T12-L1 Disc
- +20%
- Intact
- -20%
- -40%
Alteration in Passive Properties

- Compression Force (kN)
  - +20%
  - Intact
  - -20%
  - -40%

- Muscle Moment (Nm)
  - -20
  - 20
  - 60
  - 100
  - 140
  - 180
  - 220

- Shear Force (kN)
  - 0
  - 0.5
  - 1
  - 1.5
  - 2

- Ligamentous Spine Moment (Nm)
  - 0
  - 10
  - 20
  - 30
  - 40
  - 50
LBP and Lower Limb Amputation

Locomotion secondary to lower-extremity amputation

Increased and asymmetric trunk kinematics
Spinal Loads During Walking
Cumulative effects of abnormal spinal loads
Fatigue Failure of Spinal Tissues

Injury threshold of spine motion segment:
Compressive: 5-10 kN
Shear: 1-2 kN

Maximum spinal loads during walking:
Compressive: 1.2 vs 1.8 kN
Shear: 0.5 vs. 0.7 kN
Fatigue Model (Motiwale et al 2018)

\[ \sigma_{VM} = \text{sign} \left( \frac{F_{com}}{A_{disc}} \right) \sqrt{\left( \frac{F_{com}}{A_{disc}} \right)^2 + 3 \left( \frac{F_{AP}}{A_{disc}} \right)^2 + \left( \frac{F_{ML}}{A_{disc}} \right)^2} \]

\[ N_{fi} = \frac{1}{1 - \alpha_i} \left[ \frac{\sigma_{range}}{M_0(1 - b \sigma_{mean})} \right]^{-\beta} \]
\[ \alpha_i = 1 - \left( a \frac{\sigma_{range}}{\sigma_u - \sigma_{max}} \right) \]

\[ D_{mi} = \left( \frac{n_i^{\text{eff}}}{N_{fi}} \right)^{\frac{1}{1-\alpha_i}} \quad n_i^{\text{eff}} = n_i + N_{fi}(D_{mi-1}^{r})^{(1-\alpha_i)} \]

\[ D_{mi}^{r} = D_{mi-1}^{r} + (D_{mi} - D_{mi-1}^{r})(1 - r) \]
Results
Conclusions

• The inability to determine the cause of LBP for most cases poses a significant challenge for design of effective prevention and treatment interventions.

• Forces and deformations experienced in the lower back tissues can directly and indirectly stimulate pain sensitive nerve endings within the lower back.

• Significant advances related to the assessment of lower back mechanical environment have been made.

• An enhanced and more personalized evaluation of lower back mechanical environment can help design more effective preventive and/or rehabilitation strategies.
Questions