A Dissertation

entitled

Neuromuscular and Musculoskeletal Outcomes Following Arthroscopic Partial Meniscectomy or Meniscal Repair

by

Michelle M. McLeod

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Doctor of Philosophy Degree in Exercise Science

_________________________________________
Thomas McLoughlin, Ph.D., Committee Chair

_________________________________________
Michael A. Tevald, PT, Ph.D., Committee Member

_________________________________________
Abbey Thomas, Ph.D., Committee Member

_________________________________________
Brian Pietrosimone, Ph.D., ATC, Committee Member

_________________________________________
David Sohn, M.D., J.D., Committee Member

_________________________________________
Phillip Gribble, Ph.D., ATC, Committee Member

_________________________________________
Patricia R. Komuniecki, Ph.D., Dean
College of Graduate Studies

The University of Toledo

December 2014
An Abstract of

Neuromuscular and Musculoskeletal Outcomes Following Arthroscopic Partial Meniscectomy or Meniscal Repair

by

Michelle M. McLeod

Submitted to the Graduate Faculty as partial fulfillment of the requirements for the Doctor of Philosophy Degree in Exercise Science

The University of Toledo

December 2014

**Objective:** To investigate lower extremity neuromuscular, musculoskeletal, physical and self-reported functional outcomes following arthroscopic partial meniscectomy (APM) or repair, compared to healthy volunteers without a history of lower extremity injury. Our secondary aim was to determine associations between neuromuscular and musculoskeletal outcomes, and physical and self-reported functional outcomes. **Patients and Other Participants:** Seventeen patients with a history of APM or meniscal repair (11 Male, 5 Female; age: 29.65±11.42 yrs; height: 173.84±10.98 cm; mass: 95.15±27.48 kg; and BMI: 31.45±7.91 kg/m$^2$) and 14 healthy volunteers (8 Male, 6 Female; age: 27.64±10.20 yrs; height: 171.54±9.94 cm; mass: 75.21±15.96 kg; and BMI: 25.39±3.97 kg/m$^2$) without a history of lower extremity injury participated in this study. **Design:** Case-control. **Setting:** Research laboratory. **Methods:** All participants reported to our laboratory for one test session. Overall health, and knee specific self-reported function questionnaires related to symptoms, physical function, emotions and quality of life were administered to all participants. Measures of quadriceps and hamstring strength,
quadriceps intracortical excitability, intracortical excitability, soleus spinal reflexive excitability, physical function tests including a stair climb test, single leg knee bends, and sit to stands were performed. **Main Outcome Measures:** All outcome measures were assessed bilaterally. Quadriceps and hamstring maximal isometric contraction strength were normalized to bodyweight (Nm/kg). Quadriceps to hamstring ratios were also calculated. Quadriceps intracortical excitability was assessed by determining active motor threshold (AMT). Motor evoked potentials (MEPs) elicited at 120% of AMT intensity were recorded (in volts, V) and used to normalize intracortical MEPs, including: short-interval intracortical inhibition (SICI), long-interval intracortical inhibition (LICI) and intracortical facilitation (ICF). Soleus muscle spinal reflexive excitability was determined via Hoffmann reflex peak-to-peak amplitudes (V) normalized to a maximal muscle response. The International Knee Documentation Committee (IKDC) subjective questionnaire, Knee Injury and Osteoarthritis Outcomes Score (KOOS) and Western Ontario Meniscal Evaluation Tool questionnaires were scored to determine self-reported function. Physical tasks of total time to complete a stair ascent-descent task, total number of single-leg knee bends performed in 30-seconds (bilaterally), and total number of chair stands performed in 30-seconds were recorded to determine overall levels of physical function. **Statistical Analyses:** Repeated measures analyses of co-variance were utilized to determine if differences existed between limbs and between groups for all outcome measures, with mass accounted for as the covariate. Spearman’s rho correlations were performed to determine associations between measures of involved limb quadriceps strength and voluntary activation with physical function and self-reported function. **Results:** There were no significant main effects or interactions between limbs between
groups for quadriceps intracortical excitability, soleus spinal reflexive excitability, quadriceps and hamstring strength and quadriceps voluntary activation. APM patients performed significantly worse self-reported function, fewer chair stands, and took longer to complete a stair climb test task. APM patients also had significantly more pain than the healthy cohort. Quadriceps strength of the involved limb of the APM group was significantly associated with measures of self-reported function as measured using the IKDC, KOOS, and WOMET tools, and was also significantly associated with physical function. For these associations, greater quadriceps strength was related to better function. **Conclusion:** Although there were no differences in quadriceps neuromuscular function or strength and activation compared between APM and healthy participants, quadriceps strength was still strongly associated with self-reported function. Additionally, voluntary quadriceps activation was lower in our healthy cohort than previously reported in our laboratory. APM is favored for its minimal invasiveness and quick return to physical activity; however, the current study demonstrated an association between quadriceps strength and self-reported function, and physical function. The APM cohort performed significantly worse on these measures, therefore, it may be that other variables other than strength may be influential in physical function. A lack of statistical power limited our ability to discern true differences in neuromuscular excitability between groups and if there were associations of excitability and self-reported or physical function. Decreased self-reported function and physical function, as well as a history of APM have been linked to the development of knee osteoarthritis; yet, there is no standard of post-surgical care for APM patients. Clinically, this may be important to consider in
the care of APM patients, and future research is warranted focused on neuromuscular function following APM, as well as interventions to improved function following APM.
Acknowledgements

Dr. Todd Evans: this was your idea! As I move forward in my career I look back and remember all that you have done to help me realize my potential through the years. I am beyond grateful and owe much of this to you.

Dr. Phillip Gribble: thank you for taking a chance on me in Philadelphia. One of the best decisions I’ve ever made was to make the move to work with and learn from you.

Dr. Abbey Thomas: I have learned so much from you in such little time. I am so thankful for your guidance as both a doctoral student and faculty member during my last year. Having you around was priceless!

Drs. Tevald and Sohn: thank you for helping me make the best of this project and for your expertise. I couldn’t ask for a better group to work collaborate with.

My fellow Rockets: Adam, Hayley, Masa, Megan, Harkey, Brittney, Amanda, Kyle & Ryan. Time flies when you’re having fun! Thanks for making life in and out of class and the lab an adventure. I am privileged to have worked with such a great group.

My family and friends, near and far, old and new: I don’t know what I would do without you all and your constant encouragement, love and laughter. You are my rock.

Last, but certainly not least, Dr. Brian Pietrosimone: there is no one more enthusiastic and passionate about changing the world and having fun while doing it. I am a better person and professional because of you and could not have asked for a better mentor and friend. “Thank you” is drastically insufficient.
# Table of Contents

Abstract .......................................................................................................................... iii

Acknowledgements ........................................................................................................ v

Table of Contents .......................................................................................................... vi

List of Tables ................................................................................................................ vii

List of Figures ................................................................................................................ viii

List of Abbreviations .................................................................................................... ix

1 Introduction ................................................................................................................ 1

1.1 Background ............................................................................................................. 1

1.2 Significance ............................................................................................................. 2

1.3 Specific Aims .......................................................................................................... 5

2 Literature Review ...................................................................................................... 7

2.1 Introduction ............................................................................................................. 7

2.2 Quadriceps Intracortical and Intracortical Excitability ........................................ 9

2.3 Soleus Spinal Reflexive Excitability ...................................................................... 12

2.4 Quadriceps and Hamstring Strength & Voluntary Quadriceps Activation .......... 13

3 Methodology ............................................................................................................. 15

3.1 Research Design .................................................................................................. 15

3.2 Overview of Methods .......................................................................................... 15

3.2.1 Patients ........................................................................................................... 15
3.2.2 Sample Size Estimates ................................................................. 16
3.2.3 Instrumentation............................................................................ 17
3.3 Outcome Measures ........................................................................ 18
  3.3.1 Quadriceps Corticospinal and Intracortical Excitability .......... 18
  3.3.2 Soleus Muscle Spinal Reflexive Excitability .............................. 21
  3.3.3 Muscular Strength & Voluntary Activation ............................... 21
  3.3.4 Self-Reported Function .............................................................. 23
  3.3.5 Physical Function ........................................................................ 24
3.4 Statistical Analyses .......................................................................... 25
  3.4.1 Demographic Data ...................................................................... 25
  3.4.2 Specific Aim 1 ........................................................................... 25
  3.4.3 Specific Aim 2 ........................................................................... 26

4 Results .................................................................................................. 27
  4.1 Demographics ................................................................................. 27
  4.2 Specific Aim 1 ................................................................................. 27
    4.2.1 Neuromuscular Excitability ....................................................... 27
    4.2.2 Muscle Strength & Voluntary Activation .................................. 28
    4.2.3 Physical Function & Self-Reported Function ........................... 28
  4.3 Specific Aim 2 ................................................................................. 28
    4.3.1 Associations Between Involved Quadriceps Strength & Activation and Self-Reported Function ................................................................. 28
    4.3.2 Associations Between Involved Quadriceps Strength & Activation and Physical Function Tasks ................................................................. 29
Discussion ........................................................................................................................................ 30

5.1 Major Findings .......................................................................................................................... 30

5.2 Neuromuscular Excitability .................................................................................................... 30

5.3 Muscle Strength & Quadriceps Activation .............................................................................. 33

5.4 Physical & Self-Reported Function ......................................................................................... 35

5.5 Associations Between Involved Quadriceps Strength & Activation and Self-Reported Function ........................................................................................................................................ 38

5.6 Associations Between Involved Quadriceps Strength & Activation and Physical Function ........................................................................................................................................ 39

5.7 Limitations ............................................................................................................................... 41

5.8 Future Research ....................................................................................................................... 42

5.9 Clinical Implications ................................................................................................................ 42

5.10 Summary & Conclusion ......................................................................................................... 43

References ...................................................................................................................................... 49

A Adult Research Subject Information & Consent Form ................................................................. 61

B Child Research Subject Assent Form .......................................................................................... 68

C Parent/Guardian Research Subject Information & Consent Form ............................................ 72

D International Knee Documentation Committee Form .............................................................. 79

E Knee Injury and Osteoarthritis Outcome Score ......................................................................... 82

F Western Ontario Meniscal Evaluation Tool .................................................................................. 87
List of Tables

3.3.1 Transcranial Magnetic Stimulation Paired-Pulse Parameters .............................................. 20

4.1 Patient and Participant Demographics .................................................................................. 45

4.2.1 Comparisons of Quadriceps Corticospinal Excitability ..................................................... 45

4.2.1a Comparisons of Soleus Spinal Reflexive Excitability ....................................................... 46

4.2.2 Comparisons of Thigh Muscle Strength & Activation.......................................................... 46

4.2.3 Comparisons of Self-Reported & Physical Function ............................................................ 47

4.3.1 Associations of Strength, Self-Reported & Physical Function in APM or Repair 48

4.3.2 Associations of Strength, Self-Reported & Physical Function in Healthy People 48
List of Abbreviations

APM ...................... Arthroscopic Partial Meniscectomy
AMT ...................... Active Motor Threshold
CAR ...................... Central Activation Ratio
EMG ...................... Electromyography
H-Reflex .................. Hoffmann Reflex
H:M ..................... Hoffmann Reflex normalized to Maximal Muscle Response
ICF ..................... Intracortical Facilitation
IKDC .................... International Knee Documentation Committee Questionnaire
KOOS .................... Knee Injury and Osteoarthritis Outcomes Questionnaire
LICI ..................... Long-Interval Intracortical Inhibition
MEP ..................... Motor Evoked Potential
MVIC ................... Maximal Voluntary Isometric Contraction
Q:H ..................... Quadriceps to Hamstring Strength Ratio
SCT ..................... Stair Climb Test
SIB ..................... Burst Superimposition Technique
SICI ..................... Short-Interval Intracortical Inhibition
30s-CST ............... 30-second Chair Stand Test
TMS ..................... Transcranial Magnetic Stimulation
VAS ..................... Visual Analog Scale
WOMET ................ Western Ontario Meniscal Evaluation Tool Questionnaire
Chapter 1

Introduction

1.1. Background

Meniscal injuries of the knee are among the most common in sport and workplace activities that demand repetitive knee joint loading.\(^1\,^2\) Damage to the meniscus is frequently a result of combined compressive and rotational forces at the tibiofemoral joint, such as with cutting or pivoting movements.\(^2\) Acute meniscal injuries typically present with knee joint effusion, pain, sensations of “clicking” or “catching” in the knee, joint-line tenderness, or an inability to bear weight to meet functional demands.\(^2\) However, meniscal injuries can also be degenerative in nature, be present without pain and are commonly an incidental finding on magnetic resonance imaging in middle-aged and elderly populations.\(^3\) Due to the multi-factorial contributions to meniscal injury, varied onset and populations in which they occur, accurate estimations of the true prevalence of meniscal pathology are often difficult to calculate. It is plausible that the current best estimates are likely under-representative.
Arthroscopic partial meniscectomy (APM) or repair is indicated to remove or repair damaged portions of the meniscus contributing to symptoms of pain, disability, or mechanical interference with joint motion.²,⁴ APM has been favored for its minimal invasiveness²,⁵ and the perceived benefit of a rapid recovery and resumption to presurgical activities.⁴-⁷ In 2006, 956,000 arthroscopic procedures (ICD-9-CM 80.26) were performed in the United States,⁸ with over 690,000 of those procedures classified as “semilunar cartilage excisions”. Despite the frequency of APM or repair procedures and the purported benefits, individuals with a previous medical history including APM or repair have been linked to a greater propensity to develop knee osteoarthritis (OA) compared to individuals with no history of knee injury.⁹ In meniscal surgery procedures, there has been a shift emphasizing the preservation of meniscal tissue; however, there remains little agreement upon the indications for meniscal repair versus meniscectomy.¹⁰ Several factors have been suggested to take into consideration for repair over a resection, including vascularity at the location of the tear, the type and size of tear and the age of the patient. The type of tear may be the most influential factor and it has been suggested that the type of tear may allow for only 5% of cases to be indicated for meniscal repair following a traumatic injury.¹¹

1.2 Significance

Approximately 50% of individuals with a history of APM go on to develop knee OA.⁹ Individuals aged 17-30 years old with isolated meniscal injuries have shown degenerative radiographic changes to the knee joint, on average, nearly ten years following an initial evaluation of the injury. In persons with the same injury older than
the same radiographic changes were observed as soon as within five years of the initial injury and examination. Furthermore, evidence of meniscal damage has been observed in as great as 70-90% of individuals with symptomatic knee OA.\textsuperscript{12-14}

It has recently been hypothesized that the development of knee OA following traumatic knee injury, such as anterior cruciate ligament rupture and reconstruction, is linked to persistent weakness of the quadriceps musculature.\textsuperscript{15} Following APM, patients may receive guided physical therapy targeting range of motion and knee extension exercises and weight bearing as tolerated, or receive verbal instructions related to an informal home exercise program.\textsuperscript{6,11} Regardless of the rehabilitative intervention received APM patients often return to unrestricted sport and activities of daily living within 4 weeks after surgery.\textsuperscript{11} However, quadriceps strength may still be markedly decreased immediately after APM,\textsuperscript{5,7,16-20} and has been demonstrated to last up to several years.\textsuperscript{21} In contrast to APM, post-meniscal repair patients generally do not return to sport activities until near 4 to 6 months following the repair procedure, depending upon the course of rehabilitation.\textsuperscript{10,22-25} Post-repair rehabilitation typically involves the use of a locking knee brace, yet, may be accelerated with early range of motion and weight bearing exercises, or may be more conservative with restricted motion and non-weight bearing for a period of up to 6-8 weeks in an effort to protect healing tissues. Neuromuscular deficits including quadriceps weakness and quadriceps voluntary activation deficits are frequently present patients with a history of anterior knee pain and anterior cruciate ligament reconstruction.\textsuperscript{26,27} Optimal neuromuscular quadriceps function is critical in resisting external knee flexion and adduction moments that occur during the heel strike
and stance phases of gait,\textsuperscript{28,29} as well as eccentrically controlling knee flexion during weight acceptance in the early stages of stance phase in walking and jogging.\textsuperscript{30} Therefore, it is plausible that these deficits contribute to aberrant biomechanical strategies and decreased shock absorption. Quadriceps weakness and activation deficits also predict disability in patients with osteoarthritis.\textsuperscript{31}

The significance of these deficits is not only consequential to the individuals living with OA, but contribute greatly to an overbearing financial burden on today’s health care system. Over 50\% of people with a history of meniscal injury will go on to develop knee OA. As of 2011, over 9.3 million adults in the US have been diagnosed with symptomatic knee OA.\textsuperscript{32} Unfortunately, a great percentage of this population including 52\% of males and 50\% of females will be indicated to have a total knee arthroplasty intervention. In 2004, over 500,000 total knee arthroplasties were performed, with a cost of nearly $14.3 billion. By 2007, the direct costs associated with total knee arthroplasty sharply increased to $22.8 billion. Projections for the year 2030 estimate a drastic increase in the number of total knee arthroplasties from 500,000 to an estimated 3.5 million procedures.\textsuperscript{33} More troublesome is the growth of younger populations electing for total knee arthroplasty and the increasing likelihood of requiring a revision before death.\textsuperscript{33,34} These demonstrate the imperativeness to determine if neuromuscular and musculoskeletal differences or relations exist in further understanding sequelae of knee OA, in particular post-traumatic knee osteoarthritis, to better develop and reform current treatment standards and the development of cost-effective interventions to ultimately delay or prevent the onset of knee OA.
It is important to note that an abundance of the current literature has focused on anterior cruciate ligament rupture populations in light of the growing attention towards post-traumatic knee OA. A recent systematic review\textsuperscript{35} suggests that the presence of meniscal pathology may be more detrimental. However, there continues to be a substantial gap in the investigations focused on the pathological meniscal population and the potential neuromuscular consequences to APM or repair and their origins, as well as the potential contributions to physical impairments associated with diminished joint-health. It is well accepted that there are increased contact pressures when portions of the meniscus are removed\textsuperscript{36,37}; thus, optimal muscle function may play a crucial role in maintaining stability and attenuating forces.

1.3 Specific Aims

Our long-term goal is to decrease physical and self-reported disability following lower extremity joint injury. As a first step toward achieving this goal, the objective of this specific study was to determine if neuromuscular function, lower extremity physical function, and self-reported function are different following APM or repair compared to a healthy population as well as determine the relations between these outcomes. Our central hypothesis was that neuromuscular alterations exist following APM, and are related to overall musculoskeletal and self-reported function. Making these determinations are critical so that improvements may be made upon existing standards of care and rehabilitative paradigms. Specifically, this information can facilitate the identification and development of cost-effective interventions targeting neuromuscular deficits in an attempt to maintain force attenuation capabilities, stability during
movement strategies, and maintenance of joint health following circumstances where APM or meniscal repair is indicated. We plan to achieve this objective by completion of the following specific aims:

1. **Determine if there are differences in quadriceps intracortical excitability and soleus spinal reflex excitability, quadriceps strength and voluntary activation, hamstring strength, self-reported function, and physical function, compared between the injured and uninjured limbs following arthroscopic partial meniscectomy (APM) or repair, as well as compared to healthy matched controls without a history of lower extremity joint injury.** We hypothesized that APM or repair patients will exhibit: 1) decreased quadriceps intracortical excitability; 2) increased soleus spinal reflexive excitability; 3) decreased strength and voluntary activation of the affected knee quadriceps; 4) decreased self-reported function; and 5) poorer physical function compared between limbs and with healthy matched controls.

2. **Determine if measures of neuromuscular excitability, strength and voluntary activation are related to self-reported function and physical function in patients following APM or meniscal repair.** We hypothesized that measures of neuromuscular excitability, and quadriceps strength and voluntary activation will predict outcomes in self-reported function, and physical function.
Chapter 2

Literature Review

2.1 Introduction

Arthroscopic partial meniscectomies (APM) and meniscal repairs are the most common orthopedic surgical intervention performed in the United States,\(^8\) accounting for over 70% of all arthroscopies performed in 2006. Despite APM’s minimal invasiveness\(^2,5\) and boasted benefits of quick return to sporting and activities of daily living,\(^4-7\) individuals with a history of APM or meniscal repair procedures are at risk for exhibiting radiographic signs of knee joint osteoarthritis (OA) as soon as 5-10 years after the initial injury.\(^9\)

Currently, there is little consensus on best practices in the management of either APM or meniscal repair procedures. Rehabilitation following APM may include formal physical therapy to restore range of motion and to monitor the progression of pain free weight bearing, or may consist only of verbal and written instructions for a home exercise program.\(^6,11\) Following meniscal repair, patients receive a more guided progression back to daily, work, and sport activities. Typically, following a repair procedure, the patient is
restricted from full knee range of motion via a locking knee brace and are non-weight bearing in an effort to protect the healing meniscus and surrounding soft tissue in the knee joint. Although the progression of rehabilitation following meniscal repairs may be accelerated or conservative in methods of restoring knee range of motion and knee extensor strength, patients are commonly allowed back to unrestricted activity in between 4 and 6 months, whereas APM populations may be back at an unrestricted status by 4 weeks.

A recent study\textsuperscript{11} demonstrated that at an average of 3 years following APM or repair, there were no differences in regarding the progression of knee OA development. However, at approximately 9 years following APM or repair, APM patients showed significantly greater OA deterioration and a greater loss in sport related activity, but there were no significant changes in the meniscal repair population. Furthermore the meniscal repair group showed more of a protective effect against knee OA in patients less than 30 years of age, and no protective benefit in patients older than 30 years old. It should be noted that in this study in particular, the authors acknowledge that they were able to include a larger distribution of repair patients than what was expected, due to their inclusion criteria. It was reported that approximately only 5% of all meniscal lesions are indicated for meniscal repair procedures.

A recent systematic review\textsuperscript{38} suggests that independent of the type of meniscal repair procedure performed, failure rates for meniscal repairs are approximately 22-24% after 5 years, and that there may be a greater risk for reoperation when repairs are performed. Additionally, the development of grade I knee OA ranged from 8-25% in all
meniscal repair populations at 5 years, and a greater prevalence of radiographic findings of OA in failed meniscal repairs compared to successful repairs.\textsuperscript{38}

Patients with a history of APM or meniscal repair may also display persistent quadriceps weakness\textsuperscript{21} which has recently gained notoriety as a potential precursor to the development of knee OA in other pathological knee populations.\textsuperscript{15,27} Post-traumatic OA has gained increasing attention, however, consideration of the role of the meniscus in long-term knee joint health remains overlooked. An increasing understanding of the neuromuscular, physical, and self-reported functional alterations following APM and meniscal repair is imperative for the long-term prevention of disability following meniscal injury. Furthermore, this information is critical in the development of cost-effective interventions specifically targeting neuromuscular function and modification of current rehabilitative paradigms. Therefore, the purpose of this literature review is to provide a comprehensive appraisal of the current evidence regarding neuromuscular function following meniscal and other pathological knee conditions, physical and self-reported function, and the connection to degenerative joint disease.

2.2 Quadriceps Intracortical and Intracortical Excitability

The generation of movement arises from two major neural pathways in the nervous system: cortical pathways, and spinal reflexes.\textsuperscript{39,40} Section 2.2. focuses on measurement of the motor cortex. Transcranial magnetic stimulation is a widely used, noninvasive research tool to investigate deep cortical regions of the brain and physiology using quickly changing magnetic fields produced by an electrical current along a coil.\textsuperscript{41,42} The current stimulus created by the TMS may then stimulate neurons at a distance below
the coil. The stimulation of these neurons can be observed via a synchronous muscle response, termed a motor evoked potential (MEP), visualized using surface electromyography. Using single TMS pulse parameters, measuring MEPs of a muscle at rest provides an estimation of the excitability of a core of individual neurons and the local density of that core. Paired-pulses may be utilized to study the excitability of interneurons within the motor cortex, including inhibitory or facilitory networks.

When investigating intracortical excitability with paired-pulses, a conditioning stimulus is delivered first to activate cortical neurons without resulting in propagation of action potentials to the spinal cord. A test stimulus follows after a short period (interstimulus interval, ISI), typically at a suprathreshold intensity. The effects of the conditioning stimulus on the cortical neurons modulate the magnitude of the test stimulus MEP amplitude. With a subthreshold conditioning stimulus and a short ISI of less than 5 ms, MEPs are typically inhibited and are referred to as short interval intracortical inhibition, or SICI. It is hypothesized that inhibitory networks are largely mediated via the neurotransmitter \( \gamma \)-aminobutyric acid (GABA).\(^{41,43}\) During longer interval ISIs, between 8 and 30 ms, the MEPs are facilitated, termed intracortical facilitation, or ICF and appear to be mediated via N-Methyl-D-aspartate (NMDA). When both the conditioning and test stimuli are suprathreshold intensity with an ISI ranging between 50-200 ms, long interval intracortical inhibition, or LICI, is elicited.\(^{44}\)

There is a limited but growing body of evidence related to intracortical and intracortical excitability and quadriceps muscle function. In individuals with a history of anterior cruciate ligament reconstruction\(^ {45}\) there was greater corticospinal excitability of
the quadriceps compared to healthy controls. It was proposed that this may indicate a compensatory upregulation of corticospinal projections targeting muscle transmitting altered afferent signals consequential to pain or impaired function. Recent work by Lepley et al.\textsuperscript{46} investigated the contributions of neural pathways to quadriceps strength in an anterior cruciate ligament reconstructed population compared to healthy counterparts. This study demonstrated that corticospinal excitability predicted 2% of the variance in muscle strength in reconstructed individuals. While the contribution of 2% may appear menial, the healthy participants did not demonstrate associations to muscle strength. These results suggest that even small alterations in this pathway may be an underlying mechanism for quadriceps weakness, potentially as a result of altered sensory input from the joint mechanoreceptors in this population.

Using a simulated knee joint effusion model,\textsuperscript{47} there were no immediate changes in corticospinal excitability, as determined using active motor thresholds and MEP amplitudes, when compared with a control session separated by one-week. In another investigation sampling knee osteoarthritis (OA) patients,\textsuperscript{48} there were no differences in corticospinal excitability as measure by resting motor threshold, nor for intracortical measures of SICI and ICF, compared to healthy counterparts. There were, however, associations between pain and resting motor threshold as well between pain and ICF in patients with knee OA, suggesting that pain may have a role in neural quadriceps function in this population. To our knowledge, there have been no investigations specifically targeting pathological meniscus populations and the influence of neuromuscular alterations. With varied results between multiple injured knee populations
additional research centered on corticospinal and intracortical mechanisms of knee joint musculature are certainly warranted and necessary.

2.3 Soleus Spinal Reflexive Excitability

The spinal reflexive pathway is another major neural pathway responsible for the generation of movement. The stretch reflex is initiated by an excessive stretch on a muscle and serves as a mechanism to preserve balance and protection against injury from an unexpected addition of weight, excessive postural sway, or other stimuli.\textsuperscript{49} Excitability of this pathway can be measured clinically using the Hoffmann (H) reflex, which has been thought of as an electrically induced reflex analogous to stretch reflex,\textsuperscript{50} differing such that the H-reflex bypasses the muscle spindle. Quantification of the H-reflex allows for an estimation of alpha motor neuron pool excitability in the spinal cord and is commonly used to assess neuromuscular responses to conditions such as pain, musculoskeletal injury, and therapeutic modalities. H-reflex measures are normalized to a muscle (M) response, which appear before the H-reflex electromyographically, as a result of the the direct stimulation of efferent fibers in the periphery traveling directly to the neuromuscular junction, away from the stimulation point.\textsuperscript{51} When eliciting H-reflexes and M-responses, the stimulating electrode is placed directly over the mixed nerve supplying the target muscle. The percutaneous electrical stimulus is increased in increments of 0.2V until the peak-to-peak amplitude of the H-reflex maximizes. It is important to note the location of the appearance of the evoked action potential on EMG, as the distance of the muscle from the spinal cord will influence the location of the
evoked potential, such that the closer the muscle to the spinal cord, the shorter the latency period.

Once the H-reflex has been identified, the M-response is elicited as the electrical stimulus continues to be delivered in with increasing intensity until the peak amplitude plateaus. The M-response typically appears later than the H-reflex, as these efferent fibers have a greater threshold to depolarize. Additionally, due to the shorter the distance they have to travel to the neuromuscular junction, they will appear at latencies shorter than that of the H-reflex\(^\text{52}\). The M-response is representative of the maximal availability of the corresponding motor neuron pool.

Similarly to corticospinal and intracortical excitability there is, to our knowledge, no investigations that have focused on a pathological meniscus population. An abundance of the existing evidence remains centered around anterior cruciate ligament reconstruction\(^\text{46,53-55}\) and simulated effusion models\(^\text{52,56,57}\) in an effort to further understand mechanisms of arthrogenic muscle inhibition, the reflexive inhibition of intact musculature surrounding an injured joint\(^\text{58,59}\). Further investigation is warranted, as there are inconsistencies in the study findings, and the contribution of meniscal resection on neuromuscular function is unknown.

### 2.4 Quadriceps and Hamstring Strength & Voluntary Quadriceps Activation

As previously mentioned a consistently boasted advantage of APM interventions is a relatively quick return back to work and sport, and activities of daily living. However, there is increasing evidence suggesting that the quadriceps may be weak, and perhaps chronically weak following APM\(^\text{7,17,18,20,21,60-66}\) although some studies also do
show that quadriceps strength may become more representative of a healthy population over time. Furthermore there is not consistent agreement on the best approach for rehabilitation following APM, ranging from no guided physical therapy, to individualized progressive rehabilitation exercises.\(^1\) This may indicate that patients have decreased quadriceps strength when returning back to activities, potentially increasing the risk for re-injury or hastened progression of degenerative joint disease. Fewer studies have investigated voluntary quadriceps activation in APM populations.\(^20,67,68\) In addition to varying methods of investigating quadriceps strength and activation and because of the lack of standard of care for APM patients post-surgery, there is also contention regarding if exercise intervention is effective in targeting these impairments,\(^6,7,17,60,65,69,70\) likely due to a uncertainty about the origins of these impairments and the need to identify interventions to effectively target neuromuscular function, specifically, in rehabilitative paradigms.
Chapter 3

Methodology

3.1 Research Design

We utilized a cohort study design to explore the differences (Aim 1) and associations (Aim 2) of our outcome measures in patients with a history of unilateral arthroscopic surgery for a partial meniscectomy (APM) or meniscal repair compared to individuals without a history of lower extremity joint injury. The methods of this study were reviewed and approved by The University of Toledo’s institutional review board (IRB #108243; Appendices A-C).

3.2 Overview of Methods

3.2.1 Patients

Patients aged 15-60 years with a history of APM or meniscal repair without major ligamentous involvement were recruited from The University of Toledo community and from a single orthopedic surgeon, David H. Sohn, MD, JD, at The University of Toledo Medical Center in Toledo, Ohio. APM or meniscal repair patients had no other history of surgery or injury to the lower extremity of either the involved or uninvolved limbs. Once
APM patients were recruited and enrolled healthy participants were recruited and matched on age, sex, and height for enrollment in the control group. All patients and participants were pre-screened for transcranial magnetic stimulation (TMS) exclusionary criteria, in accordance with the National Institutes of Neurological Disorders and Stroke. Patients and participants were excluded if they had a history of metal plates in the cranium (except for the mouth), intracardiac lines, increased intracranial pressure, pregnancy, childhood, heart disease, cardiac pacemaker, medication pumps, tricyclic antidepressants, neuroleptics, and family history of epilepsy. Additional safety concerns that also resulted exclusion were anyone who: smokes, has been diagnosed with a neurologic disorder (e.g. Parkinson’s disease, multiple sclerosis, stroke), suffered a back or lower extremity injury to either limb in the previous six months or any previous lower extremity surgery, has a cognitive status that does not allow the individual to consistently comprehend or verbalize back directions regarding the details and nature of the study, has fibromyalgia, has peripheral neuropathy (numbness, tingling, loss of sensation in the hands or feet), or cannot ambulate without an assistive device, due to the nature of the functional tests. Lastly, individuals with a body mass index (BMI) ≥ 40 were excluded, as a high BMI can negatively impact the ability to record muscular responses to neuromuscular test procedures (TMS, H-reflex, voluntary activation).

3.2.2. Sample Size Estimates

An a priori power analysis was performed to determine 17 subjects per group would be necessary to find a statistical difference with strong effect sizes \( d=1.0, \alpha=0.05, 1-\beta=0.80 \), using previously published\(^{26}\) neuromuscular activation means and variances.
Our surgical group consisted of both partial meniscectomy and meniscal repair patients. We did not anticipate enrolling a large number of meniscal repair patients since repairs are only feasible in 5% of pathological meniscus cases; therefore we did not create subgroups in order to maintain statistical power.

3.2.3. Instrumentation

Corticospinal and intracortical excitability outcome measures were assessed using a Magstim BiStim\(^2\) (The Magstim Company, Wales, UK) and a double-cone coil (the Magstim Company, Wales, UK). All torque measures were acquired using a Biodex System III Pro isokinetic dynamometer (Biodex Medical Systems, Shirley, NY). The Biodex was also used to standardize patient positioning during corticospinal and intracortical, and strength and voluntary activation measures. Pre-gelled 10-mm Ag-AgCl surface electromyography (EMG) electrodes (EL503, BIOPAC Systems, Goleta, CA, USA) were positioned over the muscle bellies to record muscle responses during neuromuscular excitability measures. EMG signals were converted using a 16-bit analog-to-digital converter (MP150, BIOPAC Systems, Inc., Goleta, CA, USA) and visualized using Acqknowledge BIOPAC software (BIOPAC Systems Inc., Goleta, CA, USA). EMG signals were band-pass filtered from 10 to 50 Hz and collected at 1024 Hz with a common-mode-rejection ratio of 110dB, EMG signals were sampled at 2000 Hz, with the amplification set at a gain of 1000 (EMG100C BIOPAC Systems, Inc., Goleta, CA, USA). A 1-ms square wave stimulus was produced using a BIOPAC stimulator module (STM100A, BIOPAC Systems Inc., Goleta, CA, USA) and a 200V maximum stimulus isolation adaptor (STIMISOC, BIOPAC Systems Inc., Goleta, CA, USA) was used to
stimulate the common sciatic nerve using a 2-mm shielded disc stimulating electrode (EL254S, BIOPAC Systems, Inc., Goleta, CA, USA). Voluntary quadriceps activation was assessed using a square wave stimulator (S88, GRASS telefactor W. Warwick, RI, USA) and a stimulus isolation unit (SIU8T, W. Warwick, RI, USA).

3.3 Outcome Measures

Our primary aim was to determine if there are differences in quadriceps corticospinal and intracortical excitability, and soleus spinal reflexive excitability, isometric quadriceps strength and voluntary activation, hamstring strength, self-reported function, and physical function, compared between the injured and uninjured limbs following APM or meniscal repair, as well as compared to healthy matched controls. Outcome measures were collected bilaterally on all patients and participants. Healthy participants were assigned an “involved limb” matching the involved limb of his or her post-surgical counterpart. All outcome measures were collected in a single test session.

3.3.1 Quadriceps Corticospinal and Intracortical Excitability

Quadriceps corticospinal and intracortical excitability were determined via transcranial magnetic stimulation (TMS) testing. Muscular responses were assessed using surface electromyography (EMG). Two 10mm pre-gelled Ag-AgCl electrodes were positioned 1.75mm apart over the distal vastus medialis muscle belly, at approximately a 55° angle from the superior pole of the patella and 2cm medially. This collection site was removed of hair as necessary and the skin debrided and cleaned with alcohol prior to the application of the EMG electrodes. Patients and participants were positioned in a Biodex
System III Pro Isokinetic Dynamometer with their hips in 85° of flexion and their knees in 90° of flexion. The limb being assessed was secured to the arm of the dynamometer with a padded Velcro strap just proximal to the ankle joint. Straps were secured over the lap and trunk to minimize involvement of muscles other than the quadriceps during strength testing to determine 5% of the participant’s maximal voluntary isometric contraction (MVIC) to standardize quadriceps force production during TMS testing. (See 3.3.3 for detailed strength assessment methods.)

Participants wore a Lycra swim cap with a coordinate grid system mapped onto its surface to allow optimal positioning of the magnetic coil across testing paradigms. The center of the coordinate grid (0,0) was positioned such that the axes were centered over the scalp, bisecting the left and right hemispheres as measured from one external auditory meatus to the other, and bisecting the frontal plane half of the distance from the bridge of the nose to the external occipital protuberance. Using a double cone TMS coil, single-pulse magnetic stimuli set initially at 55% of machine output (2 Tesla maximum intensity) were delivered using a Magstim BiStim² starting at (0,0) and working over points in the direction of the hemisphere contralateral to the test limb. Two pulses were administered at each coordinate and the location that elicited the largest and most consistent motor evoked potential (MEP) amplitudes was designated as the site for subsequent stimulus delivery for the remainder of the TMS testing parameters for that limb.

Active Motor Threshold & Single Pulse Testing at 120% AMT
Active motor threshold (AMT) was determined next, defined as the lowest TMS intensity required to evoke measurable MEPs (peak-to-peak amplitude >100µV) in four out of 8 trials.\textsuperscript{72} For example, if five trials are positive for a given set of stimuli, the intensity was reduced for the next set. Participants were asked to maintain a quadriceps contraction at 5% of his/her previously determined MVIC as displayed on a monitor in front of the participant. After AMT was determined, one set of 8 single pulses at 120% of AMT was delivered. Average peak-to-peak MEP amplitudes from these stimuli were used to normalize paired-pulse data described below.\textsuperscript{73}

\textit{Paired-Pulse Testing}

Three paired-pulse testing paradigms were conducted: short interval intracortical inhibition (SICI), long interval intracortical inhibition (LICI), and intracortical facilitation (ICF). Paired-pulse testing involved the delivery of two consecutive stimuli, a subthreshold or suprathreshold conditioning stimulus, followed by a suprathreshold test stimulus.\textsuperscript{74} For each paradigm, the stimuli were separated by various inter-stimulus intervals. The parameters used in this study were selected based on paradigms used in several well-cited studies and are summarized below (Table 3.3.1).\textsuperscript{75-77}

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|l|}
\hline
Paradigm & Conditioning Stimulus & Test Stimulus & Inter-stimulus Interval \\
\hline
SICI & 80% AMT & 120% AMT & 3ms \\
ICF & 80% AMT & 120% AMT & 15ms \\
LICI & 120% AMT & 120% AMT & 100ms \\
\hline
\end{tabular}
\caption{Transcranial Magnetic Stimulation Paired-Pulse Parameters}
\end{table}

SICI: Short-interval intracortical inhibition; ICF: Intracortical Inhibition; LICI; Long-interval intracortical inhibition; AMT: active motor threshold; ms: milliseconds
For each paradigm, one set of 8 pairs of stimuli was delivered. During each paired stimulus, the participant was asked to maintain a quadriceps contraction of 5% of his/her MVIC. The MEPs were recorded and normalized to the raw MEP values evoked at 120% AMT and averaged for analysis.

3.3.2 Soleus Muscle Spinal Reflexive Excitability

Soleus muscle spinal reflexive excitability was assessed bilaterally with patients lying prone on a padded plinth with the legs extended and the knee slightly flexed, resting on a foam bolster. The collection site was shaved as necessary and debrided and cleaned with alcohol. Two 10-mm pre-gelled Ag-AgCl electrodes placed 1.75-mm apart were placed over the muscle belly of the soleus, over the midline of the distal third of the leg just distal to the musculotendinous junction of the gastrocnemius muscle. A self-adhesive, 2-inch round was placed over the distal quadriceps to serve as a dispersive electrode. The stimulus intensity was increased in increments of 0.2V until a maximal Hoffmann (H) reflex was observed, determined via peak-to-peak amplitude. Three maximal H-reflexes were recorded and averaged. We continued to increase the stimulus intensity until a maximal muscle (M) response was elicited or until the stimulus intensity was maximized. Three M-responses were recorded and averaged. H-reflexes were normalized to M-responses; the H:M ratio was utilized for our analyses.

3.3.3 Muscular Strength & Voluntary Activation

Maximal Voluntary Isometric Contractions

Quadriceps and hamstring maximal voluntary isometric contraction (MVIC) strength were measured using the Biodex System III Pro isokinetic dynamometer.
Patients were positioned in the dynamometer as previously described in section 3.3.2. For quadriceps strength, patients were given warm-up trials and were instructed to extend their leg into the padded stationary arm of the dynamometer at 25%, 50% and 75% of their perceived maximal effort. Next, patients were allowed practice trials at 100% of their maximal effort. All trials were separated by at least one-minute to prevent fatigue. Verbal encouragement was provided to the patient during all trials. Test trials were repeated until torque production no longer increased from the previous trial. Between 3-5 practice trials were performed for each participant. The same procedures were followed for hamstring strength, except that patients were instructed to pull their leg back into the padded stationary arm of the dynamometer. All torque measures were normalized to patient body mass (Nm/kg) for use in our final analyses.

**Voluntary Quadriceps Activation**

We utilized the burst superimposition technique to assess voluntary quadriceps activation and quantified activation using the central activation ratio. Two 7 x 13 cm self-adhesive Dura Stick II electrodes (Chattanooga Group, Hixson, TN, USA) were positioned on the distal vastus medialis and proximal vastus lateralis muscles. A square wave stimulator and a stimulus isolation unit delivered a 100ms train of 10 stimuli at 100 pulses per second with a pulse duration of 0.6 ms and a 0.01 ms pulse delay. These measures and parameters have previously been deemed reliable.

All patients and participants performed practice trials at 25%, 50% and 75% of their perceived maximal effort superimposed with 25%, 50% and 75% of the maximal 125 volts associated with the electrical stimulation. During the activation testing trials,
patients were instructed to extend their leg out into the padded arm of the dynamometer as hard as he or she should, reaching towards a target displayed on a monitor in front of him or her. Once the maximum torque was produced and started to decrease, the drop in torque production prompted an automated trigger for delivery of the 125V stimulus.

**3.3.4 Self-Reported Function**

All patients and participants completed a battery of patient-oriented questionnaires to quantify symptoms and function related to daily and sport related activities. (Appendices D-F)

*International Knee Documentation Committee (IKDC)*

The IKDC[^82] assess patient-oriented outcomes of symptoms and function in activities of daily living. Scores range from 0-100, with lower scores indicating greater symptoms and functional impairments.

*Knee injury and Osteoarthritis Outcome Score (KOOS)*

The KOOS[^83,84] is a patient-oriented questionnaire that assess the outcomes of: pain, symptoms, activities of daily living, sport and recreation function, and knee-related quality of life. The KOOS and each of its subscales is scored from 0-100, with lower scores indicating greater symptoms or functional limitations.

*Western Ontario Meniscus Evaluation Tool (WOMET)*

The WOMET[^85] is a disease-specific, health-related quality of life questionnaire for patients with meniscal pathology. The WOMET is scaled from 0-100 with higher scores indicating greater symptoms.

*Visual Analog Scale (VAS)*
A 10-cm visual analog scale was used to assess pain\textsuperscript{86} in the involved knee for all patients and participants at rest during the test session. Patients and participants were instructed to draw a vertical mark on the line corresponding to how much pain he or she was in at that time. The distance of the mark was measured from the left side (indicating no pain) in millimeters and converted to a percentage. Higher scores on the VAS indicated a greater sensation of pain in the involved knee.

3.3.5 Physical Function

We assessed physical function utilizing three separate tasks: 1) a stair climb test (SCT),\textsuperscript{87} 2) 30s chair stand test (30s-CST),\textsuperscript{87} and 3) total number of single-leg knee bends in 30 seconds (performed bilaterally).\textsuperscript{88} The order of the physical function tasks was randomly assigned prior to the start of the test session.

During the SCT patients started with both feet on level ground and were instructed to ascend one flight of 10 stairs, turn around and descend back to the starting position as quickly and safely as possible. A handrail was used as necessary for comfort. One trial was performed, and recorded in seconds.

For the 30s-CST task, patients were seated in a standard chair with the knees flexed to 90 degrees and instructed to keep their back flush up against the back of the chair. Patients were asked to cross their hands over their chest and to move from their seated position into a standing position, and to return back to the seated position, repeating this motion as quickly as possible for 30s. Practice moving through the motion of the task was permitted as necessary. The total number of 30s-CSTs completed during one-30s trial was recorded.
During the single-leg knee bend task, patients stood in front of a table with the knee in alignment with one leg of the table and their toes positioned against the edge of the leg of the table. Patients were instructed to bend their knee until they felt the front of the knee make contact with the table. Knee flexion was measured and their foot position was adjusted (distance from the edge of the leg of the table) until they reached 30-35 degrees of knee flexion. For this task, patients were instructed to balance on the test limb, using the top of the table for fingertip support only, and to bend their leg until they felt the front of the knee touch the leg of the table and then return to the starting upright position. Instructions were to repeat this motion as quickly as possible for 30s. The investigator visually inspected that the knee touched the leg of the table and recorded the total number of knee bends in a 30s period. The same test procedures were performed on the opposite limb.

3.4 Statistical Analyses

3.4.1 Demographic Data

Separate, two-tailed independent t-tests were performed to determine differences between the surgical and healthy groups on measures of age, height, mass, and BMI, and time since surgery. Significance was set a priori at P<0.05.

3.4.2 Specific Aim 1

Separate 2 x 2 (limb x group) analyses of variance (ANOVA) with repeated measures on limb were used to determine differences between the APM or repair limb and the uninvolved limb, and matched healthy controls for quadriceps intracortical excitability (SICI, LICI, ICF), soleus spinal reflexive excitability (H:M), quadriceps and
hamstring strength (Nm/kg) quadriceps to hamstring ratio (Q:H), voluntary quadriceps activation (CAR, %). In the event of significant interaction effects Tukey post-hoc tests were performed to determine where there were differences. Significance was determined a priori at P<0.05. Separate, two-tailed independent t-tests were performed to determine differences in self-reported and physical function outcomes between groups. Significance was also determined a priori at P<0.05.

3.4.3 Specific Aim 2

We assessed the normality of our data using skewness (normal distribution: absolute value > 1) and kurtosis (normal distribution: 3) statistics. For normally distributed outcome measure means, Pearson bivariate correlation analyses were performed to determine relations between neuromuscular function outcomes and physical function and self-reported patient outcomes in the surgical group only. For non-normal distribution of outcome measures, Spearman’s Rho correlation analyses were performed. Alpha level was set a priori at P <0.05. The magnitude of associations were defined as follows: 0.1-0.3 = weak, 0.3-0.5 = moderate, >0.5 = strong.
Chapter 4

Results

4.1 Demographics

A total of 31 patients and participants volunteered for our study (Table 4.1). The surgical group: APM (n=10) and meniscal repair (n=7), was significantly heavier than the healthy participants (n=14) and had significantly greater BMIs than the healthy participants. To account for these differences, analyses of covariance (ANCOVA) were performed with mass entered as the covariate variable.

4.2 Specific Aim 1

4.2.1 Neuromuscular Excitability

There were no differences between limbs or groups for quadriceps corticospinal and intracortical excitability (Table 4.2.1). There were also no differences between limbs or groups for soleus spinal reflexive excitability (4.2.1a). It should be noted that due to exclusionary criteria or immeasurable data, complete neuromuscular data could not be completed on 14/17 APM or meniscal repair patients and on 8/14 healthy participants.
4.2.2 Muscle Strength and Voluntary Activation

There were no differences between limbs or between groups for quadriceps and hamstring muscle strength, and quadriceps voluntary activation (Table 4.2.2).

4.2.3 Physical Function & Self-Reported Function

Patients after APM or meniscal repair performed significantly fewer repetitions of the 30s-CSTs, and took longer to complete SCT when compared to healthy controls. There was no difference in the number of single-leg knee bends between groups. Patients after APM or repair also consistently had greater self-reported impairments as assessed using the IKDC, KOOS, and WOMET scales, and had more pain at rest (VAS). (Table 4.2.3)

4.3 Specific Aim 2

4.3.1 Associations Between Involved Quadriceps Strength & Activation and Self-Reported Function

In the involved limb of the APM and meniscal repair group, there were significantly moderate to strong associations between quadriceps strength and all measures of self-reported function as assessed by the IKDC, KOOS, and WOMET scales (Appendices X-X). (Table 4.3.1) Absolute magnitudes of associations ranged from $\rho = 0.522$, to $\rho = 0.861$, such that with increased quadriceps strength there was greater self-reported function. It should be noted that the WOMET aggregate score is interpreted such that a greater number indicates better function whereas greater scores on the remaining
WOMET subscales indicate greater impairments. There were no significant associations between involved limb voluntary quadriceps activation and self-reported function.

**4.3.2 Associations Between Involved Quadriceps Strength & Activation, and Physical Function Tasks**

In the involved limb of the APM and meniscal repair group, there were significantly moderate to strong associations between quadriceps strength and physical function tasks of single-leg knee bends ($\rho = 0.807$), 30s-CSTs ($\rho = 0.848$), and SCT ($\rho = -0.674$). These results indicate that with increased quadriceps strength, patients after APM or repair performed a greater total number of repetitions in 30 seconds, or completed the SCT task faster than those with weaker quadriceps (Table 4.3.1). There were no significant associations between involved limb voluntary quadriceps activation and physical function tasks.
Chapter 5

Discussion

5.1 Major Findings

The major findings of this study were that 1) there were no statistically significant differences between limbs, or between groups for quadriceps corticospinal and intracortical excitability or for soleus spinal reflexive excitability; 2) there were no statistically significant differences between limbs or between groups for quadriceps and hamstring strength or for voluntary quadriceps activation; 3) APM or meniscal repair patients demonstrated significantly more self-reported disability and pain compared to healthy counterparts; 4) patients performed significantly fewer repetitions of the 30s-CSTs and were significantly slower to complete a SCT when compared to healthy counterparts, but did not perform differently in the total number of single-leg knee bends between limbs and compared to healthy counterparts; and 5) in APM or meniscal repair patients, greater involved limb quadriceps strength was significantly associated with better self-reported function, and better performance in physical function tasks.

5.2 Neuromuscular Excitability
The lack of differences between limbs or between groups is likely attributed to an underpowered sample population, particularly for the intracortical parameters. A proportion of our sample population (14/17 APM and 8/14 healthy) had a previous or current medical history that excluded them from completing the transcranial magnetic stimulation portion of our study, or, we were not able to acquire measureable data. In a previous study conducted in our lab we were unable to elicit measureable data from the quadriceps in only 2/57 patients.\(^90\) While we acknowledge a very small sample size (APM: n=3), it is important to point out that of the data we were able to obtain, there is a major lack of quadriceps facilitation. Paired-pulse parameters allow the study of intracortical inhibition and facilitation.\(^91\) The mean SICI value in the involved limb was 0.78, which is not suggestive of too much inhibition. A healthy population recently demonstrated a mean SICI value of 0.62.\(^48\) However; the average ICF value was 0.98. Finding ICF values less than 1 is an interesting finding because the ICF parameters are intended to stimulate facilitatory networks in the motor cortex. We would expect these values, therefore, to be closer to 2 than 1. Healthy people have previously exhibited ICF measures on average of 3.29.\(^48\) Yet, our values were less than 1 on average. Lower than expected ICF values may suggest plastic changes occurring in the primary motor cortex in patients after APM. Patients after APM had increased amounts of pain, which have recently been demonstrated to be associated with intracortical excitability in OA patients.\(^48\) Additionally, although there were no differences between groups in quadriceps voluntary activation, the healthy cohort did have low activation compared to previously established activation means\(^92\) in healthy population suggesting that the activation deficits
in the patients following APM may be underestimated in this particular study and may be moderated by the influence of pain on intracortical excitability and neuromuscular control. Because of the variability of neural excitability measures on inhibitory or facilitory networks, continued study in this area is necessary to better draw a conclusion on the associations of pain, excitability and muscle function. Alternatively, it is possible that both groups demonstrated lower values due to systematic error and therefore the between group differences may still be accurately represented.

Although not significantly different, the APM or repair group means exhibited greater soleus spinal reflexive excitability compared to their healthy counterparts. Previous studies\textsuperscript{54,55,93-96} have investigated the association between quadriceps and soleus neural excitability in patients after anterior cruciate ligament injury, animal, and simulated knee effusion models. These investigations demonstrated less excitability of the quadriceps musculature with concurrent greater excitability of the soleus muscle. It was hypothesized that this may be a compensatory strategy in an attempt to keep an upright posture and improve stability at the knee during movement. This is further supported by work in three-dimensional biomechanical computer models demonstrating that the quadriceps and gastrocnemius and soleus complex contribute to support and forward propulsion during normal walking gait.\textsuperscript{29,97,98} Therefore, this tendency for soleus excitability to be greater than healthy counterparts may be indicative of a potential compensatory strategy in APM populations, such that inhibited quadriceps function may influence projections in the soleus to upregulate activation in an attempt to ensure stiffening of the knee joint for support as well as optimizing propulsion to complete the
walking gait cycle. Previous studies\textsuperscript{99} have also demonstrated that although there were no differences in patients after meniscectomy compared to healthy controls in outcomes such as neuromuscular activity and muscular coactivation during walking gait and stair ascent, there were kinematic differences between the operative and non-operative limb, suggesting early modulations that may be representative of early signs of knee OA development that were not captured by the neuromuscular outcome measures utilized. Further research is necessary, including three-dimensional motion analyses during walking gait, to determine the association between neuromuscular function and walking biomechanics.

\textbf{5.3 Muscle Strength \& Quadriceps Activation}

There were no significant differences in quadriceps and hamstring strength, the quadriceps to hamstring ratio, or for quadriceps voluntary activation between limbs or between our APM or meniscal repair and healthy control groups. Contrary to our findings, previous investigators\textsuperscript{64,70,100,101} have reported differences in isometric and concentric quadriceps strength and activation between patients after APM and healthy controls. A systematic review\textsuperscript{21} from our laboratory reported inter-limb deficits with effects ranging from $d = -0.30$ to -8.04 at time points ranging from 2-weeks to 4-years post-surgery.\textsuperscript{7,16,18,20} Similar to our findings, however, Thorlund et al.\textsuperscript{102} found no differences in strength in patients 2-4 years after arthroscopic resection of degenerative menisci. Our patients following APM or meniscal repair were on average 3 years post-surgery, with approximately half of the cohort tested within one year of their surgery. Thorlund et al.\textsuperscript{62,102} performed follow-up examinations on knee extensor strength in
meniscectomy patients and while there were no changes in quadriceps strength longitudinally compared to a healthy population, there were inter-limb differences of 6% in quadriceps strength, which developed in between 2 and 4 years post-surgery. Quadriceps weakness has been hypothesized to be a precursor to the development of knee OA, thus inter-limb asymmetry of quadriceps strength at 4 years post surgery may be indicative of an initial progression of knee OA in the affected and weaker limb. It is possible that at the time of testing, a majority of our patients following APM had restored strength, but these may be expected to decrease as degeneration sets in. Differences in our results may be accounted for by differences in methodology (i.e. isometric v. isokinetic strength), population sample and demographics.

Although there was no difference between groups for voluntary quadriceps activation, it should be noted that our healthy cohort had, on average, less voluntary activation compared to previous work completed by our laboratory as well as other studies quantifying voluntary quadriceps activation in healthy cohorts. Future investigations may be necessary to determine any differences in our healthy cohort from other populations our laboratory has investigated. The standard deviation for voluntary activation for both groups was also large, indicating a lot of variability in our measures. We utilized an automated trigger with the burst superimposition technique thus these differences may be due to inherent variability in our healthy population, rather than instrumentation error or operator error. Differences may also be attributed to the anticipation of the burst superimposition stimulus and the discomfort associated with the stimulus delivery. Prior studies using an interpolated twitch technique have
demonstrated a decrease in torque production in patients who were anticipating a delivery of the noxious stimulus. The between limb differences in voluntary quadriceps activation were also non-significant; however, previous work\textsuperscript{109} have demonstrated that small changes in quadriceps voluntary activation predict changes in quadriceps strength, knee extensor moment and ground reaction forces during gait. The 5% difference observed in our APM cohort may still be significant in consequential alterations in movement strategies. However, we acknowledge that the inference that this small difference in voluntary activation in our APM limbs may have implication on strength, kinetics and kinematics, and physical function is speculative, given the lack of motion capture biomechanical data in this investigation.

There were no differences between limbs or between groups for hamstring strength. Prior studies\textsuperscript{7,18,65} have demonstrated similar results, revealing either no differences between limbs,\textsuperscript{18} or had recovered compared to the contralateral limb by 6-weeks.\textsuperscript{7,65} Because a majority of our patients were beyond 6-weeks post-surgery, it is possible that our patients had also restored hamstring strength by the time of the test session.

5.4 Physical & Self-Reported Function

For all measures of self-reported function, the APM group reported significantly greater impairments associated with symptoms, function, and overall quality of life. These outcomes are consistent with other pathological knee populations when compared to healthy controls. Interestingly, although there were no significant differences in quadriceps strength, measures of strength were significantly associated with self-reported
function. Associations between strength and self-reported function and physical activity have been demonstrated in knee OA populations such that muscular weakness is associated with greater reports of disability.\textsuperscript{110-113} There is currently no standard of care following APM. Patients may receive no formal rehabilitative progression or be referred for guided physical therapy,\textsuperscript{7,16,18,20} although the rehabilitation protocols vary greatly with little consensus on best approaches.\textsuperscript{69} In the case of an APM rather than a meniscal repair, anecdotally, patients may return back to activities of daily living once the incision sites have healed and are pain free with full knee joint range of motion. The associations we observed between strength and self-reported function suggests an explicit importance in the necessity to restore quadriceps strength following APM or meniscal repair to prevent disuse atrophy, and decreased physical activity that may result in increased weight gain, cardiovascular disease, and other co-morbidities associated with the development of knee OA.\textsuperscript{114} Associations between quadriceps strength and self-reported function also indicate a need for more thorough investigation on the effects of guided rehabilitation efforts following APM interventions in order to determine best practices for the management of post-surgical care in this population.

APM or repair patients also performed fewer repetitions of the 30s-CSTs in a 30-second period and were slower to perform a SCT task than their healthy counterparts. Differences in physical function performance were an interesting finding given there were no differences in muscular strength and activation between our cohorts. The 30s-CST and SCT are representative of commonly required tasks performed during activities of daily living. It is possible that there may be differences in performance due to
significantly different greater pain associated with the knee in our APM population. In the construct of our study, pain was not assessed after each of the physical performance tasks and is thus a limitation since we cannot infer that pain during the tasks was a direct contributor in the ability to complete the task, in addition to pain he/she might have had during rest. Additionally, it is possible that there may be differences in neuromuscular contributions to these movement strategies. As previously discussed we were not able to discern an association to neuromuscular function and physical function due to our limited sample sizes. There were no differences in single-leg knee bends between limbs or between APM and healthy cohorts. The tasks chosen for our investigation were determined based on previous studies utilizing the same or similar tasks in APM or osteoarthritic populations. The single-leg knee bend task in 30-seconds has previously been shown to be valid and have a good test-retest reliability. Performance of single-leg knee bends requires good neuromuscular control due to the demands of changing from concentric to eccentric contractions at the hip and knee musculature, and APM and knee OA patients performed worse during this task compared to healthy counterparts. Results of the current study were not consistent with these previous findings; however, there were no significant differences in thigh muscular strength and activation in our APM and healthy cohorts. It may be that the APM or meniscal repair cohort were equally as strong and had similar levels of neuromuscular control to their healthy counterparts. However, this does not account for differences observed in the 30s-CST or SCT. In both groups, the variability in the results was also high. Therefore, it may be that we did not have an adequate sample size in order to see a difference, if one truly exists. Lastly, of the three
physical function tasks, the single-leg knee bends are the least representative of activities performed throughout activities of daily living. Patients and participants may have been less familiar with neuromuscular and postural demands necessary to complete the task. It is possible that practice trials for the single-leg knee bends may be necessary to better familiarize participants with the task to ensure maximal effort was put forth during the test trials; however, the contributions to a lack of differences specifically for the single-leg knee bend task is unclear.

5.5 Associations Between Involved Quadriceps Strength & Activation, and Self-Reported Function

Moderate to strong associations were demonstrated between involved quadriceps strength and self-reported function, such that with greater quadriceps strength, APM patients had greater self-reported function. These findings are consistent with chronically disabled populations such as those with knee osteoarthritis, anterior cruciate ligament reconstruction, and chronic obstructive pulmonary disease. The APM cohort did have greater pain than our healthy controls and pain is known as a contributing factor to impaired voluntary muscle activation. Average pain at rest assessed via the Visual Analog Scale was 24/100 (range: 0 – 83), indicating that on average, patients were in a moderate amount of pain during their test session in our lab. Because quadriceps strength was negatively and moderately associated with pain at rest, it is possible that pain may be a driving source of impaired function during activities of daily living. Associations between pain and corticospinal resting motor threshold and intracortical facilitation in patients with knee OA have previously been demonstrated, suggesting that
pain influences neuromuscular control of the quadriceps.\textsuperscript{122} Patients who are weak and have greater self-reported limitations may be at risk for decreased levels of physical activity. Not only is a sedentary lifestyle related to the development of disease such as cardiovascular myopathy and diabetes, recent work has established that the inability to walk is strongly associated with mortality in patients with hip or knee osteoarthritis.\textsuperscript{123} The associations of quadriceps function and self-reported function and the lack of associations between quadriceps voluntary activation and function may also be suggestive of other influences on self-reported function that have yet to be identified. Our limited neuromuscular data prevent us from drawing conclusions on the contributions of neuromuscular alterations to self-reported outcome measures. Although we did not see associations between activation and physical activity this is an area for further research. In an osteoarthritic population, physical disability was worse in patients who had more quadriceps weakness with greater voluntary activation deficits than those who were weak with greater levels of activation.\textsuperscript{31} Previous work\textsuperscript{54} has demonstrated differences between corticospinal and spinal reflexive excitability in anterior cruciate ligament reconstructed populations compared to healthy controls as well as associations between corticospinal and spinal reflexive excitability.\textsuperscript{55} It is possible, therefore, that with a larger APM cohort, these differences and associations would have been observed.

5.6 Associations Between Involved Quadriceps Strength & Activation, and Physical Function

Similarly to the associations observed between involved limb quadriceps strength and self-reported function, there were moderate to strong associations related to
quadriceps strength and task performance to determine physical functional status. Greater quadriceps strength was associated with more single-leg knee bends performed, more 30s-CSTs performed, and quicker completion of a SCT. These results were also intuitive, as we hypothesized the APM group would not perform as well as our healthy cohort. While there was a significantly moderate positive correlation between quadriceps strength and the number of knee bends performed in our healthy participants (Figure 4.3.2), the association was not as strong, and there was no association between quadriceps strength and the number of 30s-CSTs performed and the time to complete the SCT. Equally interesting to the associations between strength and self-reported measures were that these associations appeared despite no between group differences in quadriceps muscle strength or voluntary activation. These tasks are similar to tasks patients would endure during activities of daily living and require good muscular function to ensure stability during changes from concentric to eccentric contractions required to complete the tasks. Another potential explanation for the association between strength and physical function may be related to the resection of the meniscal tissue. One of the primary roles of the knee menisci are to attenuate and distribute contact forces between the articulating surfaces in the tibiofemoral joint. Previous studies have demonstrated that with resection of meniscal tissue, contact area decreases, contact pressures increase, and stability of the knee decreases. These changes to the structure and potentially the healthy physiology of the knee joint may influence sensory information and neuromuscular control of the surrounding knee joint musculature. The associations between quadriceps strength and physical function tasks may be indicative of the role of the quadriceps
strength and neuromuscular control in tibiofemoral joint stability following APM or meniscal repair during activities of daily living that we were not able to capture by assessing strength during maximal voluntary isometric contractions alone. We acknowledge that this relation is difficult to discern with a lack of biomechanical data to support this hypothesis.

5.7 Limitations

This study was not without limitations. We recruited patients from both a single orthopedic surgeon from a local hospital (DS) as well as from the University community. However, we did not have access to medical records for patients recruited from the community. Therefore, we were not able to capture complete information related to the nature of the meniscal tear history (acute trauma versus degenerative), location of the tear, or the type of procedure performed for all patients enrolled in this study. While this allows our results to be generalized across these variables, the ability to parse out specific risk factors may be of valuable information in determining risk factors for hastened joint degeneration as well as formulating the best practices in individualized rehabilitation.

A large subset of both of our APM and healthy cohorts were unable to participate in neuromuscular excitability measures due to pre-existing medical conditions that placed them at greater risk for experiencing an adverse effect during testing procedures, or, we simply were not able to elicit measureable MEPs. It is acceptable to anticipate the inability to measure excitability in approximately 30% of patients.81 Of those who were able to safely test, 83% of APM patients and 57% of our healthy controls did not have recordable data.
5.8 Future Research

These limitations provide insight for the direction of future study. The results from our study serve as a valid foundation to continue to investigate an under-represented population in the literature. Considerations for future research include more stringent inclusion criteria for healthy populations to ensure that comparisons are made to cohorts that are more representative of a healthy, general population, such as exhibiting quadriceps strength that is consistent with previous studies’ definition of “normal” activation.\textsuperscript{92} Additionally, more extensive screening procedures may be necessary in order to capture excitability measures within both pathological and healthy populations. Lastly, future studies should consider biomechanical assessments of both kinematic and kinetic characteristics of APM populations. This information may further elucidate associations between strength and self-reported, and physical function tasks.

5.9 Clinical Implications

Although APM is frequently viewed as an ideal, non-invasive intervention for meniscal tears that allow for a quick return to activity, these data suggest that while there were no deficits in disease oriented outcomes of neuromuscular excitability, strength and quadriceps activation, patient-oriented limitations in self-reported function still exist. These self-reported limitations were demonstrated across a patient population that was as few as two-weeks to as many as 10.5 years post-surgical intervention. There is substantial evidence demonstrating the association between APM history and the development of knee OA as well as associations between strength and physical activity in people with osteoarthritis. The outcomes of our patients following APM or meniscal repair are
comparable to outcomes of thigh muscle strength and KOOS data reported by Thorlund et al.\textsuperscript{102} who suggested that there may be changes in muscle strength between years 2 and 4 post surgery that may be influential in the development of knee OA. Without three-dimensional motion capture data and more robust neuromuscular excitability measures, it is difficult to discern if this population of patients following APM are truly headed in a direction toward recovery, or if they may start to experience a decline as was observed in the Thorlund study.\textsuperscript{102} This study showed associations between muscle strength and self-reported impairments that may be influential in the amount of physical activity a person performs daily. Yet, there remains no standard of care for post-surgical APM rehabilitation. It may be of importance, then, for clinicians to consider the inclusion of self-reported objective measures in addition to disease oriented measures to individualize patient progress post-surgery and to understand the association between quadriceps strength and other factors related development of knee osteoarthritis such as knee pain. It will be imperative for clinicians to recognize these impairments over time and to intervene effectively and efficiently to minimize disability following knee joint injury or surgery, and additional research is critical in determining the best practices for management of patients following APM.

5.10 Summary & Conclusion

Patients after APM or repair, on average, did not exhibit differences in neuromuscular excitability, quadriceps strength, or quadriceps voluntary activation compared between limbs and to a healthy population. Despite no differences patients after APM reported greater pain and impairments during activities of daily living, sport
activities, and an overall decreased quality of life when compared to a healthy cohort. Additionally, quadriceps strength was moderately to strongly associated with better self-reported function and better physical performance of tasks similar to those encountered on a daily basis. Future research is necessary to determine the significance of these associations; however, clinical practices should consider the use of quadriceps strength assessments self-reported outcomes and physical function testing post-surgery to appreciate limitations that may not be captured via disease specific oriented information.
### Table 4.1: Patient & Participant Demographics: Mean (SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Mass (kg)*</th>
<th>BMI (kg/m²)*</th>
<th>Sex (%M/F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meniscectomy (n=17)</td>
<td>29.65 (11.42)</td>
<td>173.84 (10.98)</td>
<td>95.15 (27.48)</td>
<td>31.45 (7.91)</td>
<td>(65/35)</td>
</tr>
<tr>
<td>Healthy (n=14)</td>
<td>27.64 (10.20)</td>
<td>171.54 (9.94)</td>
<td>75.21 (15.96)</td>
<td>25.39 (3.97)</td>
<td>(57/43)</td>
</tr>
</tbody>
</table>

**BMI** = Body Mass Index; **M**=males; **F**=females; * = significantly greater mass and BMI in the meniscectomy group compared to the healthy group. Mass: $t_{(19)} = 2.398$, $P = 0.023$; BMI: $t_{(19)} = 2.602$, $P = 0.014$
<table>
<thead>
<tr>
<th>Group</th>
<th>INVOLVED SICI</th>
<th>UNINVOLVED SICI</th>
<th>Limb Main Effect</th>
<th>INVOLVED LICI</th>
<th>UNINVOLVED LICI</th>
<th>Limb Main Effect</th>
<th>INVOLVED ICF</th>
<th>UNINVOLVED ICF</th>
<th>Limb Main Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menisectomy</td>
<td>(n=3) 0.78 (0.53)</td>
<td>0.63 (0.55)</td>
<td>0.246</td>
<td>(n=2) 0.68 (0.05)</td>
<td>0.25 (0.21)</td>
<td>0.555</td>
<td>(n=3) 0.98 (0.36)</td>
<td>0.78 (0.26)</td>
<td>0.246</td>
</tr>
<tr>
<td>Healthy</td>
<td>(n=6) 0.59 (0.32)</td>
<td>0.54 (0.33)</td>
<td></td>
<td>(n=6) 0.40 (0.22)</td>
<td>0.54 (0.49)</td>
<td></td>
<td>(n=6) 1.33 (0.69)</td>
<td>1.11 (0.28)</td>
<td></td>
</tr>
<tr>
<td>Group Main Effect</td>
<td>0.284</td>
<td>0.907</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.292</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction Effect</td>
<td>0.943</td>
<td>0.137</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.882</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SICI = Short-interval Intracortical Inhibition; LICI = Long-interval Intracortical Inhibition; ICF = Intracortical Facilitation.
Table 4.2.1a. Comparisons of Soleus Spinal Reflexive Excitability: Means (SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>Involved Soleus H:M</th>
<th>Uninvolved Soleus H:M</th>
<th>Limb Main Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meniscectomy (n=13)</td>
<td>0.72 (0.13)</td>
<td>0.78 (0.11)</td>
<td>0.096</td>
</tr>
<tr>
<td>Healthy (n=13)</td>
<td>0.65 (0.23)</td>
<td>0.65 (0.22)</td>
<td></td>
</tr>
<tr>
<td>Group Main Effect</td>
<td>0.279</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interaction Effect</td>
<td>0.684</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

H:M = The ratio the Hoffman Reflex (H) maximal muscle response (M) wave amplitudes. There were no significant effects or interactions for soleus reflexive excitability.
<table>
<thead>
<tr>
<th>Group</th>
<th>Involved Quad (Nm/kg)</th>
<th>Uninvolved Quad (Nm/kg)</th>
<th>Between Limbs P-Value</th>
<th>Involved Hamstrings (Nm/kg)</th>
<th>Uninvolved Hamstrings (Nm/kg)</th>
<th>Between Limbs P-Value</th>
<th>Involved Q:H Ratio</th>
<th>Uninvolved Q:H Ratio</th>
<th>Between Limbs P-Value</th>
<th>Involved Quad Activation (% CAR)</th>
<th>Uninvolved Quad Activation (% CAR)</th>
<th>Between Limbs P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meniscectomy</td>
<td>(n=16) 2.13 (0.91)</td>
<td>2.36 (0.85)</td>
<td>F=0.002, P=0.961</td>
<td>(n=16) 0.89 (0.40)</td>
<td>0.97 (0.40)</td>
<td>F=0.947, P=0.340</td>
<td>(n=16) 2.62 (0.98)</td>
<td>2.51 (0.50)</td>
<td>F=0.060, P=0.961</td>
<td>(n=15) 0.79 (0.15)</td>
<td>0.84 (0.12)</td>
<td>F=0.670, P=0.421</td>
</tr>
<tr>
<td>Healthy</td>
<td>(n=14) 2.37 (0.65)</td>
<td>2.31 (0.49)</td>
<td>F=0.255, P=0.615</td>
<td>(n=12) 1.19 (0.28)</td>
<td>1.18 (0.23)</td>
<td>F=0.947, P=0.340</td>
<td>(n=12) 2.14 (0.39)</td>
<td>2.10 (0.31)</td>
<td>F=0.060, P=0.961</td>
<td>(n=13) 0.82 (0.09)</td>
<td>0.83 (0.09)</td>
<td>F=0.670, P=0.421</td>
</tr>
<tr>
<td>Between Group P-Value</td>
<td>F=1.957, P=0.173</td>
<td>F=2.149, P=0.155</td>
<td>F=0.319, P=0.577</td>
<td>F=0.319, P=0.577</td>
<td>F=3.731, P=0.060</td>
<td>F=0.746, P=0.396</td>
<td>F=1.662, P=0.209</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Quad = Quadriceps; Q:H = Quadriceps: Hamstrings; CAR = Central Activation Ratio; P-Values representative of analyses of covariance, with weight entered as the covariate. There were no significant interactions or main effects.
Table 4.2.3: Comparisons of Self-Reported Disability in Patients With and Without a History of Meniscectomy or Meniscal Repair: Mean % (SD)

<table>
<thead>
<tr>
<th>Questionnaire</th>
<th>Group:</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meniscectomy (n=17)</td>
<td>Healthy (n=14)</td>
</tr>
<tr>
<td>IKDC - Subjective</td>
<td>72.66 (21.73)</td>
<td>99.26 (1.89)</td>
</tr>
<tr>
<td>KOOS - Pain</td>
<td>77.94 (20.90)</td>
<td>100.00 (0.00)</td>
</tr>
<tr>
<td>KOOS - Symptoms</td>
<td>78.94 (19.02)</td>
<td>99.43 (1.45)</td>
</tr>
<tr>
<td>KOOS - ADLs</td>
<td>85.94 (16.88)</td>
<td>100.00 (0.00)</td>
</tr>
<tr>
<td>KOOS - Sport &amp; Rec</td>
<td>72.65 (29.11)</td>
<td>100.00 (0.00)</td>
</tr>
<tr>
<td>KOOS - QOL</td>
<td>68.53 (28.06)</td>
<td>100.00 (0.00)</td>
</tr>
<tr>
<td>WOMET - Physical Function</td>
<td>22.46 (26.22)</td>
<td>0.43 (0.94)</td>
</tr>
<tr>
<td>WOMET - Sport, Rec, Work Life</td>
<td>32.80 (28.73)</td>
<td>0.29 (0.74)</td>
</tr>
<tr>
<td>WOMET - Emotions</td>
<td>36.88 (36.39)</td>
<td>0.47 (0.94)</td>
</tr>
<tr>
<td>WOMET - Aggregate Score</td>
<td>71.61 (27.59)</td>
<td>99.60 (0.87)</td>
</tr>
<tr>
<td>Involved Knee Pain - VAS</td>
<td>24.41 (29.93)</td>
<td>2.29 (3.05)</td>
</tr>
</tbody>
</table>

IKDC = International Knee Documentation Committee, Subjective Evaluation Form; KOOS = Knee Injury and Osteoarthritis Outcome Score, Survey Subscales; ADLs = Activities of Daily Living. WOMET = Western Ontario Meniscal Evaluation Tool. Higher percentages on the IKDC, KOOS, and WOMET Aggregate indicate greater levels of function. For WOMET subscales, higher percentages indicate greater self-reported impairments. VAS = Visual Analog Scale. * = for all subscales, the meniscectomy group had significantly decreased levels of function compared to the healthy group.
<table>
<thead>
<tr>
<th>Involved Quadricep</th>
<th>IKDC</th>
<th>KOOS - Pain</th>
<th>KOOS - Symptoms</th>
<th>KOOS - ADLs</th>
<th>KOOS - Sport/Rec</th>
<th>KOOS - QOL</th>
<th>WOMET - Phys Function</th>
<th>WOMET - Emotions</th>
<th>WOMET - Sport/Rec</th>
<th>WOMET - Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ρ=0.783**</td>
<td>ρ=0.789**</td>
<td>ρ=0.781**</td>
<td>ρ=0.522*</td>
<td>ρ=0.772**</td>
<td>ρ=0.861**</td>
<td>ρ=0.836**</td>
<td>ρ=0.843**</td>
<td>ρ=0.875**</td>
<td></td>
</tr>
<tr>
<td>Involved Knee Bends</td>
<td>Uninvolved Knee Bends</td>
<td>STS</td>
<td>Involved Pain at Rest</td>
<td>Uninvolved Pain at Rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ρ=0.807**</td>
<td>ρ=0.703**</td>
<td>ρ=0.848**</td>
<td>ρ=0.674**</td>
<td>ρ=0.519*</td>
<td>ρ=0.500*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IKDC = International Knee Documentation Committee; KOOS = Knee injury & Osteoarthritis Outcomes Score; WOMET = Western Ontario Meniscal Evaluation Tool. ** = P < 0.001; * = P < 0.05
<p>| Table 4.3.2 Associations Between Quadriceps Strength and Self-Reported Function, and Physical Function in Healthy Participants |
|--------------------------------------------------|----------|----------|----------|----------|----------|----------------|----------------|----------------|----------------|</p>
<table>
<thead>
<tr>
<th>IKDC</th>
<th>KOOS - Pain</th>
<th>KOOS - Symptoms</th>
<th>KOOS - ADLs</th>
<th>KOOS - Sport/Rec</th>
<th>KOOS - QOL</th>
<th>WOMET - Phys Function</th>
<th>WOMET - Emotions</th>
<th>WOMET - Sport/Rec</th>
<th>WOMET - Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Involved Quadriceps</td>
<td>$\rho=0.456$</td>
<td>n/a</td>
<td>-0.101</td>
<td>n/a</td>
<td>n/a</td>
<td>$\rho=-0.535^*$</td>
<td>$\rho=-0.505$</td>
<td>$\rho=-0.562$</td>
<td>$\rho=0.537^*$</td>
</tr>
<tr>
<td>Involved Knee Bends</td>
<td>$\rho=0.564^*$</td>
<td>$\rho=0.515$</td>
<td>$\rho=0.252$</td>
<td>$\rho=-0.504$</td>
<td>$\rho=-0.100$</td>
<td>$\rho=-0.098$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uninvolved Knee Bends</td>
<td>STS</td>
<td>Stair Climb</td>
<td>Involved Pain at Rest</td>
<td>Uninvolved Pain at Rest</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

IKDC = International Knee Documentation Committee; KOOS = Knee injury & Osteoarthritis Outcomes Score; WOMET = Western Ontario Meniscal Evaluation Tool. $^* = P < 0.05; ^{**} = P < 0.001$
References


Appendix A

Adult Research Subject Information and Consent Form
ADULT RESEARCH SUBJECT INFORMATION AND CONSENT FORM

Musculoskeletal/Neuromuscular Outcomes following Arthroscopic Meniscectomy or Meniscal Repair

Principal Investigator: Abbey Thomas PhD ATC

Other Staff (identified by role): Michelle McLeod MA ATC (Co-Investigator)
Adam Lepley MA, ATC
David Sohn MD/JD (Co-Investigator)

Contact Phone number(s): (419) 530-2764

What you should know about this research study:

• We give you this consent/authorization form so that you may read about the purpose, risks, and benefits of this research study. All information in this form will be communicated to you verbally by the research staff as well.

• Routine clinical care is based upon the best-known treatment and is provided with the main goal of helping the individual patient. The main goal of research studies is to gain knowledge that may help future patients.

• We cannot promise that this research will benefit you. Just like routine care, this research can have side effects that can be serious or minor.

• You have the right to refuse to take part in this research, or agree to take part now and change your mind later.

• If you decide to take part in this research or not, or if you decide to take part now but change your mind later, your decision will not affect your routine care.

• Please review this form carefully. Ask any questions before you make a decision about whether or not you want to take part in this research. If you decide to take part in this research, you may ask any additional questions at any time.

• Your participation in this research is voluntary.

PURPOSE (WHY THIS RESEARCH IS BEING DONE)
You are being asked to take part in a research study that looks at different outcomes following knee joint (meniscus) surgery. The purpose of the study is to examine a multitude of outcomes pertaining to how the muscles around your knee work, how you move, and how you feel your knee is performing during different tasks. You were selected as someone who may want to take part in this study because you have recently suffered a meniscal injury to one of your knees which requires surgery,
or you are a healthy adult without a previous history of knee injury. There will be approximately 100 people participating in this study at the University of Toledo.

DESCRIPTION OF THE RESEARCH PROCEDURES AND DURATION OF YOUR INVOLVEMENT

If you decide to take part in this study, you will be asked to report to the Musculoskeletal Health and Movement Science Laboratory in the Health Science and Human Services building (Room 1409), which is located on the Main Campus of the University of Toledo. You will be asked to come in a total of 3 to 5 times which will correspond with your physician appointments or status as a healthy participant. The time points are as follows: time point 1: pre-physical therapy, if referred, time point 2: baseline(healthy participant)/prior to surgery, time point 3: post-surgery physician appointment (10-14 days post-surgery), time point 4: 6-week follow-up, time point 5: 3-month follow-up). We will work with you and the physician’s office to schedule these appointments when you schedule your follow-ups to meet with Dr. Sohn. Please remember that you can stop participating at any time. If you enroll now and choose not to participate in any of the follow-up appointments, it will not affect your medical care from the physician.

During the sessions, you will be asked to fill out knee injury questionnaires about how your knee feels during different activities. We will also test the neural function of both legs using 3 different methods. These methods include muscle activation testing, reflex testing and motor cortex testing. After neural testing, we will assess how you function during a knee bending task, and your knee joint motion will be recorded during a simple stair-walking task. Each session will last approximately 2 hours in length.

Knee Injury Questionnaires – Time Points 1-5

You will be asked to provide us information regarding your previous history of any joint injury, current and past level of activity and how your joint injury currently affects you during different activities.

Muscle Activation Testing – Time Points 1-5

You will be asked to stand near the testing chair and two electrodes will be placed on your thigh. One of the electrodes will be placed above your knee and the other will be given to you to place below your hips so that it lies flat when you are sitting. The electrodes will be held in place with an elastic bandage as necessary. These electrodes will be used to deliver a brief, mild electrical current to your thigh muscles. The electrical current will last approximately half of a second and will contract your thigh muscle for that half second.

You will be asked to sit in a chair that resembles a car seat. A seat belt will be secured over your lap and shoulders to minimize movement while you contract your leg muscles as hard as you can. You will be asked to extend your leg as hard as you can and hold it for five seconds. While you are extending out, the electrical current will be delivered to your thigh. This stimulus feels slightly more intense than a static electric shock experienced from walking across a carpet in a dry room and then touching a doorknob, although the voltage is much lower. You will be asked to repeat this a total of four times for each leg during each session. You will be given 1 minute of rest in between each repetition.

Reflex Testing – Time Points 1-5

This testing provides an estimate of how well nerves in the lower leg function. You will be instructed to lie on a table. You will have sticky electrodes placed on your thigh. These electrodes are called EMG electrodes that stand for electromyography which is a recording of
electrodes are called EMG electrodes that stand for electromyography which is a recording of the electrical activity in skeletal muscle. The area of the EMG electrode application will be shaved and cleaned with alcohol. A separate electrode that delivers a small electrical current will be taped to the front of your hip. Several measurements of your legs will be taken while you are lying down on a treatment table.

- These measurements include delivery of a 1-millisecond electrical current.
- The intensity of this electrical current will vary depending on the measurement being observed.
- The electrical current delivered in this study feels slightly more intense than that of static electricity felt when touching a doorknob after walking across a carpet, although the voltage is much lower.

**Motor Cortex Testing – Time Points 1-5**

This testing provides us important information regarding how your brain is sending messages to muscles in your legs. You will be asked to sit in the same chair as above with your arms crossed at your chest. We will position a coil over your head and adjust the position of the coil until it is in the correct spot. We will ask you to wear a bathing cap and ear plugs. A brief magnetic stimulus will then be produced which will sound like a “click.” You will not have any associated pain or discomfort in your head, but rather may feel a brief muscle contraction in the muscles of your leg or thigh. You will be asked to flex certain leg muscles at a small to moderate intensity while we provide a series of brief magnetic stimuli to your head.

**Motion Analysis Testing**

**Stair Walking: Time Points 1-5**

This testing provides us information on how your joints are moving in relationship to the rest of your body. You will have small, round reflective markers placed on different landmarks of your leg. You will be asked to walk up and down a small set of stairs for a total of 6 times up and 6 times down while motion cameras record your movement. **Note:** Stair Walking will be omitted from testing Time Point 3 if you have a meniscal repair, per instructions by your physician.

**Assessment of Knee Function**

**30 Second Knee Bend Test: Time Points 1-5**

This test provides us information on how well you knee functions with the physical task bending your knee. You will be asked to stand with your foot aligned with a line on the floor and your toes up against a second line. The examiner will provide fingertip support for balance and will ask you to bend down, without bending at the hip, until your knee comes in contact with a mark on a pole. You will rise back from this point and repeat the task. We will record the total number of knee bends you can complete in 30 seconds. **Note:** Knee bends will be omitted from testing Time Point 3 if you have a meniscal repair, per instructions by your physician.

**Timed Sit-to-Stand**

You will be asked to sit in a chair and from sitting position rise to a standing position without using your arms. You will then return to a seated position and repeat the sit-to-stand task. We will record the number of sit-to-stands you can complete in 30 seconds. **Note:** Knee bends will
be omitted from testing Time Point 3 if you have a meniscal repair, per instructions by your physician.

Timed Stair Climb
You will be asked to go up and down one flight of stairs as quickly and safely as you can. We will time, in seconds how long it takes you to complete going up and down one flight of stairs.

RISKS AND DISCOMFORTS YOU MAY EXPERIENCE IF YOU TAKE PART IN THIS RESEARCH

**Likely Risks**
- Mild discomfort for a very brief period during the electrical stimulation.
- Mild transient muscle soreness from muscle activation testing.

**Less Likely Risks**
- Mild, transient skin irritation from the sticky electrodes.

**Very Unlikely Risks**
- Mild, transient headache following magnetic stimulation
- In people with a history of seizures there is a slight possibility of causing a seizure with the magnetic stimulation; therefore you must tell us prior to testing if you have ever had a seizure so we can exclude you from the study.
- Re-injury to the surgically repaired knee joint

RISKS TO UNBORN CHILDREN
It is unknown how the electrical stimulation used in this study would affect an unborn fetus; therefore, if you are pregnant you will not be allowed to participate in this study.

POSSIBLE BENEFIT TO YOU IF YOU DECIDE TO TAKE PART IN THIS RESEARCH
We cannot and do not guarantee or promise that you will receive any benefits from this research.

COST TO YOU FOR TAKING PART IN THIS STUDY
You are not directly responsible for making any type of payment to take part in this study. However, you are responsible for providing the means of transportation to the Musculoskeletal Health and Movement Sciences Laboratories. You will not be compensated for gas for travel or any other expenses to participate in this study.

ALTERNATIVE(S) TO TAKING PART IN THIS RESEARCH
The only alternative is not to participate in this study.

CONFIDENTIALITY - (USE AND DISCLOSURE OF YOUR PROTECTED HEALTH INFORMATION)
By agreeing to take part in this research study, you give to The University of Toledo (UT), the Principal Investigator and all personnel associated with this research study your permission to use or disclose health information that can be identified with you that we obtain in connection with this study. We will use this information for the purpose of conducting the research study as described in the research consent/authorization form.
The information that we will use or disclose includes history of knee joint injury, activity level, and strength or muscle activation measurements. We may use this information ourselves, or disclose this information as part of a research study. Under some circumstances, the Institutional Review Board and Research and Sponsored Programs of the University of Toledo may review your information for compliance audits. We may also disclose your protected health information when required by law, such as in response to judicial orders.

The University of Toledo is required by law to protect the privacy of your health information, and to use or disclose the information we obtain about you in connection with this research study only as authorized by you in this form. There is a possibility that the information we disclose may be re-disclosed by the persons we give it to, and no longer protected. However, we will encourage any person who receives your information from us to continue to protect and not re-disclose the information.

Your permission for us to use or disclose your protected health information as described in this section is voluntary. However, you will not be allowed to participate in the research study unless you give us your permission to use or disclose your protected health information by signing this document.

You have the right to revoke (cancel) the permission you have given to us to use or disclose your protected health information at any time by giving written notice to Michelle McLeod MA, ATC, Mail Stop 119, 2801 W. Bancroft St. Toledo, OH 43606. However, a cancellation will not apply if we have acted with your permission, for example, information that already has been used or disclosed prior to the cancellation. Also, a cancellation will not prevent us from continuing to use and disclose information that was obtained prior to the cancellation as necessary to maintain the integrity of the research study.

Except as noted in the above paragraph, your permission for us to use and disclose your protected health information will stop at the end of the research study. A more complete statement of University of Toledo’s Privacy Practices is set forth in its Joint Notice of Privacy Practices. If you have not already received this Notice, a member of the research team will provide this to you. If you have any further questions concerning privacy, you may contact the University of Toledo’s Privacy Officer at 419-383-3413.

IN THE EVENT OF A RESEARCH-RELATED INJURY
In the event of injury resulting from you taking part in this study, treatment can be obtained at a health care facility of your choice. You should understand that the costs of such treatment will be your responsibility. Financial compensation is not available through The University of Toledo or The University of Toledo Medical Center. By signing this form, you are not giving up any of your legal rights as a research subject. In the event of an injury, contact Michelle McLeod MA, ATC (419) 530-2764.

VOLUNTARY PARTICIPATION
Taking part in this study is voluntary. You may refuse to participate or discontinue participation at any time without penalty or a loss of benefits to which you are otherwise entitled. If you decide not to participate or to discontinue participation, your decision will not affect your future relations with the University of Toledo or The University of Toledo Medical Center.

NEW FINDINGS
You will be notified of new information that might change your decision to be in this study if any becomes available.
## OFFER TO ANSWER QUESTIONS

Before you sign this form, please ask any questions on any aspect of this study that is unclear to you. You may take as much time as necessary to think it over. If you have questions regarding the research at any time before, during or after the study, you may contact: Michelle McLeod MA, ATC (419) 530-2764

If you have questions beyond those answered by the research team or your rights as a research subject or research-related injuries, please feel free to contact the Chairperson of the University of Toledo Biomedical Institutional Review Board at 419-383-6796.

## SIGNATURE SECTION (Please read carefully)

YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES THAT YOU HAVE READ THE INFORMATION PROVIDED ABOVE, YOU HAVE HAD ALL YOUR QUESTIONS ANSWERED, AND YOU HAVE DECIDED TO TAKE PART IN THIS RESEARCH.

BY SIGNING THIS DOCUMENT YOU AUTHORIZE US TO USE OR DISCLOSE YOUR PROTECTED HEALTH INFORMATION AS DESCRIBED IN THIS FORM.

The date you sign this document to enroll in this study, that is, today’s date, MUST fall between the dates indicated on the approval stamp affixed to the bottom of each page. These dates indicate that this form is valid when you enroll in the study but do not reflect how long you may participate in the study. Each page of this Consent/Authorization Form is stamped to indicate the form’s validity as approved by the UT Biomedical Institutional Review Board (IRB).

<table>
<thead>
<tr>
<th>Name of Subject (please print)</th>
<th>Signature of Subject or Person Authorized to Consent</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relationship to the Subject (Healthcare Power of Attorney authority or Legal Guardian)</td>
<td>Time</td>
<td>p.m.</td>
</tr>
<tr>
<td>Name of Person Obtaining Consent (please print)</td>
<td>Signature of Person Obtaining Consent</td>
<td>Date</td>
</tr>
<tr>
<td>Name of Witness to Consent Process (when required by ICH Guidelines) (please print)</td>
<td>Signature of Witness to Consent Process (when required by ICH Guidelines)</td>
<td>Date</td>
</tr>
</tbody>
</table>

YOU WILL BE GIVEN A SIGNED COPY OF THIS FORM TO KEEP.
Appendix B

Child Research Subject Assent Form
CHILD RESEARCH SUBJECT ASSENT FORM

MUSCULOSKELETAL/NEUROMUSCULAR OUTCOMES FOLLOWING ARTHROSCOPIC MENISCETOMY OR MENISCAL REPAIR

Principal Investigator: Abbey Thomas PhD, ATC (419-530-4467)
Other Investigators: Michelle McLeod MA ATC (Co-Investigator)
Adam Lepley MA ATC (Co-Investigator)
David Sohn MD/JD (Co-Investigator)

You are being asked to be in a study to help understand people better.

You should ask any questions you have before making up your mind. You can think about it and discuss it with your family or friends before you decide.

It is okay to say “No” if you don’t want to be in the study. If you say “Yes” you can change your mind and then quit the study at any time without any problems.

We are doing a research study about how the muscles around your knee work, how you move, and how you feel your knee is performing during different tasks. A research study is a way to learn more about people with knee injuries. If you decide that you want to be part of this study, you will be asked to report to the Musculoskeletal Health and Movement Science (MHMS) Laboratory in the Health Science and Human Services building (Room 1409), which is located on the Main Campus of the University of Toledo. You will be asked to come in up to a total of 5 times which will be scheduled near the same times as your doctor appointments. The time points are as follows: time point 1: before physical therapy, only if you are given instructions for physical therapy, time point 2: baseline/before surgery, time point 3: after-surgery, near your doctor’s appointment (10-14 days after surgery), time point 4: 6-weeks after surgery, time point 5: 3-months after surgery). We will work with you and the doctor’s office to schedule these appointments when you schedule your follow-ups to meet with Dr. Sohn. Please remember that you can stop participating at any time. If you are a healthy participant, you will be invited to participate in time points 2-5, although you will not be receiving any surgery or needing appointments with a doctor. If you enroll now and choose not to participate in any of the follow-up test-sessions, it will not affect your medical care.

During the sessions, you will be asked to fill out knee injury questionnaires about how your knee feels during different activities. We will also test the strength of both legs and your knee joint motion will be recorded during a simple stair-walking task and a squatting task. Each session will last approximately 2 hours in length.

Knee Injury Questionnaires – Time Points 1-5
We will ask you to tell us information about any joint injuries you have had in the past. We will also ask you about current and past amounts of activity and how your joint injury affects you during different activities such as walking, running, and jumping.

Reflex Testing – Time Points 1-5
This testing provides an estimate of how well nerves in the lower leg are functioning. You will be asked to lie on your back on a table. You will have sticky electrodes placed on your thigh and lower leg that measure normally occurring electrical activity in the muscle. The area where the electrodes will be placed will be shaved and cleaned with alcohol. An electrode that delivers a small electrical sensation will be taped to the front of your hip. Measurements will be taken on your leg while you are lying down.

• These measurements include delivery of a very short electrical current.
• The intensity of this current will vary depending on the reflex being measured.
• The electrical sensation will feel slightly stronger than static electricity felt as you touch a door knob after walking across a carpet.

**Muscle Activation and Strength Testing – Time Points 1-4**

You will be asked to sit near the testing chair and two electrodes will be placed on your thigh. One electrode will be placed above your knee and the other will be given to you to place below your hips so that it lies flat when you are sitting. The electrodes will be held in place with an elastic bandage. These electrodes will be used to deliver a brief, mild electrical current to your thigh muscles. The electrical sensation will last about a half of a second and will contract your thigh muscle and then relax.

You will be asked to sit in a chair that resembles a car seat. You will put on a seat belt over your lap and over both shoulders so that you do not move as you are contracting your leg muscles as hard as you can. You will be asked to push your leg out as hard as you can five seconds. While you are pushing your leg out, the electrical current will be delivered to your thigh. This sensation feels slightly stronger than a static electric shock that you could get from walking across a carpet in a dry room and then touching a doorknob. You will be asked to repeat this for a total of four times on each leg during each session. You will be given 1 minute of rest in between each repetition.

**Motion Analysis Testing**

**Stair Walking: Time Points 1-4**

This testing provides us information on how your joints are moving while walking up and down stairs. You will have small, round reflective markers placed on different parts of your legs, hips, and upper body. You will be asked to walk up and down a short set of stairs 6 times up and 6 times down while cameras record your movement.

**Knee Function Testing**

**30 Second Knee Bend: Time Points 1-4**

This testing will provide us information on how well your knee functions during bending on one knee. You will be asked to line up your foot and toes with lines on the floor while the examiner helps with balance. You will be asked to bend your knee until your knee touches a pole and then come back up to the start position. We will record how many times you can bend on one knee in 30 seconds.

**Timed Sit-to-Stand**

You will be asked to sit in a chair and from sitting position rise to a standing position without using your arms. You will then return to a seated position and repeat this motion. We will record the number of sit-to-stands you can complete in 30 seconds.

**Timed Stair Climb**

You will be asked to go up and down one flight of stairs as quickly and safely as you can. We will time how many seconds it takes you to go up and down one flight of stairs.

There are minimal risks for participating in this study, including possible muscle soreness from muscle strength testing and a very unlikely risk of re-injury to the surgically repaired knee joint during motion testing.

Not everyone who takes part in this study will benefit. A benefit means that something good happens to you. We cannot and do not guarantee or promise that you will receive any benefits from this research.

When we are finished with this study we will write a report about what was learned. This report will not include your name or say that you were in the study.

If you have any questions about the study, you can ask Michelle McLeod or one of the other investigators. You can call the investigator(s) listed at the top of this page if you have a question at any time.

If you are female, you cannot participate if you are pregnant. You should not become pregnant while you are in this study because we do not know if the study could hurt the baby.
You do not have to be in this study if you do not want to. You can decide later if you want to think about it for awhile. If you decide to be in this study, please print and sign your name below.

I, ________________________________, want to be in this research study.

(Print your name here)

Sign your Name: ___________________________ Date: ___________________________

Name of Person Explaining Assent (Print)

Signature of Person Explaining Assent ___________________________ Date ______________

I attest that I or my representative discussed this study with the above-named participant.

Signature of Principal Investigator or Sub-Investigator ___________________________ Date ______________
Appendix C

Parent/Guardian Research Subject Informed Consent Form
PARENT/GUARDIAN RESEARCH SUBJECT - INFORMED CONSENT FORM

MUSCULOSKELETAL/NEUROMUSCULAR OUTCOMES FOLLOWING ARTHROSCOPIC MENISCECTOMY OR MENISCAL REPAIR

Principal Investigator: Abbey Thomas PhD, ATC

Other Staff (identified by role): Michelle McLeod, MA ATC (Co-Investigator)
Adam Lepley MA ATC (Co-Investigator)
David Sohn, MD/JD (Co-Investigator)

Contact Phone number(s): (419) 530-2764

What you should know about this research study:

• We give you this consent/authorization form so that you may read about the purpose, risks, and benefits of this research study. All information in this form will be communicated to you and your teenaged son/daughter verbally by the research staff as well.

• Routine clinical care is based upon the best-known treatment and is provided with the main goal of helping the individual patient. The main goal of research studies is to gain knowledge that may help future patients.

• We cannot promise that this research will benefit your teenaged son/daughter. Just like routine care, this research can have side effects that can be serious or minor.

• Your teenaged son/daughter has the right to refuse to take part in this research, or agree to take part now and change his/her mind later.

• If your teenaged son/daughter decides to take part in this research or not, or if your teenaged son/daughter decides to take part now but change his/her mind later, their decision will not affect their routine care.

• Please review this form carefully. Ask any questions before making a decision about whether or not you want your teenaged son/daughter to take part in this research. If your teenaged son/daughter decides to take part in this research, please ask any additional questions at any time.

• Your teenaged son/daughter’s participation in this research is voluntary.

PURPOSE (WHY THIS RESEARCH IS BEING DONE)

Your teenaged son/daughter is invited to participate in the research project entitled Musculoskeletal/Neuromuscular Outcomes following Arthroscopic Meniscectomy or Meniscal Repair, which is being conducted at the University of Toledo under the direction of Dr. Abbey Thomas and Dr. David Sohn. The purpose of this study is to examine how
the muscles around your child's knee work, how he/she moves, and how he/she feels his/her knee performs during different tasks. We will be enrolling a maximum of 100 participants in this research study.

**DESCRIPTION OF THE RESEARCH PROCEDURES AND DURATION OF YOUR AND YOUR CHILD'S INVOLVEMENT**

If you decide to let your **teenaged son/daughter** take part in this study, you will be asked to accompany him/her to the Musculoskeletal Health and Movement Science Laboratories in the Health Science and Human Services building (Room 1409), which is located on the Main Campus of the University of Toledo. You and your child will be asked to attend a total of 4 to 5 separate sessions which will correspond with his/her physician appointments. The time points are as follows: time point 1: pre-physical therapy, if referred, time point 2: baseline/prior to surgery, time point 3: post-surgery physician appointment (10-14 days post-surgery), time point 4: 6-week follow-up, time point 5: 3-month follow-up). We will work with you (parent/guardian, and child) and the physician's office to schedule these appointments when you schedule your follow-ups to meet with Dr. Sohn. Please remember that your child may discontinue participation at any time. If you decide to let your child enroll now and he/she chooses later not to participate in any of the follow-up appointments, it will not affect his/her medical care from the physician. If your child is a healthy volunteer, you will be asked to accompany your child to test sessions 2-5. Your child may also choose to discontinue participation as a healthy volunteer at anytime, without penalty.

During the sessions, your child will be asked to fill out knee injury questionnaires about how his/her knee feels during different activities. We will also test the strength of both legs and, how many knee bends he/she can perform, and his/her knee joint motion will be recorded during a simple stair-walking task. Each session will last approximately 2 hours in length.

**Knee Injury Questionnaires – Time Points 1-5**
Your child will be asked to provide us information regarding his/her previous history of joint injury, current and past level of activity and how his/her joint injury currently affects him/her during different activities.

**Reflex Testing – Time Points 1-5**
This testing provides an estimate of how well nerves in the lower leg are functioning. Your child will be instructed to lie on a table. He/she will have sticky electrodes placed on his/her thigh. These electrodes are called EMG electrodes that stand for electromyography, which is a recording of the electrical activity in skeletal muscle. The area of the EMG electrode placement will be shaved and cleaned with alcohol in order to obtain the best recording. A separate electrode that delivers an electrical current will be taped to the front of your child’s hip. A number of measurements will be taken from muscles of the leg while your child is lying down on a treatment table.
- These measurements include delivery of a 1-millisecond electrical current.
- The intensity of this current will vary depending on the measurement being observed.
- The electrical current delivered feels slightly stronger than static electricity felt when touching a door knob after walking across a carpet.

**Muscle Activation and Strength Testing – Time Points 1-5**
Your child will be asked to stand near the testing chair and two electrodes will be placed on his/her thigh. One of the electrodes will be placed above the knee and the other will be given to your child to be placed below his/her hip so that it lies flat when he/she is sitting. The electrodes will be held in place with an elastic bandage as necessary. These electrodes will be used to deliver a brief, mild electrical stimulus to the thigh muscles. The electrical current will last approximately half of a second and will contract the thigh muscle for that half second.

Your child will be asked to sit in a chair that resembles a car seat. A seat belt will be secured over the lap and shoulders to minimize movement as your child is contracting his/her thigh muscles as hard as
Your child will be asked to sit in a chair that resembles a car seat. A seat belt will be secured over the lap and shoulders to minimize movement as your child is contracting his/her thigh muscles as hard as possible. Your child will be asked to push his/her leg as hard as he/she can for five seconds. While pushing out, the electrical current will be delivered to the thigh. This stimulus feels slightly stronger than a static electric shock that you could get from walking across a carpet in a dry room and then touching a doorknob, although the voltage is lower. Your child will be asked to repeat this for a total of four times on each leg during each session. He/she will be given one minute of rest in between each repetition.

**Motion Analysis Testing**

**Stair Walking: Time Points 1-5** This testing provides us information on how your child’s joints move. He/she will have small, round reflective markers placed on different landmarks of the legs, hips, and upper body. He/she will be asked to walk up and down a short set of stairs for a total of 6 times up and 6 times down while cameras record his/her movement. **Note: Stair Walking will be omitted from testing Time Point 3 if your child has a meniscal repair, per instructions by your child’s physician.**

**Assessment of Knee Function**

**30 Second Knee Bend: Time Points 1-5** This test provides us information on how well your child’s knee functions during bending on one knee. He/she will be asked to stand with his/her foot and toes aligned with a line on the floor. The examiner will provide fingertip support for balance and will ask your child to bend down, without bending at the hip, until the knee comes in contact with a mark on a pole. He/she will rise back from this point and repeat the task. We will record the total number of knee bends he/she can complete in 30 seconds. **Note: Knee bends will be omitted from testing Time Point 3 if your child has a meniscal repair, per instructions by your child’s physician.**

**Timed Sit-to-Stand**

Your child will be asked to sit in a chair and from sitting position rise to a standing position without using his/her arms. He/she will then return to a seated position and repeat the sit-to-stand task. We will record the number of sit-to-stands completed in 30 seconds. **Note: Knee bends will be omitted from testing Time Point 3 if your child has a meniscal repair, per instructions by your child’s physician.**

**Timed Stair Climb**

Your child will be asked to go up and down one flight of stairs as quickly and safely as possible. We will time how many seconds it takes to complete going up and down one flight of stairs. **Note: Knee bends will be omitted from testing Time Point 3 if your child has a meniscal repair, per instructions by your child’s physician.**

**RISKS AND DISCOMFORTS YOU MAY EXPERIENCE IF YOU TAKE PART IN THIS RESEARCH**

**Likely Risks**

- Mild, transient skin irritation from hypoallergenic gel, adhesive tape, or self-adhesive electrodes.
- Mild, transient muscle soreness from muscle activation and strength testing.
- Headache following transcranial magnetic stimulation

**Very Unlikely Risks**

- Re-injury to the surgically repaired meniscus.
POSSIBLE BENEFIT TO YOU IF YOU DECIDE TO TAKE PART IN THIS RESEARCH

We cannot and do not guarantee or promise that your teenaged son/daughter will receive any benefits from this research.

CONFIDENTIALITY - (USE AND DISCLOSURE OF YOUR PROTECTED HEALTH INFORMATION)

By agreeing to allow your teenaged son/daughter to take part in this research study, you, the parent or guardian, give to The University of Toledo (UT), the Principal Investigator and all personnel associated with this research study your permission to use or disclose health information that can be identified with your teenaged son/daughter that we obtain in connection with this study. We will use this information for the purpose of conducting the research study as described in the research consent/authorization form.

The information that we will use or disclose includes history of knee joint injury, activity level, and strength or muscle activation measurements. We may use this information ourselves, or we may disclose or provide access to the information as part of a research study. Under some circumstances, the Institutional Review Board and Research and Sponsored Programs of the University of Toledo may review your information for compliance audits. We may also disclose your protected health information when required by law, such as in response to judicial orders.

The University of Toledo is required by law to protect the privacy of your health information, and to use or disclose the information obtained about you or your teenaged son/daughter in connection with this research study only as authorized by you in this form. There is a possibility that the information we disclose may be re-disclosed by the persons we give it to, and no longer protected. However, we will encourage any person who receives your information from us to continue to protect and not re-disclose the information.

Your permission for us to use or disclose your teenaged son/daughter protected health information as described in this section is voluntary. However, your teenaged son/daughter will not be allowed to participate in the research study unless you give us your permission to use or disclose your teenaged son/daughter protected health information by signing this document.

You have the right to revoke (cancel) the permission you have given to us to use or disclose your teenaged son/daughter’s protected health information at any time by giving written notice to Michelle McLeod MA, ATC, MS119 2801 W. Bancroft St. Toledo, OH, 43606. However, a cancellation will not apply if we have acted with your permission, for example, information that already has been used or disclosed prior to the cancellation. Also, a cancellation will not prevent us from continuing to use and disclose information that was obtained prior to the cancellation as necessary to maintain the integrity of the research study.

Except as noted in the above paragraph, your permission for us to use and disclose your teenaged son/daughter’s protected health information will stop at the end of the research study.

A more complete statement of University of Toledo’s Privacy Practices is set forth in its Joint Notice of Privacy Practices. If you have not already received this Notice, a member of the research team will provide this to you. If you have any further questions concerning privacy, you may contact the University of Toledo’s Privacy Officer at 419-383-3413.

IN THE EVENT OF A RESEARCH-RELATED INJURY

In the event of injury resulting from your teenaged son/daughter taking part in this study, treatment can be obtained at a health care facility of your choice. You and your teenaged son/daughter should understand that the costs of such treatment will be your responsibility. Financial compensation is not available through The University of Toledo or The University of Toledo.
Medical Center. By signing this form your teenaged son/daughter is not giving up any of his/her legal rights as a research subject. In the event of an injury, contact Michelle McLeod MA, ATC (419) 530-2764

VOLUNTARY PARTICIPATION
You or your teenaged son/daughter’s refusal to participate in this study will involve no penalty or loss of benefits to which your teenaged son/daughter is otherwise entitled and will not affect your/his/her relationship with The University of Toledo. In addition, you or your teenaged son/daughter may discontinue participation at any time without any penalty or loss of benefits. Taking part in this study is completely your and your teenager's choice. You can withdraw your permission for your teenaged son/daughter to be in this study at any time for any reason. The data already collected will be included in the study. Your teenaged son/daughter will no longer receive any study compensation. This will not affect your teenaged son/daughter’s chance for other treatment. Your teenaged son/daughter will be treated as usual.

NEW FINDINGS
You will be notified of new information that might change your decision regarding your teenaged son/daughter involvement in this study if any becomes available.

OFFER TO ANSWER QUESTIONS
Before you sign this form, please ask any questions on any aspect of this study that is unclear to you. You may take as much time as necessary to think it over. If you have questions regarding the research at any time before, during or after the study, you may contact Michelle McLeod MA, ATC (419) 530-2764

If you have questions beyond those answered by the research team or your rights as a research subject or research-related injuries, please feel free to contact the Chairperson of the University of Toledo Biomedical Institutional Review Board at 419-383-6796.

SIGNATURE SECTION (Please read carefully)
YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES THAT YOU HAVE READ THE INFORMATION PROVIDED ABOVE, YOU HAVE HAD ALL YOUR QUESTIONS ANSWERED, AND YOU HAVE DECIDED TO TAKE PART IN THIS RESEARCH.

BY SIGNING THIS DOCUMENT YOU AUTHORIZE US TO USE OR DISCLOSE YOUR PROTECTED HEALTH INFORMATION AS DESCRIBED IN THIS FORM.

The date you sign this document to enroll in this study, that is, today’s date, MUST fall between the dates indicated on the approval stamp affixed to the bottom of each page. These dates indicate that this form is valid when you enroll in the study but do not reflect how long you may participate in the study. Each page of this Consent/Authorization Form is stamped to indicate the form’s validity as approved by the UT Biomedical Institutional Review Board (IRB).
<table>
<thead>
<tr>
<th>Name of Subject (please print)</th>
<th>Signature of Subject or Person Authorized to Consent</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relationship to the Subject (Healthcare Power of Attorney authority or Legal Guardian)</td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td>Name of Person Obtaining Consent (please print)</td>
<td>Signature of Person Obtaining Consent</td>
<td>Date</td>
</tr>
<tr>
<td>Name of Witness to Consent Process (when required by ICH Guidelines) (please print)</td>
<td>Signature of Witness to Consent Process (when required by ICH Guidelines)</td>
<td>Date</td>
</tr>
</tbody>
</table>

YOU WILL BE GIVEN A **SIGNED** COPY OF THIS FORM TO KEEP.
Appendix D

International Knee Documentation Committee
Subjective Form
2000 IKDC SUBJECTIVE KNEE EVALUATION FORM

Your Full Name: ____________________________

Today's Date: ______/_____/______ Date of Injury: ______/_____/______

**SYMPTOMS**:
*Grade symptoms at the highest activity level at which you think you could function without significant symptoms, even if you are not actually performing activities at this level.*

1. What is the highest level of activity that you can perform without significant knee pain?
   - [ ] Very strenuous activities like jumping or pivoting as in basketball or soccer
   - [ ] Strenuous activities like heavy physical work, skiing or tennis
   - [ ] Moderate activities like moderate physical work, running or jogging
   - [ ] Light activities like walking, housework or yard work
   - [ ] Unable to perform any of the above activities due to knee pain

2. During the past 4 weeks, or since your injury, how often have you had pain?

   Never 10 9 8 7 6 5 4 3 2 1 0 Constant

3. If you have pain, how severe is it?

   No pain 10 9 8 7 6 5 4 3 2 1 0 Worst pain imaginable

4. During the past 4 weeks, or since your injury, how stiff or swollen was your knee?
   - [ ] Not at all
   - [ ] Mildly
   - [ ] Moderately
   - [ ] Very
   - [ ] Extremely

5. What is the highest level of activity you can perform without significant swelling in your knee?
   - [ ] Very strenuous activities like jumping or pivoting as in basketball or soccer
   - [ ] Strenuous activities like heavy physical work, skiing or tennis
   - [ ] Moderate activities like moderate physical work, running or jogging
   - [ ] Light activities like walking, housework, or yard work
   - [ ] Unable to perform any of the above activities due to knee swelling

6. During the past 4 weeks, or since your injury, did your knee lock or catch?
   - [ ] Yes  [ ] No

7. What is the highest level of activity you can perform without significant giving way in your knee?
   - [ ] Very strenuous activities like jumping or pivoting as in basketball or soccer
   - [ ] Strenuous activities like heavy physical work, skiing or tennis
   - [ ] Moderate activities like moderate physical work, running or jogging
   - [ ] Light activities like walking, housework or yard work
   - [ ] Unable to perform any of the above activities due to giving way of the knee
SPORTS ACTIVITIES:

8. What is the highest level of activity you can participate in on a regular basis?

☐ Very strenuous activities like jumping or pivoting as in basketball or soccer
☐ Strenuous activities like heavy physical work, skiing or tennis
☐ Moderate activities like moderate physical work, running or jogging
☐ Light activities like walking, housework or yard work
☐ Unable to perform any of the above activities due to knee

9. How does your knee affect your ability to:

<table>
<thead>
<tr>
<th></th>
<th>Not difficult at all</th>
<th>Minimally difficult</th>
<th>Moderately difficult</th>
<th>Extremely difficult</th>
<th>Unable to do</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Go up stairs</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>b. Go down stairs</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>c. Kneel on the front of your knee</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>d. Squat</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>e. Sit with your knee bent</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>f. Rise from a chair</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>g. Run straight ahead</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>h. Jump and land on your involved leg</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>i. Stop and start quickly</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
</tbody>
</table>

FUNCTION:

10. How would you rate the function of your knee on a scale of 0 to 10 with 10 being normal, excellent function and 0 being the inability to perform any of your usual daily activities which may include sports?

FUNCTION PRIOR TO YOUR KNEE INJURY:

<table>
<thead>
<tr>
<th>Couldn’t perform daily activities</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>No limitation in daily activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td></td>
</tr>
</tbody>
</table>

CURRENT FUNCTION OF YOUR KNEE:

<table>
<thead>
<tr>
<th>Cannot perform daily activities</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>No limitation in daily activities</th>
</tr>
</thead>
</table>
Appendix E

Knee Injury and Osteoarthritis Outcomes Score (KOOS)
KOOS KNEE SURVEY

Today's date: ____/_____/____ Date of birth: ____/_____/____

Name: ________________________________

INSTRUCTIONS: This survey asks for your view about your knee. This information will help us keep track of how you feel about your knee and how well you are able to perform your usual activities. Answer every question by ticking the appropriate box, only one box for each question. If you are unsure about how to answer a question, please give the best answer you can.

Symptoms
These questions should be answered thinking of your knee symptoms during the last week.

S1. Do you have swelling in your knee?
   Never       Rarely       Sometimes       Often       Always
   □           □            □               □            □

S2. Do you feel grinding, hear clicking or any other type of noise when your knee moves?
   Never       Rarely       Sometimes       Often       Always
   □           □            □               □            □

S3. Does your knee catch or hang up when moving?
   Never       Rarely       Sometimes       Often       Always
   □           □            □               □            □

S4. Can you straighten your knee fully?
   Always      Often        Sometimes      Rarely      Never
   □           □            □               □            □

S5. Can you bend your knee fully?
   Always      Often        Sometimes      Rarely      Never
   □           □            □               □            □

Stiffness
The following questions concern the amount of joint stiffness you have experienced during the last week in your knee. Stiffness is a sensation of restriction or stiffness in the ease with which you move your knee joint.

S6. How severe is your knee joint stiffness after first wakening in the morning?
   None        Mild         Moderate      Severe      Extreme
   □           □            □               □            □

S7. How severe is your knee stiffness after sitting, lying or resting later in the day?
   None        Mild         Moderate      Severe      Extreme
   □           □            □               □            □
**Pain**

P1. How often do you experience knee pain?

<table>
<thead>
<tr>
<th>Never</th>
<th>Monthly</th>
<th>Weekly</th>
<th>Daily</th>
<th>Always</th>
</tr>
</thead>
</table>

What amount of knee pain have you experienced the last week during the following activities?

P2. Twisting/pivoting on your knee

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

P3. Straightening knee fully

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

P4. Bending knee fully

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

P5. Walking on flat surface

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

P6. Going up or down stairs

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

P7. At night while in bed

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

P8. Sitting or lying

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

P9. Standing upright

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

**Function, daily living**

The following questions concern your physical function. By this we mean your ability to move around and to look after yourself. For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

A1. Descending stairs

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>

A2. Ascending stairs

<table>
<thead>
<tr>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
</table>
For each of the following activities, please indicate the degree of difficulty you have experienced in the last week due to your knee.

<table>
<thead>
<tr>
<th>Activity</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>A3. Rising from sitting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A4. Standing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A5. Bending to floor/pick up an object</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A6. Walking on flat surface</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A7. Getting in/out of car</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A8. Going shopping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A9. Putting on socks/stockings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A10. Rising from bed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A11. Taking off socks/stockings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A12. Lying in bed (turning over, maintaining knee position)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A13. Getting in/out of bath</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A14. Sitting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A15. Getting on/off toilet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For each of the following activities please indicate the degree of difficulty you have experienced in the last week due to your knee.

A16. Heavy domestic duties (moving heavy boxes, scrubbing floors, etc)

- None □
- Mild □
- Moderate □
- Severe □
- Extreme □

A17. Light domestic duties (cooking, dusting, etc)

- None □
- Mild □
- Moderate □
- Severe □
- Extreme □

Function, sports and recreational activities

The following questions concern your physical function when being active on a higher level. The questions should be answered thinking of what degree of difficulty you have experienced during the last week due to your knee.

SP1. Squatting

- None □
- Mild □
- Moderate □
- Severe □
- Extreme □

SP2. Running

- None □
- Mild □
- Moderate □
- Severe □
- Extreme □

SP3. Jumping

- None □
- Mild □
- Moderate □
- Severe □
- Extreme □

SP4. Twisting/pivoting on your injured knee

- None □
- Mild □
- Moderate □
- Severe □
- Extreme □

SP5. Kneeling

- None □
- Mild □
- Moderate □
- Severe □
- Extreme □

Quality of Life

Q1. How often are you aware of your knee problem?

- Never □
- Monthly □
- Weekly □
- Daily □
- Constantly □

Q2. Have you modified your lifestyle to avoid potentially damaging activities to your knee?

- Not at all □
- Mildly □
- Moderately □
- Severely □
- Totally □

Q3. How much are you troubled with lack of confidence in your knee?

- Not at all □
- Mildly □
- Moderately □
- Severely □
- Extremely □

Q4. In general, how much difficulty do you have with your knee?

- None □
- Mild □
- Moderate □
- Severe □
- Extreme □

Thank you very much for completing all the questions in this questionnaire.
Appendix F

Western Ontario Mensical Evaluation Tool (WOMET)
Section A
Physical Symptoms

INSTRUCTIONS TO PATIENTS

The following questions concern the physical symptoms you have experienced due to your knee problem. In all cases, please enter the amount of the symptom you have experienced in the last week. (Please mark your answers with a slash ‘/’)

1. How much have you been bothered by a feeling of giving way or insecurity in your knee?
   not at all ___________________________ extremely bothered

2. How much are you bothered by pain or soreness in your knee after activities?
   not at all ___________________________ extremely bothered

3. How much have you been bothered by a loss of range of motion in your knee?
   not at all ___________________________ extremely bothered

4. How much have you been bothered by numbness in and around your knee?
   not at all ___________________________ extremely bothered

5. How much have you been bothered by stiffness in your knee after rising in the morning or sitting for a long period of time?
   not at all ___________________________ extremely bothered

6. How much are you bothered by weakness in your knee?
   not at all ___________________________ extremely bothered

Section A cont’d

7. How much are you bothered by swelling in your knee?
Section B
Sports/Recreation/Work/Lifestyle

INSTRUCTIONS TO PATIENTS

The following section concerns how your knee problem has affected your work, sports, or recreational activities in the past week. For each question, please indicate the amount with a slash "/" across the horizontal line.

10. How much do you fear reinjuring your knee through a return to your sport or work?

not at all / extremely fearful

11. How much has your knee affected the amount of time you can participate in your pre-injury activities?

not at all / extremely affected

12. How much has your knee affected your ability to perform the specific skills required for your sport or work? (If both are affected consider the area that is the most affected).

not at all / extremely affected

13. How much of a problem do you have squatting?

none / extreme problems
Section C
Emotions

INSTRUCTIONS TO PATIENTS
The following questions relate to how you have felt in the past week with regard to your knee problem. Please indicate your answer with a slash / across the horizontal line.

14. How conscious are you of your knee?
not at all ______________________ extremelty conscious

15. How worried are you about what will happen to your knee in the future?
not at all ______________________ extremelty worried

16. How much frustration or discouragement do you feel because of your knee?
none ________________________________________________ extreme

Thank you for completing the questionnaire