Sensorimotor Adaptations Following ACL Reconstruction: Implications for an Evidence Based Treatment Approach?

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Outline

- Joint injury as a source of disability
- Assessment techniques
- Study findings
- Evidence of sensorimotor adaptation

Learning Objectives

- Following ACL reconstruction:
  - Identify sources of sensorimotor impairment
  - Identify and interpret assessment techniques to examine sensorimotor impairment
  - Summarize the evidence supporting sensorimotor adaptation

Musculoskeletal Pathology

- ACL rupture common in sports (Beynon et al., 2003)
- ACL reconstruction often recommended to facilitate return to sport (Mars et al., 2005)

Joint Injury Drives MSK Injury

ACL Epidemiology

- 1.3% annual increase in ACL injury ('88-'04) (Hootman et al., 2007)
**Sub-Optimal Outcomes**

- 65% return to pre-injury status (Ardern et al., 2014)
  - 55% to competitive sport
- 29.5% suffer secondary ACL injury within 24 months (Paterno et al., 2014)
- Knee-related QOL at 9 years (range 6-15 years) (Filbray et al., 2014)

**Incomplete recovery post ACL-R**

- 55% return to pre-injury status
- 29.5% suffer secondary ACL injury within 24 months
- Knee-related QOL at 9 years (range 6-15 years)

**Manifestations of Joint Injury**

- Structural Changes
- Morphological Changes
- Muscle Weakness
- Neuromuscular Alterations
- Impaired Movement Strategies
- Altered Fitness Levels
- Altered Biomechanics
- Fear/Disability/Decreased Quality of Life

**Acceleration of Degeneration**

**ACL Injury and Osteoarthritis**

- 10-90% at 10-20 years (Lohmander et al., 2007)
- 2014 Systematic Review (Luc et al., 2014)
  - Total: 44%
  - 0-20 years: 36%
- 2015 Systematic Review (Harris et al., 2015)
  - 41% (95% CI 35-48%) at 12 years

Lack of evidence to suggest ACL-R will prevent knee OA

**Quadriceps Function and Joint Health**

- Post-traumatic quadriceps dysfunction
  - Altered biomechanics (Andriacchi, 1993)
  - Physical activity (Fitzgerald et al., 2004)
  - Risk of re-injury (Paterno et al., 2014)
  - Self-reported disability (Ericsson et al., 2013)
  - Onset of joint degeneration (Oiestad et al., 2011)
Defining the Problem

- Muscle is uninjured, yet unable to adequately contract
- Phenomenon is not unique to injury…
  - ACL tear/reconstruction
  - Meniscal tear/meniscectomy
  - Patellofemoral pain
  - Osteoarthritis
  - Total knee arthroplasty

Arthrogenic Muscle Inhibition

- “Arthro” = Joint
- “Genic” (genesis) = Origin
- “Muscle inhibition” = Inability to contract muscle
- AMI = Inability to contract an uninjured muscle due to pathology at the joint

What Causes AMI?

- Altered afferent stimuli from joint receptors transmitted to spinal cord
  (de Andrade et al., 1965; Stokes and Young, 1984)

Neuromuscular Adaptation

Healthy MN Pool
- Peripheral

Inhibited MN Pool
- Sensorimotor Assessment

A Clinical Dilemma
**Superimposed Burst Technique**

- Central Activation Ratio (CAR)
- Knee Extension MVIC Torque

\[
\text{CAR} = \frac{F_{\text{FVIC}}}{F_{\text{MVIC}} + F_{\text{CM}}}
\]

**Measuring Quadriceps Activation**

- Reliability:
  - Healthy
  - Patellofemoral pain
  - Closed-Chain

- Studied in:
  - ACL reconstruction
  - ACL deficient
  - Patellofemoral pain
  - Osteoarthritis

**Hoffmann Reflex**

- Estimate of motoneuron pool activity (Palmieri et al., 2004)
  - αMN excitability of target muscle

- Think stretch reflex minus the stretch

**H-Reflex Pathway**

- Stimulator (B)
- Sensory Nerve
- Motor Nerve
- EMG (A)

**Hoffmann Reflex**

- H-Reflex
  - MN that are available for use...not what is going to be used

- M-Response
  - Entire αMN pool

- H:M Ratio
  - Proportion of motoneuron pool capable of being recruited

**Measuring Spinal Reflexes**

- Soleus
- Peroneals
- Tibialis Anterior
- Quadriceps

- Reliability:
  - Peripheral nerves

- Studies In:
  - Musculoskeletal injury
  - Effects of therapeutic modalities/ pain
  - Response to exercise
  - Performance of motor tasks


**Transcranial Magnetic Stimulation**

“Non-invasive tool for measuring neural conduction and processing time, activation thresholds, facilitation and inhibition in cerebral cortex, and neural connections.”

(Anand and Hotson, 2002)

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**Measuring Cortical Reflexes**

- Single or paired pulse
  - Multiple sclerosis
  - Amyotrophic lateral sclerosis
  - Stroke
  - Movement disorders
  - Spinal cord disorders
  - Musculoskeletal injury

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**TMS Procedures**

- **Diagnostic**
  - Peroneals
  - Gluteus

- **Repetitive**
  - Tibialis anterior
  - Quadriceps

**ICC**

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**Creating a Motor Program**

- Creating a Motor Program

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**Creating a Motor Program**

- Creating a Motor Program
Evoking a Motor Potential

Understanding the Motor Threshold

- Lowest intensity capable of eliciting MEP
  - Reflects excitability of central core of neurons

What Does a Higher Threshold Mean?

Early Identification

- Theoretical temporal changes following knee joint injury
  - Strength
  - Activation
  - Fatigue
  - Spinal reflex
  - Corticospinal
  - Motor control
**PICO Clinical Question**

- In young, active persons with **ACL reconstruction** compared to healthy individuals, do **a)** peripheral, **b)** spinal, and **c)** supraspinal pathways of the sensorimotor system differ over time?

**P** – Young, active persons with **ACL reconstruction**

**I** – **ACL reconstruction**

**C** – Healthy, matched controls

**O** – Sensorimotor pathways

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**Experimental Design**

- **Cross Section**

- **Independent Variables**
  - Group (ACL-R – 6 months, 1 year, > 2 years, Healthy)
  - Limb (Injured, Uninjured)

- **Primary Outcome Measures**
  - Knee extension torque (Nm/kg)
  - Quadriceps central activation ratio (%)
  - Hoffman Reflex (H:M ratio)
  - Active Motor Threshold (%)

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**Patient Reported Outcomes**

- **IKDC subjective knee evaluation form (IKDC)**
- **Knee Osteoarthritis Outcome Score (KOOS)**
  - Pain, Symptoms, ADL, Sport, QOL
- **Tampa Scale for Kinesiophobia (TSK)**
- **Veteran’s Rand 12-Item Health Survey (VR-12)**
- **Tegner Activity Scale**
- **Godin Leisure-Time Questionnaire**
- **Visual Analog Scale for pain (VAS)**

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**Participants**

- **ACL Reconstruction (n = 39)**
  - 15-45 years
  - Primary, unilateral
  - Uncomplicated
  - Time from surgery

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**CONSORT Flow Diagram**

Assessed for Eligibility (n = 54)

No

Embarrassed (n = 5)  
Followed up (n = 17)

Group Allocation (n = 52)

ACL-R – 6 months (n = 15)

ACL-R – 12 months (n = 8)

ACL-R – 2+ years (n = 16)

Healthy Control (n = 13)

Hoffmann Reflex

Knee Extension MVC

Supraspinale Stimulation

Transcranial Magnetic Stimulation

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**Quadriceps Torque Reduced**

Peak Knee Extension Torque (Nm)

6 month 1 year 2 year Healthy

P = 0.014  
P = 0.024  
P = 0.024

Injured  
Uninjured

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Quadriceps Activation Reduced

Spinal Excitability

Corticospinal Excitability Reduced

Clinically Meaningful?

Reduced Strength

Explaining Strength

Neuromuscular Adaptations

• Following ACL-R:
  - Quadriceps strength > 2 years*
  - Quadriceps activation at 12 months*
  - Corticospinal excitability at 6-12 months*
  - Spinal reflexes are unchanged (trend)

*Large magnitude Δ!

• Do neurophysiologic measures influence strength and/or patient reported outcomes?
Explaining Patient Outcomes

<table>
<thead>
<tr>
<th>IKDC (R2)</th>
<th>6 months</th>
<th>1 year</th>
<th>2+ years</th>
</tr>
</thead>
<tbody>
<tr>
<td>HM</td>
<td>0.002</td>
<td>0.102</td>
<td>0.019</td>
</tr>
<tr>
<td>AMT</td>
<td>0.019</td>
<td>0.042</td>
<td>0.023</td>
</tr>
<tr>
<td>MVIC</td>
<td>0.003</td>
<td>0.186</td>
<td>0.250</td>
</tr>
<tr>
<td>CAR</td>
<td>0.000</td>
<td>0.051</td>
<td>0.068</td>
</tr>
</tbody>
</table>

Meaningful to Patient?

Cohen’s d effect sizes with 95% confidence intervals

| IKDC (6 month) | 0.000 |
| IKDC (1 year)  | 0.051 |
| IKDC (2+ years)| 0.068 |
| KOOS (6 months)| 0.051 |
| KOOS (1 year)  | 0.068 |
| KOOS (2+ years)| 0.250 |
| TSK (6 months) | 0.051 |
| TSK (1 year)   | 0.068 |
| TSK (2+ years) | 0.250 |
| VR-12 (6 months)| 0.051 |
| VR-12 (1 year) | 0.068 |
| VR-12 (2+ years)| 0.250 |

Self-Perceived Function

- Following ACL-R:
  - ↓ Knee-specific function (IKDC, KOOS) > 2 years
  - ↑ Fear of movement (TSK) at 6 months
  - ↓ Global health (VR-12) at 6 months

  Large magnitude Δ!

Voluntary Activation Deficits

2-24 months from surgery

Immediate Change in Spinal Reflexes

- Early effusion models used to demonstrate an acute decrease in quadriceps motor neuron pool (DeAndrade et al, 1965; Spencer et al, 1984; Roumdile et al, 1985; Jensen and Graf, 1993; McNair et al, 1996; Wood et al, 1996)

- Immediate changes in:
  - ↑ Soleus (Hopkins et al, 2001)

Spinal Reflexes in Pathology

- Alterations in spinal reflexes
  - Functional ankle instability (Palmeier-Smith et al, 2009; McVey et al, 2005)
  - Acute ankle sprain (Klykken et al, 2011)

- ACL Injury? (Heroux and Tremblay, 2006)
  - N=5 ACL deficient
  - Injured limb trended toward lower H-reflex amplitude ($p = .07$)
Evidence of Cortical Changes?

- ACL deficient
  - 10 ACL-D
  - 8 Healthy
- Injured limb had lower resting threshold in ACL group
- Chronic adaptation to maintain function?


Corticospinal Adaptation

- 20 healthy knees artificially effused
- Results
  - No immediate changes in corticospinal excitability!
  - Evidence for chronic adaptation?


Cortical Change and Ankle Instability

- Case control
  - Chronic ankle instability (n=10)
  - Control (n=10)
- Results
  - Higher resting threshold in fibularis longus


Neural Changes and ACL-R

- Case control
  - ACL-R (n=29)
  - Matched healthy (n=29)
- Results
  - Higher resting threshold in fibularis longus


What Matters?

- Neural alterations are related to quadriceps strength
  - CAR (37%) + H:M (10%) + AMT (2%) predicted 49% of variance in MVIC (Lepley et al., 2014)
- Strength and cortical excitability are related to self-reported disability
  - MVIC (61%) + AMT (5%) predicted 66% of variance in IKDC score (Pietrosimone et al., 2013)
**Evidence of Neuromuscular Change?**

- **Quadriceps activation:** Level 1-2, B
- **Quadriceps spinal reflex:** Level 3-5, C
- **Quadriceps corticospinal reflex:** Level 2-3, B

**Evidence of Neuromuscular Change?**

<table>
<thead>
<tr>
<th>6 months</th>
<th>12 months</th>
<th>&gt;24 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>Activation</td>
<td>Cortical</td>
</tr>
</tbody>
</table>

**Significance**

- **Research**
  - Understanding nature of post-traumatic neurophysiologic modulation
    - Validate patient-specific intervention

- **Clinical Implications**
  - Early identification = Early treatment!

**What’s Next**

- 6 months
- 12 months
- >24 months

**Take Home Points**

- Modulation of the sensorimotor system occurs following knee joint trauma
- Worthwhile to look beyond gross strength measures as an outcome to identify source of impairment
- Identifying sensorimotor adaptations, specifically mal-adaptations early may provide a targeted treatment approach

**Clinical Bottom Line**

- Early identification is key!
- Cost-effective treatment approaches to target sensorimotor impairments exist that may supplement traditional rehabilitation techniques after ACL reconstruction

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Resources for EBP

- Centre for Evidence Based Medicine
  – http://www.cebm.net/
- PubMed Literature Searching Tutorial

Patient Reported Outcomes

<table>
<thead>
<tr>
<th></th>
<th>6 months (n = 15)</th>
<th>1 year (n = 8)</th>
<th>2+ year (n = 16)</th>
<th>Healthy (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IKDC</td>
<td>81 ± 13</td>
<td>89 ± 17</td>
<td>97 ± 11</td>
<td>99 ± 3</td>
</tr>
<tr>
<td>KOOS</td>
<td>88 ± 11</td>
<td>91 ± 5</td>
<td>93 ± 6</td>
<td>99 ± 1</td>
</tr>
<tr>
<td>KOOS: Pain</td>
<td>91 ± 9</td>
<td>97 ± 6</td>
<td>94 ± 5</td>
<td>99 ± 1</td>
</tr>
<tr>
<td>KOOS: Symptoms</td>
<td>86 ± 14</td>
<td>83 ± 13</td>
<td>90 ± 9</td>
<td>98 ± 4</td>
</tr>
<tr>
<td>KOOS: ADL</td>
<td>93 ± 8</td>
<td>99 ± 2</td>
<td>97 ± 4</td>
<td>100 ± 1</td>
</tr>
<tr>
<td>KOOS: Sport</td>
<td>77 ± 19</td>
<td>87 ± 12</td>
<td>90 ± 12</td>
<td>98 ± 5</td>
</tr>
<tr>
<td>KOOS: QOL</td>
<td>65 ± 22</td>
<td>71 ± 13</td>
<td>81 ± 13</td>
<td>99 ± 2</td>
</tr>
<tr>
<td>VAS (cm)</td>
<td>0.6 ± 0.8</td>
<td>0.6 ± 0.9</td>
<td>0.4 ± 0.6</td>
<td>0.1 ± 0.2</td>
</tr>
<tr>
<td>Tegner</td>
<td>6 ± 2</td>
<td>8 ± 2</td>
<td>7 ± 2</td>
<td>8 ± 1</td>
</tr>
<tr>
<td>Godin</td>
<td>62 ± 23</td>
<td>63 ± 21</td>
<td>55 ± 26</td>
<td>67 ± 30</td>
</tr>
<tr>
<td>Tampa</td>
<td>54 ± 8</td>
<td>54 ± 7</td>
<td>40 ± 6</td>
<td>26 ± 7</td>
</tr>
<tr>
<td>VR-12</td>
<td>80 ± 10</td>
<td>84 ± 6</td>
<td>85 ± 5</td>
<td>88 ± 6</td>
</tr>
</tbody>
</table>

Treating Neural Impairment

- Paradigm shift?