The Influence of Quadriceps Strength and rate of Torque Development (RTD) on the Recovery of Knee Biomechanics During Running After ACLR

Reference: Knurr, Keith A., et al. "The Influence of Quadriceps Strength and Rate of Torque Development on the Recovery of Knee Biomechanics During Running After Anterior Cruciate Ligament Reconstruction." *The American Journal of Sports Medicine* 51.12 (2023): 3171-3178.

Background:

- Previous research has shown that following ACLR running biomechanics are altered following surgery
    - Greatest deficits include: decreased knee flexion angles and decreased knee extensor moments
- These long term altered biomechanics may lead to increased reinjury rates, cartilage degeneration, and decreased performance upon return to sport
- An increase in quadriceps strength has been shown to improve running mechanics, but even after quad symmetry is restored, some running deficits often remain
- It takes 500ms to generate peak torque, which may indicate why this factor alone is not responsible for resolving running mechanics, as most athletic and daily tasks require force generation in a time of 50-200ms
- Minimal research has been done to date to correlate rate of torque development (RTD) symmetry to running mechanics in patients in the initial months following ACLR
- Increased RTD has been associated with improved subjective knee function, walking gait and jump and landing mechanics, but this is often in cohorts >2 years out from their ACLR

Methods:

- Participants: 39 D1 athletes across sports (19 female), tested over 106 testing sessions, with running analysis between 3-24 months following ACLR
- Longitudinal data was collected from the Badger Athletic Performance lab cohort where athletes undergo routine testing as a part of their health care following ACLR
- Patient's with ACLR were tested serially throughout their recovery on both quad performance (peak torque and rate of torque development) and running biomechanics (using a marker based, 3D motion capture system)
    - **Quadriceps testing**: performed isometrically at 90 deg for all assessments below, with the non surgical limb tested first, torque output was sampled at 2000hz, best effort across all trials were recorded
        - Peak torque MVIC
            - Warm up followed by 2 max voluntary isometric contractions over 5 seconds, repeated if there was a difference of 10% or more between trials
        - Rapid voluntary contractions (RTD testing)
            - Athletes were cued to kick as "hard and fast" as possible
            - Warm up followed by 5 max effort repetitions were recorded
    - **Gait analysis testing**: with joint placement markers applied on instrumented treadmill (23 anatomic markers, 52 total, kinematics were sampled at 200Hz, GRF were sampled at 2000 Hz, the system utilizes 8 cameras)
        - 2 min walking warm up
        - Speed then increased from 2.68m/s to 4.47 m/s (10min/mile to 6min/mile) or until athlete subjectively report they reached their max
        - Outcomes from treadmill:

        - Peak knee extensor moment (PKEM) (normalized to body weight, and LSI)
        - Peak knee flexion angle during stance (PKF)
        - Peak knee flexion angle difference between limbs (PKF diff), negative means decreased knee flexion on surgical leg
    - *Exclusion criteria:* any athlete with a secondary ACL surgery or any other lower extremity injury within the 24 months following ACLR
    - *Stats analysis:* means and standard deviations used to describe the athlete population

Findings: ·

- **Running peak knee flexion difference**
    - There was a statistically significant (P<0.001) association between peak knee flexion difference and rate of torque development LSI
    - There was no statistically significant (p= 0.24) difference between peak knee flexion difference and peak torque LSI
    - "For a 10% increase in rate of torque development, an average of 0.9 deg improvement in knee flexion angle can be expected" after adjusting for time post ACLR and peak torque
    - There was a significant association between PKF difference and time from ACLR (p = 0.02), for every month after ACLR an improvement of 0.2deg is expected after adjusting for quad performance measures
- **Running peak knee extensor moment**
    - There was a statistically significant (P<0.001) association between peak knee extensor moment and rate of torque development LSI
    - There was no statistically significant (p= 0.6) difference between peak knee extensor moment and peak torque LSI
    - "For a 10% increase in rate of torque development there was an expected 3.5% improvement in peak knee extensor moment LSI was expected after adjusting for time from ACLR"
    - There was a significant association between PKEM LSI and time from ACLR (p = 0.001), for every month after ACLR an improvement of 1.3% LSI is expected after adjusting for quad performance measures

Limitations:

- Because this study is from clinical testing, not all athletes underwent the same amount of testing sessions or observations, and there is a variety of when the testing occurred between athletes
- Pain at the time of testing may affect both RTD and gait data, and it was not included in the analysis in this study
- Specific rehabilitation programs were not controlled across athletes
- The majority of grafts in this sample were bone patellar bone grafts which may limit ability to apply it to other surgical grafts

Clinical Implications:

- Rate of torque development LSI may be more critical to improving running mechanics post ACLR instead of peak torque LSI
- Time out from surgery also is associated with improved running biomechanics even when adjusting for quad performance measures

- During running, the quad needs to fire rapidly, as it only has the time when the foot is on the ground (150-300ms) to generate force, so training the quad to fire rapidly as part of the rehab process may be important to mechanics recovery to avoid compensation strategies
- Peak torque is still an important variable to recover as part of the rehab process with ACLR both for normal function, and because it is a correlate to developing quadriceps rate of torque development

Discussion Questions:

1) How do you differentiate your training and how early do you start training RTD in patients with ACLR? Are there any safety concerns associated with this?
2) For those unable to test this accurately, do you have any advice or clinical pearls on how to assess this functionally?
3) Are there specific cut offs that you suggest waiting to hit from a peak torque or rate of torque development standpoint before beginning return to run in patients with ACLR?

Quadriceps Strength and Knee-Related Symptom State 6 Months After Anterior Cruciate Ligament Reconstruction

Reference: Michelle C. Walaszek, Terry L. Grindstaff, Joseph M. Hart, Thomas Birchmeier, Ashley Triplett, Katherine Collins, Matthew Harkey, Michael Shingles, Michael Straus, Christopher Kuenze; Quadriceps Strength and Knee-Related Symptom State 6 Months After Anterior Cruciate Ligament Reconstruction. *J Athl Train* 1 June 2023; 58 (6): 536–541.

Background:

- Quadriceps function following ACLR is pivotal during tasks such as running, cutting, jumping.
- The criterion for adequate quadriceps strength 3.0 nm/kg has been shown as the most uncommonly unmet criteria 6-9 month post ACLR.
- A recent systematic review and meta-analysis of 28 studies reported that the average isometric quadriceps strength fell below 3.0 Nm/kg in all but 3 studies. In this same analysis, they found, on average, the patients also failed to achieve 3.0 nm/kg in uninvolved limb in all but 4 of these studies as well.
- On average, at 6 to 12 months post-ACLR, patients demonstrated a 24% ACLR-limb deficit in isometric quadriceps strength compared with their uninvolved limb.
- ACLR-limb isometric quadriceps strength (3.0 Nm/kg) and quadriceps strength symmetry (LSI 90%) have been associated with acceptable patient-reported function at 6 months to 13 years after ACLR.
- Englund et al developed a composite score from the Knee injury and Osteoarthritis Outcome Score (KOOS) subscales to identify individuals who describe their reconstructed knee as symptomatic enough to seek medical care.
- Evidence for the relationship between quadriceps weakness and asymmetry and knee-related symptoms is lacking.

Methods:

- *Type:* Cross sectional study

- *Purpose:* To determine if categorization of isometric quadriceps strength and quadriceps strength symmetry in patients after ACLR was associated with acceptable clinical knee-related symptoms at 6 months.
- *Hypothesis:*
    - Patients who displayed quad strength at 3.0 Nm/kg or greater and quadriceps strength symmetry of LSI 90% or more would report acceptable clinical knee-related symptoms compared with those who exhibited quadriceps weakness, asymmetry, or both.
- *Inclusion criteria:*
    - Participants were included if they were between 13 and 30 years old and 5 to 7 months post first time, unilateral ACLR.
- *Exclusion criteria:*
    - Patients were excluded if they had a multiligament reconstruction involving the posterior cruciate ligament or a history of cardiovascular, neurologic, or another medical condition that prohibited them from being tested safely.
- *Measurement of quad strength*:
    - Isometric quad contraction on Biodex, 90 deg of knee flexion, 85 deg of hip flexion. 2-5 second holds for each MVIC and 3-2 maximal trials with visual feedback and loud oral encouragement. Quad strength was then normalized to body weight.
        - Participants were classified according to whether the isometric quadriceps strength of the ACLR limb normalized to body weight and quadriceps strength symmetry criteria were met or not
        - Patients with 3.0 Nm/kg and 90% quadriceps LSI or greater were categorized as both strong and symmetric

- *PRO Classification:*
    - Participants were categorized as exhibiting unacceptable clinical knee-related symptoms if they scored ≤87.5 on the KOOS QOL subscale and met greater than or equal to 2 of the following subscale cutoff scores: KOOS symptoms ≤85.7; KOOS pain ≤86.1; KOOS ADLs ≤86.8; or KOOS sports and recreation ≤85.0. Those who did not meet both criteria were considered to have acceptable clinical knee-related symptoms.

- *Stats:*
    - Demographics were then compared among quadriceps strength classification groups using analyses of covariance (ANCOVAs), with the data-collection site as the covariate.
    - The distributions of participant sexes, meniscal surgery at the time of ACLR, and graft sources were compared among groups using a chi squared test.
    - Tegner activity levels were evaluated among groups using a Kruskal-Wallis test.
    - Quadriceps strength variables were compared among groups using ANCOVAs with enrollment site as a covariate.
    - Binary logistic regression was used to calculate relative risk ratios (RRRs) and 95% CIs to describe the relative risk.

Findings:

- 15% of individuals were classified as both strong and symmetric (3.0 Nm/kg and 90% LSI), 2.3% as strong only (>3.0 Nm/kg but <90% LSI), 17.3% as symmetric only (<3.0 Nm/kg but >90% LSI), and 65.4% as neither strong nor symmetric (3.0 Nm/kg and <90% LSI).
- Nearly 40% of participants demonstrated unacceptable clinical knee- related symptoms, regardless of quadriceps strength classification group, at 6 months post ACLR.
- The relative risk of a participant in the strong and symmetric group being categorized as having acceptable clinical knee-related symptoms was not greater than that of a participant in the neither strong nor symmetric group (RRR 1⁄4 1.28; 95% CI 1⁄4 0.94, 1.74).
- The relative risk of a participant in the symmetric-only group being classified as having acceptable clinical knee-related symptoms was not greater (RRR 1⁄4 1.30; 95% CI 1⁄4 0.97, 1.73) than in the neither strong nor symmetric group.
- At 6 months after ACLR, quadriceps weakness is experienced by 82.7% of patients, quadriceps strength asymmetry by 67.6%, and unacceptable clinical knee-related symptoms by 39.9%.
- Of those who reported unacceptable clinical knee-related symptoms, 30.8% were classified as both strong and symmetric, 30% as symmetric only, and 46% as neither strong nor symmetric. The relative risk of experiencing acceptable compared with unacceptable symptom states was not different among groups.
- Previous studies cited 55% of individuals with ACLR had a quadriceps strength LSI 90% at 6 months post-ACLR, only 32.4% of this study participants met this criterion.
- Among participants, 82.7% did not meet ACLR-limb quadriceps strength (3.0 Nm/kg) recommendations at 5 to 7 months following ACLR.

Limitations:

· This data was collected at 5 to 7 months following ACLR, and may not provide information regarding changes in quadriceps strength and clinical knee-related symptom status throughout the later stages of rehab.

· An isometric quadriceps strength cutoff score of 3.0 Nm/kg was established in an adult population and this study population included adolescents. For certain individuals, such as young females, 3.0 Nm/kg may be an unrealistic measurement to reach at this age.

· The majority of participants did not meet either the quadriceps strength or symmetry threshold, which led to unbalanced group sizes and small sample sizes in symmetric-only and both strong and symmetric groups.

· Only 4 participants fit the strength-only group criterion, so this group was eliminated from the analyses due to the small sample size.

· The study did not control other possible factors, such as psychological readiness for return to sport, graft source, and concomitant injury.

Clinical Implications:

· Based on this study, it doesn't reflect that patients that met criteria for ACLR-limb isometric quadriceps strength or quadriceps strength symmetry (or both) were less likely to report unacceptable clinical knee-related symptoms compared with individuals who did not meet both quadriceps strength criteria.

· At 6 months post—ACLR, 85% of patients failed to meet 1 or both of the commonly used isometric quadriceps strength metrics which is concerning due to this time normally being associated with transition back to higher level athletic activity.

· Quadriceps strengthening should be initiated as soon as possible in course of care to return quad strength and symmetry.

Discussion Questions:

1. How do you think including graft type in inclusion criteria would have affected these results?
2. Are you using 3.0 nm/kg as a cutoff in return to sport testing currently?
3. When are you testing contralateral quad strength? Traditionally as soon as possible is cited due to belief that contralateral quad will get weaker over course of rehab, but recent literature will suggest otherwise, what are your thoughts?
4. Take me through the differences in your approach to acute (0-6 weeks) quad strengthening for different graft types.

Effects of Rehabilitation Exercise with Blood Flow Restriction after Anterior Cruciate Ligament Reconstruction

Reference: Jung W-S, Kim S-H, Nam S-S, Kim J-W, Moon H-W. Effects of rehabilitation exercise with blood flow restriction after anterior cruciate ligament reconstruction. *Applied Sciences*. 2022;12(23):12058. doi:10.3390/app122312058

Background:

• Lower extremity muscle atrophy is common after surgery, particularly in procedures like arthroscopic knee surgery and ACL reconstruction.

• Quadriceps muscle volume can decrease by as much as 33% after knee surgery, leading to atrophy in as little as two weeks.

• Compared to the contralateral limb, discrepancies in knee extensor strength can be as high as 30% on the surgical side six months after surgery

• Quadriceps weakness can impact daily activities and increase the risk of re-injury, affecting sports performance. • Lower extremity strengthening exercises, including open and closed kinetic chain exercises, are common in rehabilitation protocols.

• Blood flow restriction (BFR) training is a technique involving inflatable cuffs to limit arterial blood flow, potentially preventing atrophy or inducing hypertrophy through hypoxic environments created with the modality • BFR combined with resistance training may achieve greater muscle adaptations comparable to just general rehabilitative exercise.

• BFR may remediate muscle impairments post ACL reconstruction by affecting muscle fiber recruitment, cell proliferation, and metabolic stresses.

Methods:

• Type: Randomized Controlled Trial

• Purpose: To investigate the impact of Blood Flow Restriction (BFR) exercises as an adjunct to general rehabilitation on the functional outcomes and muscle activity in anterior cruciate ligament (ACL)

reconstruction patients. • Hypothesis:

- Patients undergoing BFR exercises in addition to general rehabilitation will demonstrate superior improvements in functional outcomes, muscle activity, and subjective scores compared to those following general rehabilitation alone.

• Inclusion Criteria:

- Anterior Cruciate Ligament Reconstruction

• Exclusion Criteria:

- Underwent sutures after an accompanying cartilage injury
- No loss of initial muscle strength due to chronic injury
- Elite athletes

• Participants:

- 30 ACL injury patients considered initially; 26 included in GRE and BFR groups after exclusions. 24 were analyzed due to discontinuation of 1 participant in each group.
- Ages between 19-36
- 9 men and 3 women in each group
- Underwent ACL reconstruction using autograft transplantation.

• Intervention:

- GRE Group (n = 12): General rehabilitation exercises.
- BFR Group (n = 12): BFR exercises + general rehabilitation.
- 12-week supervised program, 3 times a week.
- GRE: ROM exercises, weight-bearing exercises, CKC and OKC exercises.
- BFR: Same as GRE with BFR applied during CKC and OKC exercises.
    - Rep scheme: 30/15/15/15
    - Intensity: 4 weeks 10% of 1RM, 6 weeks 20% of 1RM, and 10 weeks 30% of 1RM
    - Rest: 30s between sets, 2 min between exercise
    - 40% of limb occlusion pressure (LOP)

• Assessment Timing:

- Pre-test: 1 day before ACL reconstruction.
- Post-test: 2 days after the last rehabilitation session.

• Measurements Conducted:

- Anthropometry (height and weight)
- Lysholm score and IKDC subjective score
- Muscle activity (EMG for VMO, RF, and VL)
- Isokinetic muscle function (peak torque, total work) using Biodex
- Y-Balance Test

• Statistical Analysis: Two-way ANOVA for repeated measures used to analyze effects. Significance level set at $p < 0.05$.

Findings:

• **Changes in Lysholm Score and IKDC Subjective Score:**

- Rehabilitation intervention showed significant increases in Lysholm scores in the GRE ($p < 0.01$) and BFR ($p < 0.001$) groups.
- IKDC subjective scores also significantly increased in GRE ($p < 0.05$) and BFR ($p < 0.001$) groups.

• **Muscle EMG Activity During Isokinetic Contraction:**

- Significant interaction in the muscle activity of VMO during isokinetic contraction ($p = 0.009$, $\eta2 = 0.269$).
- Significant main effect over time in the muscle activity of VMO ($p = 0.003$, $\eta2 = 0.334$) and RF ($p = 0.019$, $\eta2 = 0.224$) during isometric contraction.
- BFR showed a significant increase in VMO ($p < 0.001$) and RF ($p < 0.05$) during isometric contraction.

• **Isokinetic Muscle Function:**

- hamstring peak torque ($p < 0.006$, $\eta2 < 0.301$) and total work ($p < 0.008$, $\eta2 = 0.280$).
- quadriceps femoris peak torque ($p = 0.005$, $\eta2 = 0.311$) and total work ($p = 0.015$, $\eta2 = 0.240$).
- BFR group showed a significant increase in peak torque ($p < 0.01$) and total work ($p < 0.05$).

• **Balance Improvement:**

- Significant interaction for Y-balance anterior ($p = 0.046$, $\eta2 = 0.170$) and posterior lateral ($p < 0.048$, $\eta2 = 0.167$).
- Substantial main effect of time for Y-balanced posteromedial ($p < 0.001$, $\eta2 = 0.583$).
- BFR group showed significant improvement in Y-balance anterior ($p < 0.01$) and Y-balance posterior medial ($p < 0.05$), as well as Y-balance posterior lateral ($p < 0.05$).

Limitations

• Retrospective Design: Relies on existing data, lacking the benefits of a prospective trial.

• Uncontrolled Patient Characteristics: Factors like physical activity, genetic traits, and pain were not controlled for.

• Challenges in Patient Assignment: Difficulty in random assignment of patients to groups, affecting result interpretation.

• Unaccounted Preoperative Factors: The study did not consider preoperative physical activity and dietary intake.

• Short Follow-up Period: A 3-month follow-up may limit capturing longer-term outcomes.

• Limited Scope: Focuses on specific rehabilitation stages, with a potentially unrepresentative sample size.

Clinical Implications:

- BFR exercises, when added to traditional rehabilitation, could contribute to increased muscle strength and activity, particularly in the vastus medialis oblique (VMO), vastus lateralis oblique (VLO), and rectus femoris (RF).
- The study suggests that BFR exercise may play a crucial role in improving isokinetic muscle function, including peak torque and total work.
- BFR intervention may positively impact muscle endurance, as indicated by changes in hamstring

and quadriceps femoris endurance.

- Y-balance performance improvements were observed, with BFR showing effectiveness in enhancing anterior and posterior lateral aspects.
- The study highlights the potential benefits of BFR in mitigating muscle atrophy, improving joint range of motion, and stabilizing the knee joint after ACL surgery.
- Considering the limitations, further research is needed to establish the long-term effects and optimal application of BFR in ACLR rehabilitation.

Discussion Questions:

1. From a practical standpoint, what challenges might clinicians face when implementing BFR into standard rehabilitation programs, and how can these challenges be effectively addressed?
2. Are there identified safety concerns associated with implementing Blood Flow Restriction (BFR) and general rehabilitation exercises, particularly in the early stages of ACLR recovery?
3. For individuals unable to undergo accurate objective testing such as the biodex, what clinical pearls or alternative functional assessments do you recommend to assist in evaluating muscle strength and readiness for advanced rehabilitation?
4. Considering the study's findings on the effectiveness of BFR in ACLR rehabilitation, what are the opinions of experts regarding the integration of BFR into standard post-ACLR rehabilitation protocols, considering factors like patient variability and long-term outcomes?