The Brain has a Knee Problem: Neuromuscular Insights

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Faculty Disclosure

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Dr. Grindstaff has listed no financial interest/arrangement that would be considered a conflict of interest.
Summary

- Longitudinal neuroplastic changes
  - More resources to perform same activity
- Interventions should address peripheral and neurological causes of weakness
  - Address inhibition early
  - Appropriate exercise intensity
- Potential to better address underlying impairments and improve function
Good Outcomes

• “We like to think that we are successful in the treatment of individuals with ACL injury”
  – About 60% make a full recovery
  – < 60% return to sport
  – > 50% develop knee osteoarthritis (OA) by middle age
Uncomplicated Recovery

- Despite surgical **intervention and rehabilitation** 30-50% continue to have
  - Joint effusion
  - Weakness
  - Altered biomechanics
  - Decreased physical function
- 20-30% have reinjury within 2 years

**References:**

Omaha Data

- Twenty-two unilateral ACL-R
  - Ten participants failed all 3 tests (<90%)
  - Four participants passed all 3 tests (>90%)
- Quadriceps LSI most common unmet criteria (15 of 22 participants)

**ACL-R (n= 22; 15 female, 7 male)**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>18.7 ± 2.5</td>
</tr>
<tr>
<td>Time Since Surgery (mo)</td>
<td>6.4 ± 1.3</td>
</tr>
<tr>
<td>IKDC</td>
<td>82.6 ± 13.2</td>
</tr>
<tr>
<td>Quadriceps Strength (LSI)</td>
<td>78.3 ± 21.8</td>
</tr>
<tr>
<td>Single Leg Hop (LSI)</td>
<td>88.1 ± 14.7</td>
</tr>
</tbody>
</table>
Quadriceps Weakness

- Common impairment after knee injury
  - Rapid onset
  - Protective mechanism
- Contributes to knee joint loading
- Can persist 15-20 years after injury

DeAndrae et al., 1965; Shakespeare et al., 1985; Stokes et al., 1984; Palmieri-Smith et al., 2007; Urbach et al, 2001; Svantesson et al, 2005; Krishnan and Williams, 2001
Quadriceps Contributions

- Physical activity levels
- Quality of life
- Sport performance
- Landing biomechanics

Quadriceps and Health Status

- Older/elderly adults
- Coronary artery disease
- Chronic obstructive pulmonary disease

Altubasi, 2015, Chan et al., 2014, Fragala et al., 2016, Kozicka and Kostka, 2016; Ghroubi et al., 2007, Kamiya et al., 2015; Osthoff et al., 2013, Seymour et al., 2012, Swallow et al., 2007
Correlation

- Older Adults
- Coronary artery disease
- COPD
- Knee injury
Other Muscles

- Initial weakness → recovery
  - Hip Extensor, ER, Abd, Add
  - Ankle PF
- Graft type impacts strength
  - Quadriceps > Hamstring

Quadriceps Strength

• Early measures predict later
  – Presurgical
  – Early rehab

• Better strength → Better function

Hartigan et al., 2012; Logerstedt et al., 2013; Schmitt et al, 2012
Sample Case
Interventions

• “Can’t we just make the muscle stronger?”
• Traditional strengthening may not address inhibition
  – Inhibition limits strength gains

Knowledge Gap

• Causes of quadriceps weakness are not well understood
  – Intervention efficacy is mixed
Causes

• Peripheral muscle
  – Atrophy

• Neurological
  – Motor unit firing rate
  – Spinal reflex excitability
  – Corticospinal excitability
Quadriiceps Atrophy

- Muscle cross-sectional area and fiber type contribute to quadriiceps strength
  - Thigh circumference
  - Ultrasound imaging
  - MRI
- Type II > Type I

Quadriceps Inhibition

- Knee joint effusion (experimental)
- Patellofemoral joint pain
- Meniscectomy
- ACL injury/ reconstruction
- Osteoarthritis

Quadriceps Inhibition

• Most severe immediately following injury or surgery
  – May persist despite return to function
• Limits strength gains

Shakespeare et al., 1985; Mizner et al., 2005; Petterson et al., 2011; Ingersoll et al., 2008; Hart et al., 2010; Harkey et al., 2016
Reflex Inhibition

Fig 2. Pickar, 2002
Quantifying Quadriceps Inhibition

- Voluntary activation
  - Burst-superimposition or Interpolated twitch
- Spinal reflex
  - H-reflex
- Corticomotor
  - TMS, EEG, fMRI, fNIRS
Quadriceps Voluntary Activation

\[ \text{Percent Activation} = \left[1 - \frac{(a - b)}{c}\right] \times 100 \]
Limitations

• Does not provide insights into specific pathways (cortical and spinal) that contribute to quadriceps activation failure
Spinal Reflex Excitability

- Decreased with experimental knee joint effusion
- Decreased after ACL injury
  - Further decrease after surgery (2 weeks)
  - Appears to normalize by 6 months

Spinal Reflex Excitability

- **H-reflex**
  - Measure of maximal reflex activation (motoneuron pool)

- **M-response**
  - Represents activation of entire motoneuron pool

- $H_{\text{max}}/M_{\text{max}}$
  - Proportion of entire motoneuron pool that can be recruited
Spinal Reflex Excitability Limitations

- Individual variability
- Influenced by descending CNS contributions
Corticcomotor Excitability

- Transcranial Magnetic Stimulation (TMS)
  - AMT
  - MEP/Mmax Ratio
Primary Motor Cortex
Longitudinal Changes

- Before surgery no difference in AMT
- Decreased AMT after surgery (2 weeks)
- Increased AMT 6 months post ACL-R
Impacts Quadriceps Strength

• Too much corticomotor excitability?
  – Increased AMT \(\rightarrow\) lower strength
  – High strength AMT not different from healthy

Lepley et al, 2014
EEG and fMRI

- More resources to perform the same activity
  - ↑ Prefrontal cortex
  - ↑ Visual
  - ↑ Somatosensory
  - ↓ Primary motor

- Longitudinal changes
# Neural Contributions

<table>
<thead>
<tr>
<th></th>
<th>After Injury/Before Surgery</th>
<th>Acute Post-Surgical</th>
<th>&gt; 6 months post-surgical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Strength</strong></td>
<td>Decreased</td>
<td>Greater Decrease</td>
<td>Decreased or No Difference</td>
</tr>
<tr>
<td><strong>Voluntary Activation</strong></td>
<td>Decreased</td>
<td>Greater Decrease</td>
<td>Decreased or No Difference</td>
</tr>
<tr>
<td><strong>Spinal Reflex</strong></td>
<td>Decreased</td>
<td>Greater Decrease</td>
<td>No Difference</td>
</tr>
<tr>
<td><strong>Corticospinal Excitability</strong></td>
<td>Decreased or No Difference</td>
<td>Decreased</td>
<td>No Difference (normal strength) Increased (low strength)</td>
</tr>
</tbody>
</table>

Heroux and Tremblay 2006; Lepley et al, 2014; 2015; Kuenze et al, 2014
Target Specific Cause

- Inhibition (neurological)
- Atrophy (peripheral)
Afferent Pathways

- Cryotherapy
- TENS
- Vibration
- Joint Mobilization

Fig 2. Pickar, 2002
Efferent Pathways

- NMES
- Biofeedback
- Transcranial direct current stimulation (tDCS)
- Repetitive TMS

Fig 2. Pickar, 2002
Cryotherapy

- Facilitate quadriceps function
  - Spinal reflex excitability
  - Voluntary activation
- Consider use prior to exercise
  - Applied to knee joint

Hopkins et al, 2002; Pietrosimone et al, 2009
Sensory TENS

- Increase strength, voluntary activation, and function
  - Effective during treatment
  - Better effects with extended wear

Sensory TENS

- History of partial meniscectomy (n=23)
  - Voluntary activation increased 6% (P= .01)
  - Effect greater when inhibition present (10%; d= .71)

Grindstaff et al, In Review
Sensory TENS Parameters

- Electrodes surround knee joint
- **Strong, comfortable sensation** without muscle contraction (150 Hz, 150 µs)
- > 8 hours per day during activity

Vibration

- Improves balance, strength, hop performance
  - Reduces quadriceps inhibition (~5%)
- Mixed findings for joint reposition sense

Fu et al, 2013; Moezy et al, 2008; Berschin et al, 2014; Blackburn et al, 2014; Pamukoff et al, 2016; 2017
NMES

- Augments quadriceps strength, reduces inhibition
- Better patient reported outcomes
- Incorporate early and often
  - Weeks 1-4 post-op
  - 6 weeks duration

Kim et al., 2010; Lepley et al, 2015; Dantas et al, 2015
NMES Parameters

- Large electrodes
- Secure limb 60° or 90°
- Maximum tolerable level
- 1:5 $\rightarrow$ 1:3 $\rightarrow$ 1:1
Biofeedback

- Measures electrical activity (amplitude)
  - Not force
- External cue used to improve retention
- Increases corticomotor excitability

Lepley et al, 2012; Pietosimone et al, 2015
Biofeedback Parameters

- Prep skin
- Secure electrodes
  - Recording
  - Reference (ground)
- Determine threshold
  - MVIC
- Set target threshold above
  - Auditory or visual cue when EMG signal above target

Lepley et al, 2012; Pietosimone et al, 2015
tDCS

• Healthy
  – Acute increase (10%) quadriceps peak torque ($d = 0.6-0.95$)
  – Did not augment 3 week exercise program

• Knee OA
  – Augments exercise with decreased pain (4/10), improved function (10 points WOMAC)

Vargas et al, 2017; Maeda et al, 2017; Ahn et al, 2017; Chang et al, 2017
Exercise Dosing

- Exercise intensity **too low** to elicit substantial gains in strength

Angelozzi et al., 2012; Augustsson, 2013
Resistance Training

• Healthy individuals (3x/week; 3-4 weeks)
  – Decreased AMT
  – Increased MEP/Mmax ratio

• Knee OA case study with 8 weeks of rehabilitation
  – Increased MEP/Mmax ratio

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Thank You

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