Force Production Variability during Leg Press Exercise in ACL Reconstruction Patients

Project Description

More than 200,000 anterior cruciate ligament (ACL) injuries occur each year in the United States, with approximately 65% of those injuries being treated with reconstructive surgery (Benjaminse et. al., 2006). A large proportion of these surgeries are on patients under the age of 20 and account for more than 40% of ACL surgeries each year (Mall et. al., 2014). This is likely due to high levels of participation in athletics for this age group, with athletes generally placing greater demands on their knee compared to individuals not involved in athletics. When these younger athletes return to sport following their surgery, however, their incidence rate of experiencing a second ACL injury is 6 times greater than athletes who have not had ACL reconstructive surgery (Paterno et. al., 2014). This high incidence rate serves as motivation for rigorous rehabilitation and return-to-sport testing.

Figure 1. Setup for measuring the force while the participant uses the leg press and attached measuring device.

A main focus of current rehabilitation and return-to-sport testing is restoring quadriceps strength. Quadriceps weakness of the surgical limb, while most prevalent during the first few months following surgery (de Jong et. al., 2007; Ingersoll et. al., 2008; Keays et. al., 2007), can still persist after being cleared to return to full activity (Palmieri-Smith et. al., 2008). This is problematic as quadriceps weakness of the surgical limb at return-to-sport testing has been related to asymmetric loading during bilateral vertical drop landings (Schmitt et. al., 2016), asymmetric knee movement in the sagittal plane (Palmieri-Smith & Lepley, 2015), poor self-reported function (Schmitt et. al., 2012), and poor functional performance (Schmitt et. al., 2012; Palmieri-Smith & Lepley, 2015). Thus, incorporating exercises that strengthen the quadriceps while encouraging symmetric loading and sagittal plane movement, such as the leg press and squat, is common throughout rehabilitation (Bousquet et. al., 2018) and is frequently used during return-to-sport testing. These exercises, especially when performed bilaterally, present their limitations. When completing the bilateral squat, for example, ACL reconstruction patients may shift effort from the surgical limb to the contralateral limb (Salem et. al., 2003), and further perpetuate quadriceps imbalances.

As a method to combat the issue of effort being shifted away from the surgical limb during bilateral exercise, our lab has recently developed and validated a force platform that is capable of interfacing with a standard leg press machine (Figure 1), allowing feedback for patients and clinicians to evaluate force production symmetries during exercise. In addition to evaluating force production symmetry, our custom platform also aids in evaluating patients' ability to effectively and smoothly control load. One measure that does this is the Lyapunov exponent (LyE). LyE is a nonlinear measure that is commonly used in biomechanics research to describe the amount of variability that an individual demonstrates throughout a cyclical task. Use of LyE in ACL research has commonly focused on stride-to-stride knee flexion angle variability during gait with greater divergence (larger LyE) in trajectories seen in ACL deficient and reconstructed limbs of individuals compared to their uninvolved limbs (Moraiti et. al., 2010; Stergiou et. al., 2004). The greater divergence of the knee flexion angle trajectories of the involved limb indicate less control of the knee joint and may demonstrate functional deficits (Lanier et. al., 2018). More recently, LyE has been used to evaluate force control in healthy individuals during a novel cutting task, with the intent of using the same assessment in ACL patients in future research (Lanier et. al., 2018). By further describing force control in individuals with musculoskeletal injuries, we provide a more comprehensive picture of changes in motor control that occur following injury.

Using the force platform developed by our lab, we recently developed normative values of force control variability using LyE during the leg press exercise in healthy individuals. These values give us insight into what force control looks like during a clinically relevant task, however, it is unknown if these values would be altered in individuals with knee pathology. By applying the concept of optimal variability to such values would allow us to describe the stability or consistency of patients' ability to produce force from repetition-to-repetition throughout the exercise (Stergiou et. al., 2006). This may provide insight into the motor control of the quadriceps and be useful to clinicians when evaluating patient function throughout rehabilitation. Additionally, developing these assessment tools for clinicians is an important step in preventing re-injury in ACL reconstruction patients <u>Therefore, the purpose of this study is to evaluate force control via the Lyapunov exponent during the leg press exercise in ACL reconstruction patients.</u>

Aim 1: To determine typical repetition-to-repetition variability in force production during leg press exercise in ACL reconstruction patients via the Lyapunov exponent and compare these values to those of healthy controls.

Hypothesis 1.1: *Mean Lyapunov exponent values will not differ between the nonsurgical limbs of ACL reconstruction patients and either of the limbs of healthy controls. However, these values will differ between the surgical limbs of ACL reconstruction patients and both limbs of healthy controls.*

Descriptive statistics (including mean, standard deviation, and 95% confidence intervals) will be calculated to describe normative values for the Lyapunov exponent during leg press exercise in ACL reconstruction patients. These values will then be compared to normative values of healthy individuals that have previously been determined by our lab using a 2x2 ANOVA with a Tukey post-hoc test as needed.

Aim 2: To determine whether force control differs between surgical and uninvolved limbs during leg press exercise in ACL reconstruction patients via the Lyapunov exponent.

Hypothesis 2.1: *Lyapunov exponent values of the surgical limb will be greater than those of the nonsurgical limb.*

A paired t-test will be used to compare Lyapunov exponent values of the surgical and uninvolved limb of participants. This will demonstrate if the surgical limb shows altered force control relative to the uninvolved limb and if there is a need to improve force control through rehabilitation.

Aim 3: To determine the relationship between Lyapunov exponent values from the leg press task and clinical outcomes.

Hypothesis 3.1: *Lyapunov exponent values of the nonsurgical limb will not be correlated with any of the clinical outcomes measured.*

Hypothesis 3.2: *Lyapunov exponent values of the surgical limb will not be correlated with any of the clinical outcomes measured.*

Regression analysis will be used to determine if Lyapunov exponent values are significantly related to clinical outcomes. This will demonstrate if the Lyapunov exponent during leg press exercise provides unique information regarding patient function compared to current clinical measures.

Methodology

Recruitment

Previous studies investigating cycle-to-cycle variability during human movement in populations with ACL injury have recruited 10-20 participants (Moraiti et. al., 2010; Stergiou et. al., 2004). In order to account for potential 20% participant drop-out, this study will aim to recruit 30 participants with first-time unilateral ACL reconstructive surgery who have been cleared by a physician to return to full activity. Individuals will not be eligible to participate if they have had other lower extremity surgeries and if they are not between the ages of 13 and 55 years old.

Experimental Design

The study will have a cross-sectional design. Participants will come to the Biomechanics Research Building on one occasion to complete data collection.

Participant Demographics

Participants' age, height, weight, body mass index, knee girth (circumference at mid-patella region), and date of injury and surgery will be recorded.

Leg Press Task

Prior to completing the task, participants' one-repetition maximum will be determined using normative data charts based on age, sex, and self-reported fitness level (*Strength to Weight Ratios Age-Gender Norms 1-RM Bench Press and Leg Press*, 1997). The leg press task will involve participants performing one set of the leg press exercise on a standard leg press that will have a portable force measuring device interfaced with it. This set will be performed for two consecutive minutes at a cadence of 60 beats per minute as set by a metronome (i.e. one second concentric phase, one second eccentric phase) at a load of 20% of their one-repetition maximum. Participants will be given the opportunity to practice the task with sufficient rest prior to actual data collection. Force data will be collected from the force measuring device and used for analysis.

Clinical Measures

Following completion of the leg press task, participants will complete a series of clinical measures. These measures will include:

- International Knee Documentation Committee- this is a survey used to evaluate self-reported knee function.
- Quadriceps Index- using an isokinetic dynamometer, participants will complete three maximum voluntary contractions for each limb. When the participant reaches their maximum torque for each trial, functional electrical stimulation will be applied to the quadriceps in order to additionally obtain maximum involuntary contraction measures. The trial with the largest torque value for each limb will be used for analysis. The ratios of peak torque of the surgical limb to nonsurgical limb will be calculated for both voluntary and involuntary contractions.
- Central Activation Ratio- using data collected from the isokinetic dynamometer, the ratios of peak torque during voluntary contraction to during involuntary contraction will be calculated for each limb.
- Leg Press Test- participants will attempt to perform at least 15 repetitions at 100% of their body weight using their surgical limb (Lepley et. al., 2015). The number of repetitions successfully completed will be recorded for analysis.
- Single Leg Hop Test for Distance- participants will perform a one-legged hop test for distance. To complete this test, subjects will stand on their leg being tested and will hop forward as far as possible and land on the leg being tested. This will be performed three times for each leg with the best trial for each limb being used for analysis.
- Single Leg Cross Hop Test- participants will perform the one-legged cross hop test. To complete this test, participants will stand on their leg being tested and will hop forward as far as possible on the leg being tested three consecutive times, with each jump crossing a midline that will be placed on the floor. This will be performed three times for each leg with the trial resulting in the farthest distance hopped for each limb being used for analysis.
- Vertical Drop Jump- participants will stand on top of a 31-cm tall box and drop so that each foot will land on a force plate directly in front of the box and immediately transition into a maximal effort vertical jump while three-dimensional motion capture is used to record lower body kinetics and kinematics. Primary variables of interest shown to be related to ACL injury rehabilitation include peak vertical ground reaction forces, peak hip and knee flexion, as well as valgus collapse (Arundale et. al., 2018).
-

Data Processing

Leg press data will be trimmed, interpolated, and filtered using MATLAB (The MathWorks Inc, Natick, MA). Force control will be described with repetition-to-repetition variability, which will be calculated using the Lyapunov exponent (Lanier et. al., 2018). Motion capture data will be processed using Visual3d (C-motion, Germantown, MD).

Project Timeline

	2019	2020				2021	
	Oct.-Dec.	Jan.-Mar.	April-June	July-Sep.	Oct.-Dec.	Jan.-Mar.	April-June
Recruitment & Data Collection	■	■	■	■	■	■	
Data Analysis			■	■	■	■	■
Manuscript Preparation						■	■
Presentation at SRCAF						■	

Student/ Faculty Mentor Roles

The student will: prepare and submit the IRB application as well as address comments, recruit participants and lead data collections, lead data processing and analysis, prepare a thesis and manuscript to be submitted to a peer-reviewed journal.
The faculty mentor will: review IRB materials, provide guidance during data collection and analysis as needed, review thesis and manuscript.

Previous Internal Funding: None

Budget Justification

A total budget of $5,000.00 is requested for the completion of this project. A participant stipend of $1,500.00 is requested for the purchase of gift cards to be provided to participants upon completion of the experimental protocol. This will assist in expediting recruitment of participants.

Additionally, $1,000.00 is requested to purchase a leg press machine to be permanently located in the Biomechanics Research Building. This will improve the standardization of this protocol as well as future projects investigating rehabilitation techniques for populations with lower-extremity pathology. Previous work through the Biomechanics Department as utilized the cable leg press machine in the Health and Kinesiology Building. This was inconvenient for both the researchers and gym users in H&K and also provided distractions for the participants, making it more difficult for them to complete the task at hand.

Lastly, a student stipend of $3,500.00 is requested, where the student will work on the research project for a minimum of 200 hours. This stipend will allow the student to spend more time at the Biomechanics Research Building to work on the GRACA project in addition to the time they spend working on their duties as a graduate assistant.

Item	**Price**
Participant Stipend	$1,500.00 ($50.00 per participant)
Leg Press	$1,000.00
Student Stipend	$2,500.00
Total	**$5,000.00**

References/Citations

1. Benjaminse A., Gokeleer A., van der Schans C.P. Clinical diagnosis of an anterior cruciate ligament rupture: a meta-analysis. *J Orthop Sports Phys Ther,* 2006, 36, 267-288.
2. Mall N.A., Chalmers P.N., Moric M., Tanaka M.J., Cole B.J., Bach B.R., Paletta G.A. Incidence and trends of anterior crucitate ligament reconstruction in the United States. *Am. J. Sports Med.* 2014, 42(10), 2363-2370.
3. Paterno M.V., Rauh M.J., Schmitt L.C., Ford K.R., Hewett T.E. Incidence 2 years after primary ACL reconstruction and return to sport. *Am J Sports Med,* 2014, 42(7), 1567-1573.
4. de Jong S.N., van Caspel D.R., van Haeff M.J., Saris D.B. Functional assessment and muscle strength before and after reconstruction of chronic anterior cruiciate ligament lesions. *Arthroscopy,* 2007, 23, 21.e1-21.e11.
5. Ingersoll C.D., Grindstaff T.L., Pietrosimone B.G., Hart J.M. Neuromuscular consequences of anterior cruciate ligament injury. *Clin Sports Med,* 2008, 27, 383-404.
6. Keays S.L., Bullock-Saxton J.E., Keays A.C., Newcombe P.A., Bullock M.I. A 6-year follow-up of the effect of graft site on strength, stability, range of motion, function, and joint degeneration. *Am J Sports Med,* 2007, 35, 729-739.
7. Palmieri-Smith RM, Thomas AC, Wojtys EM. Maximizing quadriceps strength after ACL reconstruction. *Clin Sports Med*, 2008, 27(3), 405-424.
8. Schmitt L.C., Paterno M.V., Ford K.R., Myer G.D., Hewett T.E. Strength asymmetry and landing mechanics at return to sport after ACL reconstruction. *Med. Sci. Sports. Exerc.* 2016, 47(7), 1426-1434.
9. Palmieri-Smith R.M., Lepley L.K. Quadriceps strength asymmetry following ACL reconstruction alters knee joint biomechanics and functional performance at time of return to activity. *Am. J. Sports Med.* 2015, 43(7), 1662-1669.
10. Schmitt .LC., Paterno M.V., Hewett T.E. The impact of quadriceps femoris strength asymmetry on functional performance at return to sport following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther*, 2012, 42(9), 750-759.
11. Bousquet B.A., O'Brien L., Singleton S., Beggs M. Post-operative criterion based rehabilitation of ACL repairs: a clinical commentary. *Int. J. Sports Phys. Ther.* 2018, 13(2), 293-305.
12. Salem G.J., Salinas R., Harding V. Bilateral kinematic and kinetic analysis of the squat exercise after anterior cruciate ligament reconstruction. Arch Phys Med Rehabil 2003, 84, 1211-1216.
13. Moraiti C.O., Stergiou N., Vasiliadis H.S., Motsis E., Georgoulis A. Anterior cruciate ligament reconstruction results in alterations in gait variability. *Gait Posture*, 2010, 32, 169-175.
14. Stergiou N., Moraiti C., Giakas G., Ristanis S., Georgoulis A.D. The effect of walking speed on the stability of the anterior cruciate ligament. *Clin. Biomech.* 2004, 19, 957-963.
15. Lanier A., Knarr B., Stergiou N., Buchanan T. A novel and safe approach to simulate cutting movements using ground reaction forces. *Sensors*. 2018, *18*(8), 1-13.
16. Stergiou N., Harbourne R., Cavanaugh J. Optimal movement variability: a new theoretical perspective for neurologic physical therapy. *J. Neurol. Phys. Ther*. 2006, 30, 120-129.
17. *Strength to Weight Ratios Age-Gender Norms 1-RM Bench Press and Leg Press. The Physical Fitness Specialist Certification Manual.* 1997. Dallas, TX.
18. Lepley L.K., Wojtys E.M., Palmieri-Smith R.M. Combination of eccentric exercise and neuromuscular electrical stimulation to improve biomechanical limb symmetry after anterior cruciate ligament reconstruction. *Clin. Biomech.* 2015, 30(7), 738-747.
19. Arundale A.J.H., Silevers-Granelli H.J., Marmon A., Zarzycki R., Dix C., Snyder-Mackler L. Changes in biomechanical knee injury risk factors across two collegiate soccer seasons using the 11+ prevention program. *Scan. J. Med. Sci. Sports.* 2018, *28*(12), 2592-2603.

Letter of Mentor Support

To Whom It May Concern,

I am pleased to provide this letter of support for Lindsey Remski. Working with her as an undergraduate intern and now as a graduate student it is clear that Lindsey is driven by her desire to perform quality and meaningful research in the field of biomechanics and rehabilitation.

Lindsey's proposed project in this GRACA submission is important for moving towards improved return-to-sport assessments in ACL reconstruction patients. Her personal experience with ACL research as a patient and her thorough research background have helped Lindsey develop a project that meets her scientific aims and do so in a way that is viable and innovative. This project aligns well with the research aims of my team to improve rehabilitation and Lindsey's specific interest in clinical and translational research. The Biomechanics Department and I support Lindsey's project and believe that her proposed budget is sufficient for supporting her needs and compensating her participants.

Lindsey has shown that she is an enthusiastic and hard-working student and will undoubtedly be successful leading this project. Her ultimate goal is to obtain a PhD in Biomechanics and to focus on research involving rehabilitation of musculo-skeletal injuries. Lindsey's thorough experience of being involved in research throughout her collegiate career demonstrates her dedication toward this goal and the experience she will gain through this GRACA proposal will help her considerably. Lindsey is an asset to my research team and I am pleased to have gotten to know her as a student and researcher. It is my pleasure to support Lindsey as a recipient of the GRACA award.

Sincerely,

Brian A. Knarr
Assistant Professor
Director, Machining and Prototyping Core
Department of Biomechanics
Biomechanics Research Building| BRB 208
University of Nebraska at Omaha| coe.unomaha.edu/brb
402.554.4193
bknarr@unomaha.edu