Title: Quadriceps Activation Comparative Analysis Based on Positioning of the Ankle During Supine Straight Leg Raise and Quad Set

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1 Background / Scientific Rationale

Returning quadriceps neuromuscular control and preventing atrophy is an area of intense current interest in orthopedic rehabilitation and recovery science. It is clear that returning full autonomous control of the quadriceps, including the vastus medialis obliqus (VMO), at full knee extension is an important factor in rehab and dysfunction of the quadriceps leads to a loss of physical performance and self-reported function[1-4]. Quadriceps function is critical for optimal ambulation patterns and eccentric control is essential for the weight acceptance phase of gait[5,6,7].

Quadriceps atrophy is one of the most common post-operative side effects of anterior cruciate ligament (ACL) reconstruction, total knee arthroplasty, and many other surgeries including meniscal repairs, patella realignment procedures, and microfracture procedures[1-4]. Due to the swelling within the joint after injury or surgery to the knee, the joint inflammation cascade occurs and leads to the quadriceps being arthrogenically inhibited by spinal neuron inhibition as a protective mechanism[5]. These neural changes usually lead to decreased voluntary quadriceps contraction[6]. Additional contributions of inhibition from post-operative pain, patient apprehension, and surgical procedure requiring protection of the repaired tissue[5,7,8]. The sooner one regains control of the quadriceps muscles the less atrophy occurs, reductions in strength are minimized, and the more optimal the outcome is achieved for patient recovery[9].

Studies have shown that neuromuscular electrical stimulation (NMES), Transcutaneous electrical nerve stimulation (TENS), and biofeedback techniques can limit post-operative quadriceps atrophy and can return strength of the quadriceps back to normative values faster than without

those techniques and traditional therapeutic exercise and have better long-term outcomes based on pain, functional outcomes, and return to sport participation rates[1,7,10-12].

Irradiation effect is a proprioceptive neuromuscular facilitation technique that causes an overflow of neuronal energy from distal to proximal muscles to increase muscle activity of a targeted muscle[13,14]. This technique can be used to selectively recruit weaker motor units through the application of resistance or stimulation[13-15]. By inducing a stronger contractile force of the quadriceps, our hope is to return quadriceps function to normal quicker with less atrophy and greater strength[3,6,12].

We hypothesize that ankle positioning in maximal dorsiflexion (DF) changes the quantity of contraction as a percent of the reference voluntary contraction when performing a supine straight leg raise compared with having the foot in neutral (0°), relaxed, and plantarflexed (PF) positions. This may help provide insight into proper instruction and cuing for patients to return quadriceps neuromuscular control sooner and thus limiting quadriceps atrophy.

2 Objectives

Aim 1: Determine the effects of ankle positioning on quadriceps neuromuscular activation during supine straight leg raises.

Aim 2: Determine if there is a difference between ankle positioning on quadriceps neuromuscular activation during straight leg raises in supine in healthy versus post-operative participants.

3 Participant Eligibility

All Participants

Inclusion Criteria:

- Males and females ages 18-55

Exclusion Criteria:

- History of diagnosed cancer, neurological disorder, peripheral nerve injury affecting the lower limb or injury to the lower spine with radicular symptoms, which may affect quadriceps activation
- History of musculoskeletal injury to the quadriceps that may affect ability to maintain muscle contractions without excessive fatigue or discomfort

Healthy Controls

Exclusion Criteria:

- Injury to the knee or the quadriceps muscle group within the past 12 months to the tested side
- History of lower extremity orthopedic surgery in the past 12 months to the tested side

Participants with Arthroscopic Knee Surgery

Inclusion Criteria:

- Arthroscopic knee surgery including a meniscectomy, chondroplasty, debridement, loose body removal, and plica excision within the past 28 days
- Scheduled for physical therapy at Andrews Institute Rehabilitation

Exclusion Criteria:

- Multiple ligament reconstruction
- Total joint arthroplasty
- Major surgical complication (infection, deep vein thrombosis, surgical revision, neural impairment/pathology)

4 Participant Enrollment

We intend to enroll 100 volunteers. 50 participants with knee arthroscopy to be tested within the first 28 days after surgery and 50 healthy control participants will be recruited for this study by word of mouth and participants will be screened for inclusion and exclusion criteria. Healthy control participants will be matched by age and leg tested (dominant or non-dominant) with participants in the knee arthroscopy group. Dominant leg will be identified as the leg that the participant uses to kick a soccer ball. Potential participants will have the study described to them including potential risks and will be given the opportunity to read and sign an approved informed consent form. This process will take place prior to any study related activities. If the participant meets inclusion and exclusion criteria, the participant will be scheduled for a testing appointment at the Andrews Research & Education Foundation.

5 Study Design and Procedures

Participants will be screened for all inclusion and exclusion criteria during subject recruitment and will be asked to refrain from heavy lifting, exercise, and any activity that may cause fatigue of the leg muscles 24 hours prior to the testing session. The participants who have undergone knee arthroscopy will be tested on a day they have not done physical activity. The participant's age, date of birth, height, weight, and surgical history (if applicable) will be collected on the Knee History Form (attached), which has been adapted from the 2000 International Knee Documentation Committee Knee History Form, and participants will complete the visual analog scale for pain (VAS).

Participants will have surface electromyography electrodes placed on the skin overlying the vastus medialis oblique (VMO), rectus femoris (RF), vastus lateralis (VL), and tibialis anterior (TA). Electrode locations will be identified through palpation of the muscle belly and electrodes will be placed according to SENIAM recommendations. The identified locations for electrode placement will be shaved, abraded, and cleaned using standard medical alcohol swabs. Subsequent to surface preparation, adhesive Noraxon Single Electrodes, 4cm Ag/AgCl diameter disk shaped, surface electrodes (Noraxon USA, INC, Scottsdale, Arizona) will be attached over the muscle bellies and positioned parallel to muscle fibers using previously published standardized methods.[16] Electrodes will not be replaced or moved throughout the entire data

collection. Electromyographic data will be collected via a Noraxon myoMuscle Ultium EMG (Noraxon USA, INC, Scottsdale, Arizona). Surface EMG data will be visually monitored during the collection of data and sampled.

Following the application of surface electrodes, the reference voluntary contraction normalization method will be utilized so that all surface EMG data can be normalized[16]. The reference posture will be a SLR performed to the height of the contralateral knee flexed to 90° with a level to ensure appropriate height is achieved with the moving limb performing max dorsiflexion throughout the motion. Participants will maintain the reference posture for 5 seconds and the middle 3 seconds of the contraction will be selected for data analysis. Two reference voluntary contraction trials will be performed, and the data will be averaged. Participants will be given 30 seconds of rest between each trial. The reference voluntary contraction method was chosen for normalization to account for the knee arthroscopy participants pain and possible weakness[16]. Pain and weakness post arthroscopy could hinder obtaining maximal isometric contractions through manual muscle testing. Several studies have shown that within 3 days of knee joint surgery patients can lose up to 80-90% of their quadriceps strength due to a phenomenon called arthrogenic muscle inhibition (AMI) that is in part due to surgical trauma as well as joint effusion[17,18,19].

Participants will then have 3 practice repetitions in each position of the foot for a total of 9 repetitions. Upon completion, participants will perform 5 repetitions of SLR and quad sets with the foot in active maximal DF, PF, and a relaxed foot position. In total there will be 15 reps performed. Joint angles will be measured using a goniometer and participants will be instructed to maintain that foot position throughout the motion of the SLR as well as being verbally cued throughout the duration of the task. Video tracking will be used to determine when the motion begins and ends for each repetition. Order of foot positioning and performance of exercises will be randomized. Muscle activation will be recorded for each repetition and 5 repetitions of each foot position will be analyzed. Healthy control participants will perform the exercises on bilateral limbs as will the surgical participants with randomization determining which is done first.

Participants will place the foot in the desire position prior to the quad set and any motion of the leg and will maintain the foot position throughout the motion of the task. The participant will then perform a quad set holding for 1 second, then raise the leg taking approximately 1 second to raise the leg to the height of the contralateral limb with the knee flexed to 90° (based off goniometric measurements), hold for 1 second at the top and lower during the SLR taking approximately 1 second, then continue to hold the quad set for 1 second with the foot in the specified position while the leg is on the table, then relaxing. During the quadriceps set the participant will actively contract their quadriceps for a maximum total of 5 seconds performing 5 repetitions in each foot positioning and the muscle activation will be recorded. The knee will be extended active maximally as is customary with the performance of a quadriceps set and straight leg raise with the participant in the supine position, and remain extended throughout the task. Participants will be asked to maximally contract their quadriceps for the duration of the task as well. There will be a minimum of 1 second duration during both the concentric and eccentric

phases of the movement. Participants will have a minimum of 60 seconds of rest between each repetition.

Before starting each straight leg raise, a rest period of muscle activity will be recorded with the participants ankle in the respective testing position (active maximal DF, PF, and a relaxed foot position). This will allow for the option for the EMG signal to be rectified and adjusted for baseline noise by subtracting the mean of the rectified signal during the quiet period (before the start of each exercise) from the rectified signal.

Analysis will be performed with the first repetition and the last repetition being omitted and the average of the remaining 3 repetitions will be done for each testing position for both controls and intervention groups.

A video camera will be used to record the performance of each exercise. EMG and video acquisition will be synchronized. Each repetition will be sub-divided in 2 phases: concentric phase defined as when the participant works against gravity to actively lift their leg of eccentric phase defined as when the participant works against gravity to slow down the return to the starting point of the concentric phase.

6 Expected Risks and Benefits

Risks and Discomforts:

The risks of this study are minimal but do include quadriceps fatigue and gastrocnemius/soleus as well as tibialis anterior muscle fatigue. To minimize muscle soreness and fatigue, adequate rest breaks will be utilized between sets of contractions. The exercise is strictly designed to keep heart rates normal and measure strength of the quadriceps contraction. The appeal of this exercise regimen is that it is not strenuous and can be used during the first rehabilitation day after surgery while at the same time eliciting changes in quadriceps activation that can be used for proper instruction by therapists and trainers to their patients for optimal rehabilitation. This exercise is designed to keep heart rates in normal exercise ranges. There is a slight risk of temporary skin irritation occurring when the surface EMG electrodes are removed from the skin. The skin may appear to be red after the electrodes are removed.

Benefits:

No direct benefits are expected for the participants involved in the study, however results from the study should help clinicians better understand the current cutting edge in exercise technology.

7 Data Management Procedures

All personal information is strictly confidential and no names will be disclosed except as required by law. Data sheets will have names and identifying information replaced with a participant code to protect the confidentiality of the participant. All information provided by the

participant during this project will be recorded on the appropriate forms and stored in a locked room in the Andrews Research & Education Foundation (AREF) research facility. In addition, all participant data forms will be scanned and stored, along with summary information forms, spreadsheets, and photos, in a secure password protected folder on a laptop in which only study investigators will have access to and will be permanently deleted following any and all publications or presentations have been completed related to this research. All records related to this research will be retained in a secure location for a period of 3 years following the completion of all study related activities, at which time they will be properly destroyed.

8 Data Analysis

Data will be analyzed using custom-built MATLAB Software. Rectified EMG will be smoothed and filtered according to standard procedures for human surface EMG. Root mean square values will be calculated and normalized to the reference voluntary contraction. Root mean square values will be calculated for each repetition of the SLR and for each of the three phases (isometric, concentric, and eccentric) and across the whole trial. Processed data will be exported to Microsoft Excel and SPSS.

9 Statistical Considerations

Statistical analysis will be performed in excel and SAS Studio (Version 3.8 on SAS 9.4, SAS Institute Inc., Cary, NC). A 2 (group) x 4 (position) x 3 (phase) MANOVA will be performed for each muscle and appropriate post-hoc tests will be used to ascertain differences among variables. The alpha level will be set *a priori* at $p < .05$.

10 Quality Control and Assurance

All protocols will be monitored and analyzed data will be checked for accuracy by the principal investigator and/or a designated research team member. All medical data will be kept in compliance with HIPAA guidelines.

11 Regulatory Requirements

Informed Consent:

The informed consent process will be performed by one of the study investigators or staff. All participants will have the study described to them and will be given as much time as they would like to read an approved, stamped version of the informed consent document. After signing the informed consent document, they will be given a copy for their records. This process will take place at the AREF.

Participant Confidentiality:

Participant confidentiality information is listed above in #7 (Data Management Procedures). All medical data will be recorded and stored in compliance with HIPAA guidelines.

12 References

1. Harkey MS, Gribble PA, Pietrosimone BG. Disinhibitory interventions and voluntary quadriceps activation: a systematic review. *J Athl Train.* 2014;49(3):411-421.
2. Lewek MD, Rudolph KS, Snyder-Mackler L. Quadriceps femoris muscle weakness and activation failure in patients with symptomatic knee osteoarthritis. *Journal of Orthopaedic Research.* 2004;22:110-115.
3. Mizner RL, Petterson SC, Stevens JE, Vandenborne K, Snyder-Mackler L. Early quadriceps strength loss after total knee arthroplasty. *Journal of Bone and Joint Surgery.* 2005;87(5):1047-1053.
4. Suter E, Herzog W, Bray RC. Quadriceps inhibition following arthroscopy in patients with anterior knee pain. *Clinical Biomechanics.* 1998;13:314-319.
5. Palmieri RM, Tom JA, Edwards JE, et al. Arthrogenic muscle response induced by an experimental knee joint effusion is mediated by pre- and post-synaptic spinal mechanisms. *J Electromyogr Kinesiol.* 2004;14(6):631-640.
6. Hart JM, Pietrosimone B, Hertel J, Ingersoll CD. Quadriceps activation following knee injuries: A systematic review. *Journal of Athletic Training.* 2010;45(1):87-97.
7. Hopkins J, Ingersoll CD. Arthrogenic muscle inhibition: A limiting factor in joint rehabilitation. *Journal of Sport Rehabilitation.* 2000;9(2):135-159.
8. Palmieri RM, Weltman A, Edwards JE, et al. Pre-synaptic modulation of quadriceps arthrogenic muscle inhibition. *Knee Surg Sports Traumatol Arthrosc.* 2005;13(5):370-376.
9. Pietrosimone BG, Grindstaff TL, Linens SW, Uczekaj E, Hertel J. A systematic review of prophalyatic braces in the prevention of knee ligament injuries in collegiate football players. *Journal of Athletic Training.* 2008;43(4):409-415.
10. Palmieri-Smith RM, Kreinbrink J, Ashton-Miller JA, Wojtys EM. Quadriceps inhibition induced by an experimental knee joint effusion affects knee joint mechanics during a single-legged drop landing. *Am J Sports Med.* 2007;35(8):1269-1275.
11. Torry MR, Decker MJ, Viola RW, O'Connor DD, Steadman JR. Intra-articular knee joint effusion induces quadriceps avoidance gait patterns. *Clinical Biomechanics.* 2000;15:147-159.
12. Panariello RA, Stump TJ, Allen AA. Rehabilitation and Return to Play Following Anterior Cruciate Ligament Reconstruction. *Operative Techniques in Sports Medicine.* 2017;25(3):181-193.
13. Hopf HC, Schlegel HJ, Lowitzsch K. Irradiation of voluntary activity to the contralateral side in movements of normal subjects and patients with central motor disturbances. *European Neurology.* 1974;12:142-147.
14. Moore JC. Excitation overflow: An electromyographic investigation. *Archives of physical Medicine Rehabilitation.* 1975;56:115-120.

15. Shimura K, Kasai T. Effects of proprioceptive neuromuscular facilitation on the initiation of voluntary movement and motor evoked potentials in the upper limb muscles. *Journal of Human Movement Science.* 2002;21:101-113.
16. Choi S-A, Cynn H-S, Yoon T-L, Choi W-J, Lee J-H. Effects of Ankle Dorsiflexion on Vastus Medialis Oblique and Vastus Lateralis Muscle Activity During Straight Leg Raise Exercise with Hip External Rotation in Patellofemoral Pain Syndrome. *Journal of Musculoskeletal Pain.* 2014;22(3):260-267.
17. Holm B, Kristensen MT, Bencke J, Husted H, Kehlet H, Bandholm T. Loss of knee-extension strength is related to knee swelling after total knee arthroplasty. *Arch Phys Med Rehabil.* 2010;91:1770–1776.
18. Hurley M, Jones D, Newham D. Arthrogenic quadriceps inhibition and rehabilitation of patients with extensive traumatic knee injuries. *Clin Sci (Lond)*. 1994;86:305-310.
19. Pietrosimone B, Saliba S, Hart J, Hertel J, Kerrigan D, Ingersoll CD. Effects of transcutaneous electrical nerve stimulation and therapeutic exercise on quadriceps activation in people with tibiofemoral osteoarthritis. *Journal of Orthopedics and Sports Physical Therapy.* 2011;41:4–12.