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EFFECT OF A 12-WEEK HOME-BASED NEUROMUSCULAR ELECTRICAL STIMULATION TREATMENT ON CLINICAL OUTCOMES FOLLOWING ARTICULAR CARTILAGE KNEE SURGERY

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EFFECT OF A 12-WEEK HOME-BASED NEUROMUSCULAR ELECTRICAL
STIMULATION TREATMENT ON CLINICAL OUTCOMES FOLLOWING
ARTICULAR CARTILAGE KNEE SURGERY

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Health Sciences
at the University of Kentucky

By

Caitlin Elizabeth Whale Conley

Co-Directors: Dr. Carl G. Mattacola, Professor in the College of Health Sciences

and Dr. Anne D Olson, Associate Professor in the College of Health Sciences

Lexington, Kentucky

2017

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ABSTRACT OF DISSERTATION

EFFECT OF A 12-WEEK HOME-BASED NEUROMUSCULAR ELECTRICAL STIMULATION TREATMENT ON CLINICAL OUTCOMES FOLLOWING ARTICULAR CARTILAGE KNEE SURGERY

Articular cartilage defects in the knee are common, and can result in pain, decreased function and decreased quality of life. Untreated defects are considered to be a risk factor for developing osteoarthritis, a progressive degenerative joint disease with minimal treatment options. To address these issues, various surgical procedures are available to treat articular cartilage defects in the knee. While these procedures overall have positive results, after surgery patients experience large and persistent deficits in quadriceps strength. A contributing factor to this post-surgical weakness is believed to be the extended post-operative non-weight bearing period, with full weight bearing not initiated until approximately 4 – 6 weeks after surgery. During this non-weight bearing period a minimal amount of demand is placed upon the muscle. Subsequently, the quadriceps muscle undergoes a large degree of atrophy with a significant decrease in muscle strength. Muscular strength deficits reduce the knee joint stability, also increasing the risk of osteoarthritis development. Interventions that can be used to facilitate quadriceps strength while protecting the articular cartilage repair are needed. Neuromuscular electrical stimulation (NMES) is an effective post-knee surgery rehabilitation technique to regain quadriceps musculature. In recent years manufacturers have been developing knee sleeve garments integrated with NMES allowing for portability of the NMES treatment.

The primary aim of this study was to evaluate the effectiveness of a 12-week home-based neuromuscular electrical stimulation treatment on post-surgical clinical outcomes (quadriceps strength, lower extremity function, and patient reported outcomes) after articular cartilage knee surgery. Patients were randomized between a standard of care home-treatment group and a NMES home-treatment group. Patients completed isometric quadriceps strength testing, the Y-balance test, and the Knee Injury and Osteoarthritis Outcome Score (KOOS) before surgery and at 3-months after surgery. The secondary aims of this study were to determine the most effective NMES parameters for post-surgical quadriceps strength; and to develop a framework to identify factors that may influence a patient's adherence to a prescribed therapy program.

From our results we can make several conclusions. First, we found only a small number of studies utilize similar parameters for post-surgical quadriceps strength treatments. The majority of the parameters reported in the literature were highly variable between studies. Second, clinicians can utilize the expanded Health Belief Model to identify situational and personal factors unique to a patient that may impact adherence to a prescribed treatment. Clinicians can then implement the proposed interventional strategies to address the identified situational and personal factors. Finally, there was no difference in quadriceps strength, lower extremity function, or self-reported scores at 3-month between a home-based NMES treatment and a standard of care home-based treatment. Patients' adherence to the treatment protocols may have been a major factor contributing to these results. Utilizing a model, such as the proposed expanded Health Belief Model, may assist clinicians in improving a patients' adherence to future prescribed home-treatment programs.

KEYWORDS: Autologous Chondrocyte Implantation, Osteochondral Allograft, Quadriceps Strength, Patient Reported Outcomes, Adherence

Caitlin E Whale Conley

April 17th, 2017

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Chapter 1: Introduction

Background

Articular cartilage, comprised of hyaline cartilage, is a connective tissue lining the bone ends of diarthrodial joints. During joint loading articular cartilage provides a lubricating surface to reduce friction.¹ The cartilage has a smooth, white, and shiny appearance that is firm when palpated inter-operatively.¹ The tissue is devoid of vascular supply, nerves, or lymphatic drainage. Thus, the ability to heal itself when damaged is severely diminished.^{1,2}

Patients with articular cartilage defects frequently present with pain, swelling, and mechanical symptoms.³ However, reported symptoms between patients are inconsistent or simply absent making diagnosis problematic.⁴ Articular cartilage injuries are commonly diagnosed through patient history, physical examination, and imaging (x-rays and magnetic resonance imaging).⁵ While the previously listed diagnostic techniques are helpful in a diagnosis, arthroscopic evaluation is currently considered the gold standard for evaluating possible articular cartilage injuries.⁴

Articular cartilage defects are common with 60-66% of patients undergoing an arthroscopic surgery documented to have the presence of a lesion.^{4,6-8} The articular surface of the patella and the medial femoral condyle had the largest percentage of documented lesions.^{4,6-8} In this study, the size of the lesions highly varied from less than 0.5cm² to greater than 4cm.^{4,6} Patients found to have lesions were overall younger in age with an average age around 40 years old.^{6,7} Furthermore, a large percentage (34%) of patients were between the ages of 21 – 30yrs. A higher prevalence (61.6-66%) of lesions was seen in males compared to females.^{6,7}

Articular cartilage lesions are classified based upon structural characteristics of the defect. The Outerbridge classification and the ICRS scales are two common grading scales utilized when evaluating articular cartilage.^{5,9,10} While the Outerbridge classification may be more widely utilized the ICRS scale may provide a more complete description of the defect.⁵ Both classification systems are scaled from 1 to 4, however the ICRS scale includes subset distinctions.^{9,10} The ICRS scale expands upon the characteristics originally included in the Outerbridge scale to include the depth of the lesion (Table 1.1).⁹ The majority of lesions found during arthroscopic evaluations were classified as either an Outerbridge classification grade II,⁶ Outerbridge classification grade III⁷ or an ICRS classification grade⁴. According to the ICRS classification a grade III or larger would be considered to be a full thickness lesion requiring a repair or restoration procedure.^{8,11} If the defect is not treated patients are left with a defect in their knee that resembles a pothole in a highway. Furthermore, lesions left untreated have been found to be a risk factor for increasing the progression of Osteoarthritis (OA).¹²⁻¹⁴

Table 1.1: International Cartilage Repair Society (ICRS) articular cartilage defect grading scale^{9,10}

Grade	Property
0	Normal cartilage
1	Superficial lesions, fissures and cracks, soft indentation
2	Fraying, lesions extending down to <50% of cartilage depth
3	Partial loss of cartilage thickness, cartilage defects extending down >50% of cartilage depth as well as down to calcified layer
4	Complete loss of cartilage thickness, bone on

Osteoarthritis is a progressive degenerative joint disease estimated to impact 31 approximately million people.¹⁵ Currently there are few treatment options available to

address OA. Currently, intra-articular injections and surgical joint replacements are the most common options. Examples of surgical joint replacement procedures frequently implemented are total knee replacements, unicondylar replacements, or patellofemoral arthroplasties. In patients over 45 years of age, it is estimated that over 600,000 total knee replacements are performed a year.¹⁵ In 2007 the total estimated cost of total knee arthroplasty surgeries performed was \$9.2 billion.¹⁶ While these surgical procedures are successful in treating end-stage OA they have limited longevity and are frequently reserved for older individuals. Thus, limited treatment options are available for younger individuals.

Cartilage repair and restoration procedures are available to decrease the risk of early OA progression and the symptoms associated with a cartilage defect. Surgical treatments for articular cartilage lesions vary from marrow stimulating techniques (microfracture), to cell-based treatment (ACI or particulated juvenile tissue), to osteochondral transplantation (allograft and autograft). The decision regarding which surgical technique is appropriate is based on multiple factors such as size, depth, and location of the lesion. Additionally, surgeons take into consideration what surgical treatment will not be detrimental if further cartilage surgeries are required. The treatment algorithm frequently applied begins with a marrow stimulating technique for smaller more shallow lesions and progresses to other cartilage treatments such as cell-based treatments or osteochondral allografts.¹⁷ Osteochondral allograft transplantation procedures are considered the last salvage procedure available if prior repairs to the articular cartilage fail.¹⁸ However, this procedure is also implemented if the patient initially presents with a large and deep lesion involving the subchondral bone.¹⁸

Nevertheless, all the procedures aim to restore the articular cartilage surface with a cartilage-like or donor cartilage material. Ultimately the goal is to delay a patient's need for further knee surgery, such as a total knee replacement.

The success of different cartilage surgical procedures has mainly been documented through procedure survival rates and patient reported outcomes.^{19,20} Patient reported outcomes (PROs) are questionnaires regarding surgical outcomes that are completed by the patients. Patient reported outcomes provide a subjective report on outcomes that are valued by the patient (such as function, quality of life, and pain) after a surgical procedure. Patient reported outcome (PRO) instruments provide clinicians a method to evaluate outcomes after knee surgery in a method that is noninvasive and easily administered.

Common PROs in the cartilage literature vary from knee specific to general health forms to activity scales. Examples of knee specific PROs are: the Knee Injury and Osteoarthritis Outcome Score (KOOS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), International Knee Documentation Committee Subjective Knee Form (IKDC), Lysholm Scale, and the Cincinnati Knee Score.²¹ Examples of general health PROs are: The Medical Outcomes Study Short-Form 12 or 36 items (SF-12, SF-36), the Veterans RAND 12 or 36 Health Survey (VR-23, VR-36), and the EuroQoL-5 Dimensions (EQ-5D).²¹ Examples of activity scales are: Tegner activity score or the Marx activity rating scale.²¹ Many of these instruments (the KOOS, IKDC, WOMAC, Lysholm, and SF-36 to name a few) have been validated and are reliable in the articular cartilage population.²²⁻²⁵

Additionally, clinicians can use PROs to document a patient's progression over time after surgery. Specifically, clinicians can focus on a PRO's responsiveness, the ability of a instrument to detect changes over time.^{26,27} The responsiveness of an instrument can be reported with statistical approaches such as effect size, minimal detectable change, and minimally clinically important differences calculations.²⁸ Minimally clinically important difference (MCID) is an approach that can assist a clinician in determining if the change that occurred is clinically meaningful to the patient.²⁹ Interestingly, the responsiveness of a PRO will vary between PRO instruments and can vary between surgical population.³⁰ Thus, it is important for clinicians to be familiar with the PRO instrument implemented and the patient population being treated.

In the articular cartilage population the IKDC, Lysholm, KOOS, SF-36 PCS, and the Modified Cincinnati Knee Rating System (MCKRS) have been found to be overall responsive.³¹ More specifically, the IKDC and the Lysholm have been found to be the most responsive, defined by the large effect sizes across all time points, in patients undergoing an autologous chondrocyte implantation (ACI).³¹ When comparing the IKDC and KOOS instruments in a varied sample of articular cartilage patients both were found to include questions important to articular cartilage patients.³² The International Knee Documentation Committee Subjective Knee Form (IKDC) is an 18 item knee specific questionnaire that measures symptoms, function, and sport activity.^{33,34} The KOOS is a 42-question knee-specific questionnaire comprised of 5 individual subscales: Pain (9 items), Symptoms (7 items), Activities of Daily Living (ADL) (17 items), Sport and Recreation (5 items), and Knee-Related Quality of Life (QOL) (4 items).^{35,36} The IKDC was found to have a slight advantage over the KOOS in symptoms and functional

disability.³² However, the ability of the KOOS to provide information on specific constructs represented in the subscales is a benefit not achievable with the IKDC.^{21,31} When focusing on the 5 KOOS subscales rather than the individual questions of the KOOS the sports/recreation subscale and the quality of life subscale were both found to be important to patients and include events frequently experienced by patients.³² Additionally, the sport/recreation and quality of life subscales have been found to be the most responsive KOOS subscales in articular cartilage patients.³⁷

Cartilage surgery outcomes are positive when measured by patient reported outcomes; however evaluating how a patient is actually able to perform functional tasks or produce muscle strength has had minimal focus. Over the last 10 years there has been an increased focus on patients' strength and function after articular cartilage surgery³⁸ with the largest upsurge occurring in the past 6 years. This research, in addition to the PRO research, is critical for illustrating a complete picture of patients' outcomes after articular cartilage surgery.

Surprisingly, the picture that has become apparent related to regaining strength and function after such articular cartilage procedures is that, while improvements have been seen, substantial deficits in function and strength persist up to 7 years after surgery.³⁸ Deficits in function are observed with both high impact and low impact activities. While there is ongoing discussion regarding the most appropriate limb symmetry index value, less than 85-90% is thought to be unfavorable.³⁹⁻⁴¹ Deficits in function, assessed via a battery of high impact one limb hop tests (single-limb hop, crossover hop, and single-limb time hop) have been documented in patients undergoing either a microfracture and an ACI procedure.⁴² Patients who underwent an ACI did not

surpass the desired 85% until 2 years after surgery.⁴² Conversely, microfracture patients were able to surpass the 85% value in all tests, but not until approximately 9 months after surgery.⁴² Additionally, in ACI patients functional impairments have been documented with lower demand activities, such as walking. Specifically, ACI patients who underwent a matrix-induced ACI procedure were found to walk slower and with less knee flexion compared to a control group.⁴³ Furthermore, when compared to pre-operative values deficits in walking have been documented in ACI patients up to 6 months after surgery.⁴⁴

Furthermore, deficits in quadriceps strength are reported to be persistent and significant. Quadriceps strength has primarily been measured through isokinetic testing.³⁸ This form of testing is reliable and considered the gold standard; being ideal for isolating the quadriceps muscle throughout a range of motion.⁴⁵ In articular cartilage patients quadriceps strength deficits as large as 70-77% are reported at 1 year and as large as 73-86% at 4 and 5 years post-surgical, when compared bilaterally.^{46,47} Overall, muscles weakness is detrimental to the joint as the generation of force is critical for function and joint stability.⁴⁸ Therefore, if functional activities are performed before the muscle is able to stabilize the joint the patients' joint health is at risk.⁴⁸ Furthermore, muscle weakness has been found to be a risk factor for Osteoarthritis.^{49,50} Therefore, patients who initially present with a symptomatic cartilage defect requiring treatment are continually stuck in a cycle where they are at risk of osteoarthritis progression even though a surgical intervention was performed.

After a cartilage repair or restoration procedure a standard rehabilitation protocol is prescribed to restore strength and function. A unique factor in the rehabilitation

protocol is a long non-weight bearing period. Commonly full weight bearing is not achieved until 8-12 weeks after surgery.⁵¹ This non-weight bearing period is prescribed to protect the repair tissue.⁵¹ However, the delayed non-weight bearing is believed to contribute to large quadriceps strength deficits seen post-operatively.⁵¹ Therapeutic interventions such as neuromuscular electrical stimulation have been found to be effective in regaining quadriceps strength after knee surgery.^{52,53} Therefore, it is necessary to investigate if such interventions aid in decreasing the degree of strength lost during the non-weight bearing period immediately after surgery.

Significance/Purpose

The primary purpose of this study was to investigate available rehabilitation treatment options for addressing post-surgical quadriceps weakness after articular cartilage surgery. Additionally, researchers wanted to develop a model to explain a patient's adherence to a health care provider's recommendations.

Specific aims

Specific Aim 1: To determine the most effective neuromuscular electrical stimulation (NMES) treatment parameters for post-operative quadriceps strength.

Specific Aim 2: To propose a theoretical framework for influencing adherence to a post-surgical rehabilitation. From this aim we will (1) provide health care providers with a set of guidelines to systematically identify situational and personal factors that may impact the rehabilitation process and (2) propose interventions to address the factors identified.

Specific Aim 3: To evaluate the effect of a 12-week home-based neuromuscular electrical stimulation treatment program compared to the standard of care on isometric quadriceps strength, functional performance, and subjective function at 3-month post-surgery in articular cartilage patients. *We hypothesize that a post-operative home-based NMES treatment will result in greater isometric quadriceps strength, improved lower extremity function and reported subjective function at 3-months when compared to the current standard of care treatment.*

Overview

This dissertation is organized in the following order. Chapter 2 is a systematic review of the most effective neuromuscular electrical stimulation (NMES) parameters for regaining post-operative quadriceps strength. Chapter 3 is a theoretical paper presenting a model for how health care clinicians can affect adherence to prescribed treatments, both at home and in clinic settings. Chapter 4 is a randomized clinical trial investigating the effects of a home-based NMES treatment on 3-month isometric quadriceps strength, lower extremity function and subjective function in articular cartilage patients.

Operational Definitions

Patient reported outcomes (PRO):

Self-reported outcome measures that come directly from the patient's perspective.

Autologous Chondrocyte Implantation (ACI)

An Autologous chondrocyte implantation is a two-step cartilage procedure. During the first step the patient undergoes an arthroscopic evaluation where chondrocyte cells are

harvested from a non-weight bearing surface of the knee. The harvested cells are grown in a lab and subsequently implanted in the symptomatic lesion during a second surgery.

Osteochondral Allograft procedure (OCA)

An Osteochondral allograft procedure is a cartilage procedure where a plug from a donor condyle is harvested and then implanted into the location of the symptomatic lesion.

Particulated Juvenile Tissue (Denovo)

A cell-based one-stage cartilage procedure that is similar to an autologous chondrocyte implantation. Particulated juvenile allograft tissue is implanted into the location of the symptomatic cartilage defect after the defect area has been prepared.

Assumptions:

1. Patients exerted maximal effort when completing the functional Y-Balance Test and strength testing via maximal voluntary isometric contraction.
2. Patients answered all patient reported outcome questionnaires honestly.

Delimitations:

1. Participants in the randomized clinical trial (chapter 4) were patients who underwent an articular cartilage repair or restoration procedure in the knee.
2. Patients in the randomized clinical trial (Chapter 4) will be recruited from one active center for cartilage repair and restoration.
3. Patients participating in the randomized clinical trial, chapter 4, were provided a standardized physical therapy protocol. However, physical therapy services were provided by multiple clinics and the therapy was not controlled.
4. One clinician conducted all testing for outcome measures of interest in the randomized clinical trial (Chapter 4.)

Limitations

1. Patients in the randomized clinical trial (Chapter 4) were not blinded to the treatment group due to the sensation experienced with the experimental intervention.
2. The researchers were not able to objectively document treatment adherence for patients in the standard of care treatment group. Both treatment groups completed patient diaries to document treatment adherence.
3. Patients were instructed to continually increase the intensity level of the NMES intervention. However, the intensity level of the interventional treatment (NMES treatment) was not quantified against the patient's maximal voluntary isometric contraction (MVIC) during the course of the treatment. Therefore, the percentage of the MVIC stimulated by the treatment intensity level varied between patients.

Chapter 2: A Comparison of Neuromuscular Electrical Stimulation (NMES) Parameters for Post-surgical Quadriceps Strength in Patients After Knee Surgery: A Systematic Review

Introduction:

Knee pathologies such as anterior cruciate ligament (ACL) tears, meniscal injuries and chondral injuries are frequently treated with surgical interventions to address symptoms or improve the overall health of the joint. One consequence of knee surgery is the subsequent quadriceps weakness experienced by patients.^{54,55} Strength deficits greater than 20% are often reported years after surgery.^{38,55} This is concerning because muscles are responsible for providing joint stability and initiating movements.⁴⁸ Furthermore, a decrease in joint stability increases the risk of damaging the joint further.⁵⁶

Neuromuscular electrical stimulation (NMES) is utilized to target quadriceps weakness by assisting the muscle's ability to elicit a contraction. Electrical stimulation generates a muscle contraction by activating the motor units for the target muscle.⁵⁷ Electrical stimulation of the nerve results in an action potential which causes depolarization of the membrane of the muscle fiber and a release of calcium from the sarcoplasmic reticulum.⁵⁷ The effectiveness of NMES to activate motor units and induce a muscle contraction has led to this modality being used in the rehabilitation setting to address muscle weakness and atrophy.

The overall goal of NMES is to elicit a strong contraction of the quadriceps muscle with minimal pain for the patient. The NMES parameters and setup options can be adjusted based upon the clinician's goals during the treatment and/or to modify the patient's experience during treatment. Pain, one form of a patient experience, is

frequently a limiting factor in the treatment protocol.^{58,59} Therefore, educating a patient to expect a degree of discomfort is important during NMES. The goal is to achieve a strong contraction to overload the muscle repetitively while trying to prevent excessive muscle fatigue. NMES parameter selection can assist a clinician to achieve a balance between muscle overload and the patient's ability to tolerate the NMES treatment.

Favorable results after a NMES treatment protocol have been reported.⁶⁰ After a 6-week NMES treatment program patients were reported to recover approximately 70% of their quadriceps strength.⁶¹ Conversely, other studies have reported no benefit from an NMES treatment.⁶² A factor contributing to the inconsistent results is theorized to be the wide variety of parameters and patient set-up options used among NMES treatments.⁶⁰ Understanding the most effective parameters for recovering quadriceps strength after surgery is important so that treatment effectiveness can be maximized. Therefore, the purpose of this review was to investigate the most effective parameters (waveform, treatment time, patient position, initiation of treatment, frequency, intensity) of a NMES treatment protocol designed to target post-surgical quadriceps weakness.

Methods:

Searches were performed during May 2016 using the following electronic databases: PubMed, CINAHL, MEDLINE, and SportsDiscus (Table 2.1). All titles and abstracts identified from the search strategy were reviewed to determine study inclusion. Lastly, a manual search by hand was performed from the references of the included articles. If the information provided in the abstract was not sufficient for a decision regarding inclusion or exclusion the article was retrieved and reviewed in its entirety.

Selection Criteria:

Based upon the Center for Evidence Based Medicine (CEBM) hierarchy for studies examining Treatment Benefits, studies classified as level 2 were included in this review.⁶³ The CEBM hierarchy ranges from 1 to 5 where a level 5 represents a low level of evidence and a level 1 represents the best level of evidence.⁶³ Limits were set to include English-language and human based articles. Included studies were required to have measured volitional quadriceps strength and report the NMES parameters utilized. Additionally, the included studies were required to include a control group that did not receive any form of a NMES treatment and instead performed voluntary quadriceps muscle contractions. Studies were excluded if they did not measure volitional quadriceps strength, and/or applied NMES to other muscles in addition to the quadriceps. These exclusions were chosen to isolate the effect of a NMES treatment applied directly to the quadriceps on post-surgical quadriceps strength. Lastly, studies were excluded if post-intervention means and standard deviations were not available. In the instance authors did not report means and standard deviations the authors were contacted to obtain the information.

Assessment of Methodological Quality:

An assessment of the methodological quality was performed utilizing the Physiotherapy Evidence Database (PEDro) scale.⁶⁴ The PEDro scale consists of 11 questions; however, only questions 2-11 are utilized for the total score calculation. Therefore, the PEDro is based upon a 10 point scale with higher score (10) reflecting a high-quality study. A study with a score greater than or equal to 6 was considered to be of moderate to high quality.⁶⁵ Two independent reviewers (CWC and KNJ) assessed the quality of evidence for each article using the PEDro criteria. Once each reviewer had

completed the independent assessment of the articles they met to discuss any disagreement. There was no disagreement between the authors.

Strength of Recommendation:

Strength of recommendation was assessed utilizing the Strength of Recommendation Taxonomy (SORT).⁶⁶ The strength of recommendation is evaluated with grades A, B and C.⁶⁶ According to the taxonomy a C is a recommendation based upon case series, consensus, disease oriented evidence, or expert opinion.⁶⁶ A B recommendation is given when there is inconsistent or limited quality patient-oriented evidence.⁶⁶ Lastly, a recommendation strength of an A is given to consistent good quality patient-oriented evidence.⁶⁶

Data Extraction:

From each study the intervention parameters, administration instructions, and quadriceps strength measures (isometric or isokinetic) were extracted and input into an Excel spreadsheet by the primary author (CWC). The NMES treatment intervention parameters consisted of: treatment volume, treatment duration, duty cycle, pulse duration, frequency, intensity, ramp time, patient position, and if a voluntary muscular contraction was performed concurrent to the stimulation. Secondly, means and standard deviations for quadriceps strength at baseline and post-treatment intervention were extracted. One article⁶⁷ presented strength means and standard deviations in a graph. The means and standard deviations were extracted from the graph utilizing a digital caliper (Mitutoyo, Kawasaki, Japan).⁶⁸

Data Analysis:

Hedges's g effect size and 95% confidence intervals (CI) were calculated to determine the effect of the treatment on quadriceps strength. Effect size calculations were interpreted as small 0.2, moderate 0.5, and large 0.8.⁶⁹ Statistically significant treatment effects occurred where the CI did not contain zero. To further aid in the interpretation of the post-treatment effect sizes, and account for potential group differences, pre-intervention effect sizes and effect size change scores were calculated when possible. The pre-intervention effect sizes are calculated aid in understanding if the post-intervention effect sizes are due to the intervention or dissimilarity between groups at baseline.

Results:

The search strategy resulted in 488 articles from the specified databases (Table 2.1). A total of 296 duplicate articles were excluded, an additional 155 articles were excluded based upon title and abstract. From the remaining 37 articles a total of 7 studies were included in this review (Figure 2.1).^{53,67,70-74} The PEDro scores for the 7 articles ranged from a 2 to 7 with an average of 5 (Table 2.2). There was no disagreement between the two independent reviewers. No study blinded the subjects or the treatment administrators (criteria 5 & 6). The majority of studies failed to conceal group allocation (criteria 3), include a baseline group assessment (criteria 4), and/or blind the assessor of the key outcome (criteria 7).

Study Characteristics:

Individual study characteristics are presented in Table 2.3. Five articles applied the NMES treatment to ACL patients^{67,70-73}, 1 to TKA patients⁵³, and 1 to meniscectomy patients⁷⁴. Patients (ACL) in 2 articles^{72,73} were casted during the post-operative NMES

treatment. Quadriceps strength was measured through isometric testing at various knee angles including 30°, 60°, 75°, and 90° in 5 studies,^{53,67,71-73} and with isokinetic testing at speeds of 90°/s, 120°/s, 180°/s, 240°/s, and 300°/s in 2 studies^{70,74}.

Baseline effect sizes varied for the included studies. Baseline effects sizes were not measurable for two studies⁷² as no baseline measures were reported. For the remaining 5 studies, baseline effect sizes for two studies were close to 0,^{53,70} with the remaining three as follows: Lieber et al = -0.36⁶⁷, Wigerstad-Lossing et al = 0.29⁷³, and Williams et al = 0.71 – 0.78⁷⁴ (Table 2.3).

Pre-Post effect size change scores are presented in Figure 2.2 to aid in interpretation of the post-operative treatment effect. Post-intervention quadriceps strength measures were found to statistically improve in 4 of the 7 studies.^{53,70,71,73} However, effect sizes calculated for each time point tested and each strength assessment resulted in a ranges of -0.37 to 1.03 (Figure 2.2).^{53,70,71} Statistically significant moderate to large effect sizes were found in 3 studies.^{53,70,73} The post-intervention effect sizes for both Lieber et al⁶⁷ (-0.37) and Williams et al⁷⁴ (0.65 - 0.89) did not largely differ from the baseline effect sizes (-0.36 and 0.71 – 0.78 respectively). Therefore, it can be interpreted that the intervention in both studies had a limited effect on post-surgical quadriceps strength. Furthermore, the CIs for a large majority of the effect sizes did cross zero; however overall there was a favorable trend for the effect of NMES on post-operative quadriceps strength when compared to the standard of care treatment.

Treatment Parameters:

The treatment administration set-up and parameters can be found in Table 2.4 and Table 2.5. Overall the parameter varied between studies preventing a meta-analysis from

being able to be conducted. Only two studies^{53,73} reported all the NMES parameters of interest for this review. Commonly studies failed to report pulse duration, current type and/or waveform shape, and electrode pad size. The majority of studies consistently utilized an intensity level of maximal toleration. When setting the intensity all studies but one⁶⁷ instructed the patients to continually increase the intensity. The devices used to deliver the NMES treatment varied between battery operated^{53,70,72,73} and AC volt powered^{67,71,74}. Specific duty cycle ratios were highly varied between studies; however, contraction/relaxation ratios around 1:2^{67,70,73} and 1:3^{53,61,72} were most frequently utilized. All but one study utilized a two electrode pad placement, with Feil et al⁷⁰ utilizing a four electrode pad placement in one intervention group (group 1). Predominantly a frequency of 50Hz^{53,67,70,74} was utilized and, when reported, a pulse duration of 250-300µsec^{53,67,70}. The NMES treatment was most commonly implemented during the first post-surgical week.^{53,70,72,73}

Discussion:

Quadriceps weakness after surgery is a common issue clinicians face during the rehabilitation process. Regaining quadriceps strength after surgery is a focus during rehabilitation, for quadriceps weakness has been found to increase joint loading⁷⁵ and contribute to the development of osteoarthritis⁷⁶. In this review effect sizes for NMES as compared to control group on post-surgical quadriceps strength ranged from small (-0.37) to large (1.03). Nonetheless, out of the seven^{53,67,70-74} included studies 4 studies^{53,70,71,73} reported a statistical improvement in post-surgical quadriceps strength. From the 4 studies, Feil et al (group 1)⁷⁰, Stevens-Lapsely et al⁵³, and Wingerstad-Lossing et al⁷³ showed the largest between group post-operative effect sizes (0.61 – 1.03). The study by

Fitzgerald et al⁷¹ had a moderate post-operative effect size (.47). However, a baseline effect size was unable to be calculated with in turned limited our interpretation of the between group post-operative effect size. While these results align with other reviews^{60,77,78} supporting NMES as a positive post-surgical treatment directed at regaining quadriceps strength, little focus has been placed on the most effective parameter settings.

This review sought to evaluate the most effective NMES parameters for recovering post-surgical quadriceps strength. Evaluation of the included articles revealed large variations in the parameters selected for the NMES treatments. However, when evaluating the NMES parameters in studies with large effect sizes some similarities were observed regarding treatment initiation time, intensity level, electrode size, frequency and dosage of the NMES treatment.^{53,70,73} All studies implemented the NMES treatment during the first week post-operative at an intensity level of maximum toleration.^{53,70,73} Feil et al⁷⁰ and Stevens-Lapsely et al⁵³ both used large electrodes (>90cm²), a frequency of 50Hz, and prescribed NMES multiple times per day. Of the remaining parameters, there were several inconsistencies among the studies thus a consensus about the effects of these parameters on quadriceps strength were not possible. However, the similarities noted among the available parameters provide a good indication for the optimal parameter selections that may be advantageous for recovering quadriceps strength after surgery. Each of these parameters will be discussed in further detail below.

Intensity of the NMES treatment is one of the more difficult parameters to control due to the limiting factor of patient comfort. However intensity is emerging as one of the most important parameters for regaining quadriceps strength. A linear relationship is

reported to exist between the level of intensity during an NMES treatment and the amount of quadriceps strength recovered.^{52,79,80} Furthermore high intensity levels have been associated with both increased cortical activity⁸¹ and increased muscle cross sectional activation which resulted in greater muscle torque⁸². All of the above findings would suggest that to maximize a NMES treatment on post-operative quadriceps strength the intensity should be set to a high level. In addition, when selecting a high intensity level participants have been found to adapt to the intensity level over time.⁸³ Therefore, to further derive benefit from the treatment the participant should continually increase the intensity. While all studies in this review implemented maximum toleration intensity^{53,67,70-74}, one study did not progressively increase the intensity level which may have contributed to the lack of a difference between groups⁶⁷. Therefore, to maximize motor unit recruitment to achieve a muscle contraction a high intensity level should be applied, and the intensity ought to be progressively increased as tolerated.

While less is known about the effect of the NMES frequency and the timing of the NMES treatment on quadriceps strength, the literature appears to align with the similarities found between the studies with positive results. Based upon the property of summation, a higher frequency (>30Hz) is necessary to sustain a tetanic contraction.⁵⁷ Furthermore the contraction produced by the higher frequencies (50Hz and 100Hz) is reported to be more comfortable.⁵⁸ All the included studies utilized a frequency greater than 30Hz, however, they did not all have a positive effect on quadriceps strength. The studies with positive effects used frequencies of 50Hz^{53,70}, 30Hz⁷³, and 75Hz⁷¹. Consequently clinicians are left with a wide range of available frequencies. At this time a conclusion regarding a specific frequency is difficult to make from the studies reviewed.

However, it has been recommended that clinicians utilize a frequency closer to 50Hz in order to minimize excessive fatigue.⁵⁷ Therefore, when choosing a frequency it is recommended that a frequency closer to 50Hz be implemented and the other parameters (duty cycle and pulse duration) be adjusted to minimize excessive fatigue.

Lastly, the results suggest that the timing of treatment initiation may impact quadriceps strength. In the reviewed studies the NMES treatment was initiated anywhere from 2 days after surgery to almost a month after surgery. The studies with the largest effect sizes initiated the NMES treatment within the first 4 days after surgery.^{53,70,73} There was less consistency when evaluating the length of the NMES treatment. Of the studies with large effect sizes, two of the studies^{53,73} prescribed a 6-week NMES treatment while the remaining study⁷⁰ prescribed a 12-week treatment. The effect of NMES on post-operative quadriceps strength over time is presented in Figure 2.3. While the effect sizes highly vary, the overall effect size for initiating a NMES treatment immediately after surgery is moderate. As time progresses to 3 and 6 months the effect of NMES on quadriceps strength appears to become smaller. However, given that many of the studies did not measure quadriceps strength beyond 6 months, it is difficult to predict the longer term impacts. Furthermore, only 4 studies^{53,70-72} measured quadriceps strength over time. Thus, it appears the largest effects of a NMES treatment is seen when the treatment is implemented during the first 4 days postoperative, however more research should be conducted to evaluate the residual effect of NMES.

It is theorized that the early positive effect of NMES on quadriceps strength may be attributed to characteristics immediately after surgery, such as muscle activation failure and neuroplastic changes at the cortical level, that impair the ability to generate a

muscle contraction post-surgical.^{84,85} The external stimulation generated by an NMES treatment is believed to assist the muscle in achieving a full contraction when activation failure is present.^{55,85} In addition, the act of performing a volitional contraction during NMES stimulation may be beneficial based upon neuroplasticity principles. For example, introducing a new activity and placing attention on the given task, such as contracting the quadriceps, can increase the motor maps within the cortex.^{86,87} The development of this additional motor pattern may assist the participant after the stimulation treatment is discontinued. However, while promising, the above theories have not been fully supported in NMES treatments, thus more research is needed to confidently determine what mechanism NMES influences during the immediate post-operative phase to effect post-operative quadriceps strength.

While the precise nature of defining the remaining NMES parameters is hindered in this review due to inconsistencies in studies, some evidence from the literature provides further direction. For example, in this review waveform shapes of rectangular^{72,73} and triangular⁷¹ were implemented in several studies. Currently there is minimal research documenting the effect of waveform shape on quadriceps strength. However the shape of the waveform does appear to have an impact on an individual patient's comfort level and varies between individuals.⁸⁸ Adjusting the waveform to a more comfortable simulation experience may allow the clinician to reach a higher intensity level during treatment. Additionally, pulse duration ranged from 250 μ sec to 300msec and the type of current was either a biphasic or alternating current for the NMES treatments.^{67,70-74} Focusing on pulse duration, a long pulse duration (300 – 450 μ sec) is recommended to achieve a greater quadriceps force.⁸⁹ It is believed, a longer pulse duration (~300 μ sec) stimulates larger

areas of the muscle.⁹⁰ For the type of current selected, findings are inconclusive, as both a biphasic current and an alternating current (also called Russian) are supported for quadriceps recovery.^{77,91} Lastly, patient position ranged from full extension to 90 degrees of knee flexion. A knee flexion angle of 60 degrees has been shown to produce the largest voluntary knee extension torque during an exercise.⁹² However not all patients can achieve a flexed position immediately after surgery and require position modifications. The variable results discussed above suggests that while progress has been made to better understand the relationship among parameters more information is needed to fully understand the effect of each parameter on quadriceps strength. Thus from the limited information available, clinicians should utilize a biphasic or alternating current, a waveform shape comfortable to the patient, a long pulse duration (300 – 450 μ sec) and position the knee as close to 60 degrees as is medically safe.

The information included in this review provides researchers and clinicians with a starting point for administering NMES. Adjusting the parameters with the recommendations provided will assist a clinician in achieving the overall goal of improving post-surgical quadriceps strength. However, more information about the other parameters and their interactions with one another is needed. One can speculate the inconsistencies in the effect sizes among the studies discussed may be due to the apparent variation in parameter selection and the resulting interactions.

Limitations:

A few limitations should be noted. The number of studies that met inclusion criteria was small limiting the amount of data available for comparison in the review. Additionally, parameters were not consistently reported and highly varied between

studies. Therefore, in certain situations the sample size was further reduced and a meta-analysis was unable to be performed. Lastly, the majority of the studies reviewed did not include a compliance diary or monitor adherence for the prescribed treatment. Thus, it is difficult to know if the lack of statistical differences between groups is due to the parameters selected or adherence to the prescribed treatment.

Conclusion:

There is B level evidence to support NMES for improving post-surgical quadriceps strength. The recommended set-up parameters following knee surgery are: pulse duration of 300 – 450µsec, rectangular biphasic current or alternating current with a frequency of 50Hz, duty cycle ratio of 1:2 or 1:3 and large electrodes (>96cm²). However, the biphasic waveform can be changed from rectangular if the patients experiences excessive discomfort. The treatment should be initiated within the first week of surgery preferably starting on the 2nd – 4th day post-surgery. The intensity of the stimulation treatment should be set to the maximal tolerance of the patient. Additionally, the patient should be educated that during each treatment the intensity will need to be continually increased as tolerance to the stimulation increases. Furthermore, the literature suggests that the treatment should be delivered for 6 - 12 weeks post-surgical performed 5 to 7 days a week 2 times a day for 30 minutes a day with the patient in a flexed position (~60°) actively contracting with the stimulation.

Table 2.1: Search terms with the number of articles returned for each search strategy

	Search Strategy	Results	
		Ebsco Host (1988-2016) CINAHL with Full Text, Sports Discus, MEDLINE	PubMed (1966-2016)
#1	Neuromuscular electrical stimulation	1,862	6,898
#2	Electrical stimulation	55,375	169,900
#3	Clinic* electrical stimulation	612	22,649
#4	Home-based electrical stimulation	47	93
#5	Battery operated electrical stimulation	6	47
#6	Portable electrical stimulation	30	260
#7	#1 OR #2 OR #3 OR #4 OR #5 OR #6	55,376	169,900
#8	Anterior cruciate ligament	27,617	16,268
#9	ACL	35,192	23,127
#10	Anterior cruciate ligament reconstruction	11,653	8,491
#11	Anterior cruciate ligament revision	405	627
#12	Anterior cruciate ligament repair	667	1,868
#13	Anterior cruciate ligament surgery	4,249	12293
#14	Total knee arthroplasty	17,241	22,299
#15	Meniscectomy	3,463	2,304
#16	Meniscus transplant	39	628
#17	Meniscus repair	855	1,320
#18	Knee	194,764	131,399
#19	Knee injury	13,910	32,765
#20	Knee surgery	18,696	61047
#21	#8 OR #9 OR #10 OR #11 OR #12 OR #13 OR #14 OR #15 OR #16 OR #17 OR #18 OR #19 OR #20	220,689	141,638
#22	Rehabilitation	486,444	417,238
#23	Therapy	4,966,555	7,937,761
#24	#22 OR #23	5,297,225	8,002,032
#25	Muscle strength	56,100	48,912
#26	Muscle weakness	21,535	36,460
#27	Quadriceps weakness	3,859	1,151
#28	Quadriceps strength	733	3,980
#29	#25 OR #26 OR #27 OR #28	75,617	81,703
#30	#7 AND #21	2,020	1,865
#31	#30 AND #24	1,140	1,116
#32	#31 AND #29	238	250

Figure 2.1: Study selection flow chart for all studies returned in the search

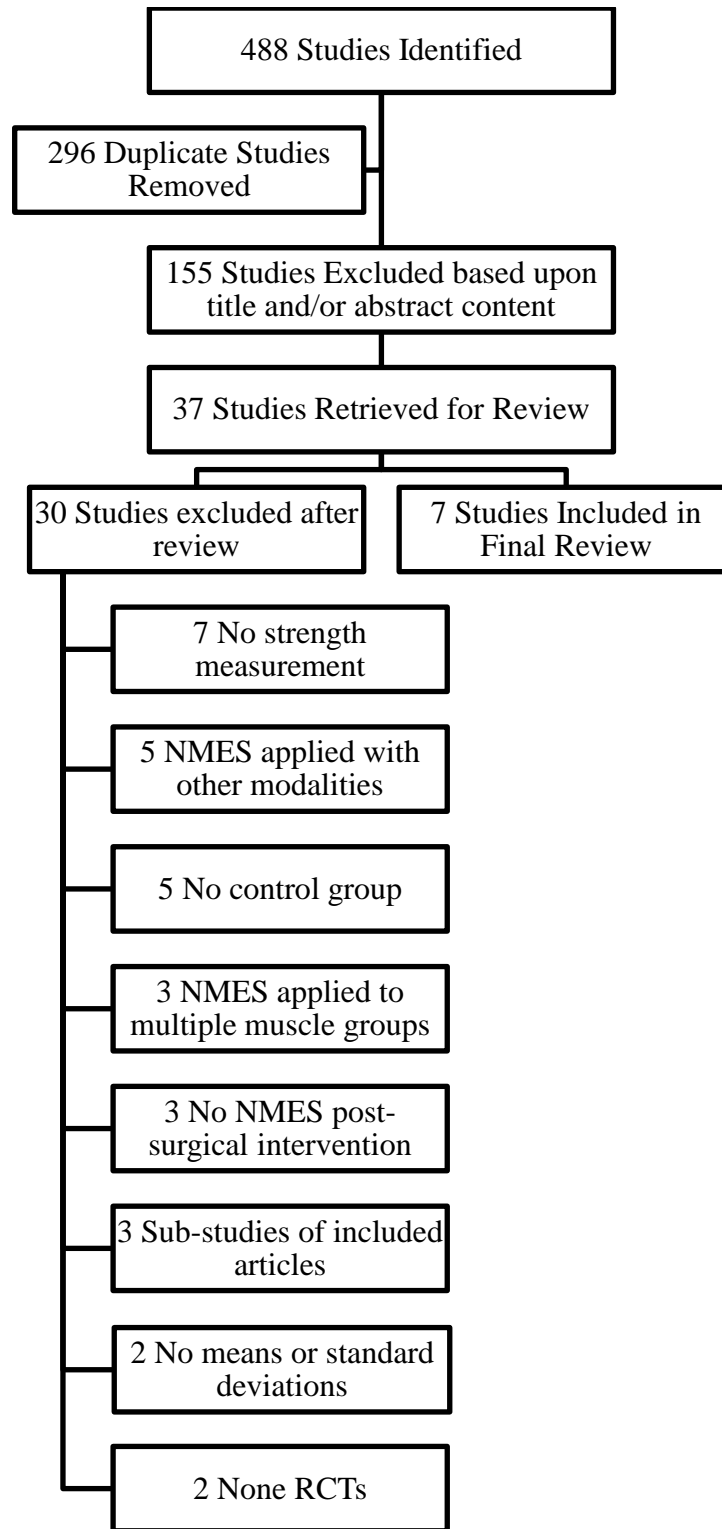


Table 2.2: Physiotherapy Evidence Database scale (PEDro) Methodological Quality Assessment Scores for each included article.

	1*	2	3	4	5	6	7	8	9	10	11	Total
Feil et al ⁷⁰	X	X	-	X	-	-	X	-	X	X	X	6/10
Fitzgerald et al ⁷¹	X	X	-	-	-	-	X	X	X	X	X	6/10
Liber et al ⁶⁷	X	X	-	-	-	-	-	X	X	X	X	5/10
Sisk et al ⁷²	X	X	-	-	-	-	-	X	-	X	X	4/10
Stevens-Lapsley ⁵³	X	X	X	X	-	-	-	X	X	X	X	7/10
Wigerstad-Lossing et al ⁷³	X	X	-	-	-	-	-	X	X	X	X	5/10
Williams et al ⁷⁴	X	X	-	-	-	-	-	-	-	-	X	2/10

“X” denotes criteria was satisfied, “-“ denotes criteria not satisfied

*Question 1 is not included in the score total

Table 2.3: Study demographic characteristics for each included article.

	NMES (n)	Age (yrs)	Control (n)	Age (yrs)	Procedure	Strength Measurement	Baseline Effect Size [#]
Feil et al ⁷⁰	G1: 42* G2: 45*	G1: 31.1±1.52 G2: 34.8±1.49	44	31.6±1.36	ACL	Isokinetic 90°/s, 180°/s (Nm/kg)	G1: 0.09* G2: -0.06*
Fitzgerald et al ⁷¹	21	29.2±10.1	22	31.9±10.9	ACL	Isometric at 60°	-
Liber et al ⁶⁷	20	28.0±8.2	20	27.3±8.5	ACL	Isometric (Nm) at 90°	-0.36
Sisk et al ⁷²	11	23.4±7.5	11	23.9±9.2	ACL	Isometric (Nm/kg) at average of 75°	-
Stevens-Lapsley et al ⁵³	35	66.2±9.1	31	64.8±7.7	TKA	Isometric at 60°	0.02
Wigerstad- Lossing et al ⁷³	13	28 (21-45)	10	26 (21-33)	ACL	Isometric at 30°	0.29
Williams et al ⁷⁴	13	32.8±7.9	8	32.9±7.7	Meniscectomy	Isokinetic 120°/s, 180°/s, 240°/s, 300°/s (ft lb)	120°/s: 0.71 180°/s: 0.77 240°/s: 0.73 300°/s: 0.78

All comparisons were between NMES and control groups receiving standard of care, except Feil which had a control group and 2 NMES groups G1: Group 1 (Kneehab), G2: Group 2 (Polystim)

*Group 1 (G1): Kneehab NMES, Group 2 (G2): Ploystim NMES

[#]Baseline effect sizes calculated from baseline quadriceps strength values

- unable to be calculated due to no baseline comparison reported

Table 2.4: A summary of the neuromuscular electrical stimulation (NMES) treatment administration and set-up parameters utilized in the included articles.

	Treatment Duration	NMES Treatment	Time Initiated	Muscle Contraction	Knee Angle
Feil et al: G1* ⁷⁰	12wk (20min 3x/d, 5d/wk)	NMES (Battery)	3-4 th Day Post-Op	Active	Full Extension
Feil et al: G2* ⁷⁰	12wk (20min 3x/d, 5d/wk)	Poly-Stim (Battery)		Active	Full Extension
Fitzgerald et al ⁷¹	12wk (11-12min/d, 2d/wk)	NMES (AC volt)	1-3 wks Post-Op	Passive	Full Extension
Liber et al ⁶⁷	4wk (30min/d, 5d/wk)	NMES (AC volt)	2-6 wks Post-Op	-	-
Sisk et al ⁷²	6wk (8hrs/d, 7d/wk)	-	2 nd Day Post-Op	Active or Passive	90° Flexion
Stevens-Lapsley et al ⁵³	6wk (15min 2x/d, 7d/wk)	NMES (Battery)	2 nd Day Post-Op	Passive	60° Flexion
Wigerstad-Lossing et al ⁷³	6wk (40min/d, 3d/wk)	NMES (Battery)	2 nd Day Post-Op	Active	20-30° Flexion
Williams et al ⁷⁴	3wks (10min/d, 5d/wk)	NMES (AC volt)	Ave 31d Post-Op	-	65° Flexion

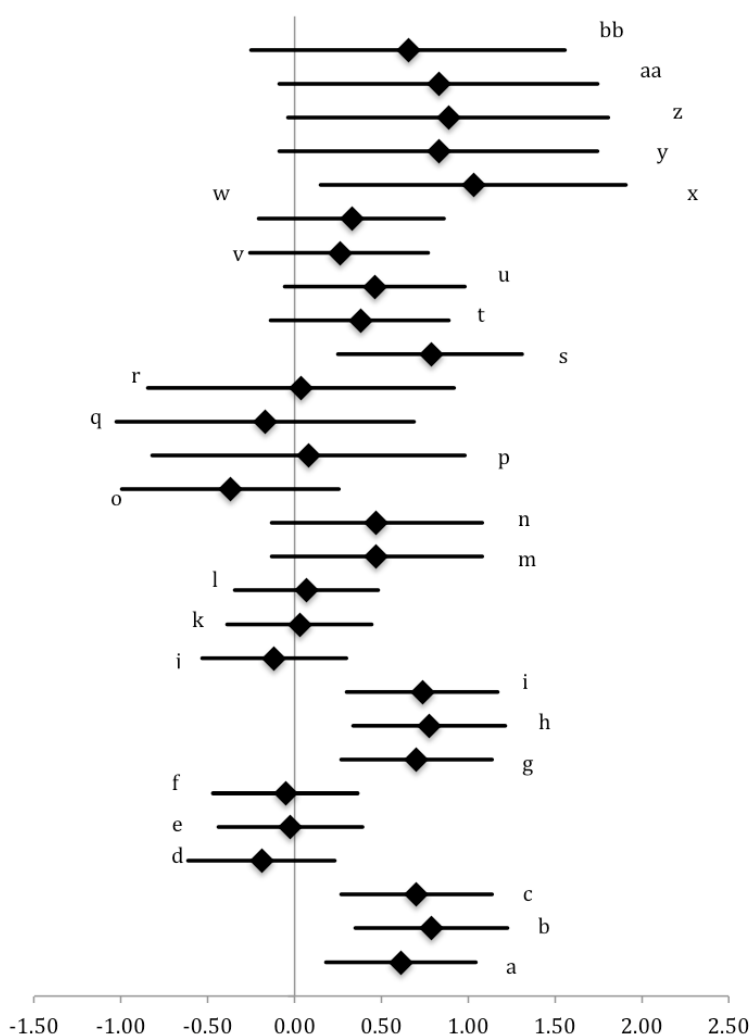
*Group 1 (G1): Kneehab NMES, Group 2 (G2): Ploystim NMES
- information not provided

Table 2.5: A summary of the neuromuscular electrical stimulation (NMES) treatment parameters utilized in each included article.

	Frequency	Duty Cycle (sec)	Ramp	Intensity	Pulse Duration	Current/ Waveform	Pad Size
Feil et al ⁷⁰	50	5on 10off	2s/1s down	-	300-400 μ	-	G1: 10 x 20cm, 3 x 18cm, 7 x 14cm
	50	10on 20off	1.5s/1s down	-	-	-	G2: 4 x 70mm
Fitzgerald et al ⁷¹	75	10on 50off	2s up	MT	-	Triangular Alternating Burst	6.98 x 12.7cm
Liber et al ⁶⁷	50	10on 20off	2s up	MT constant	250 μ	Asym-Balanced	-
Sisk et al ⁷²	40	10on 30off	0.5s up	MT	300ms	Rectangular Waveform	5 x 10cm
Stevens-Lapsley et al ⁵³	50	15on 45off	3s up	MT	250 μ	Sym-Biphasic	7.6 x 12.7cm
Wigerstad-Lossing et al ⁷³	30	6on 10off	2s up	MT	300ms	Rectangular Asym-Balanced Biphasic	4 x 10cm
Williams et al ⁷⁴	50	15on 50off	3.5s up	MT	-	Alternating Sinusoidal	-

-information not provided, MT = maximal toleration, Asym = Asymmetrical, Sym = Symmetrical

Figure 2.2: Hedge's g effect sizes and 95% confidence intervals for the effect of the neuromuscular electrical stimulation (NMES) treatment on post-operative quadriceps strength.



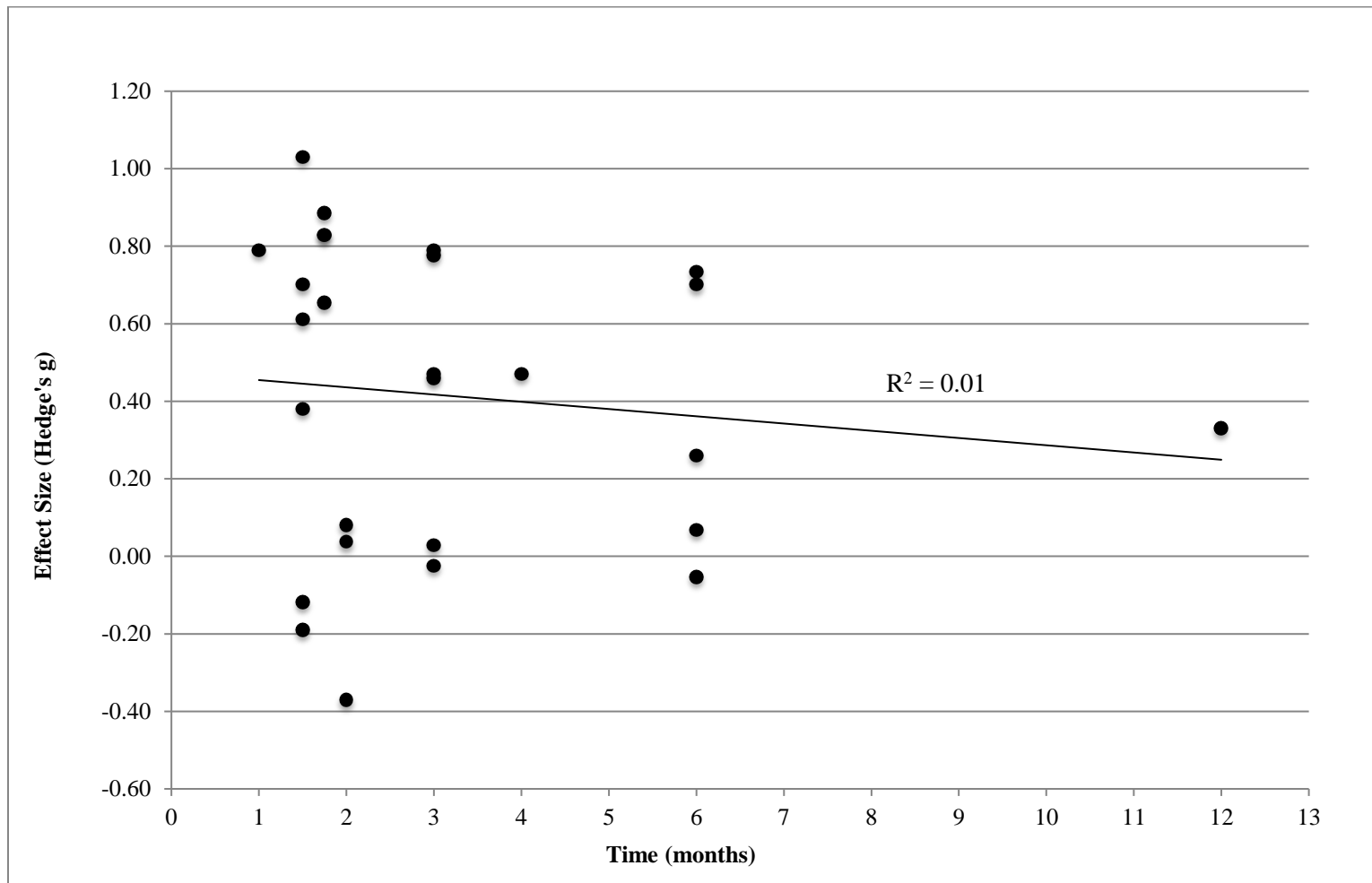
Study	Article	ES	Lower	Upper
a	Feil et al 6wk (Group 1) 90°/s ⁷⁰	0.61	0.18	1.04
b	Feil et al 12wk (Group1) 90°/s ⁷⁰	0.79	0.35	1.23
c	Feil et al 24wk (Group1) 90°/s ⁷⁰	0.70	0.27	1.14
d	Feil et al 6wk (Group 2) 90°/s ⁷⁰	-0.19	-0.61	0.23
e	Feil et al 12wk (Group2) 90°/s ⁷⁰	-0.02	-0.44	0.39
f	Feil et al 24wk (Group2) 90°/s ⁷⁰	-0.05	-0.47	0.36
g	Feil et al 6wk (Group 1) 180°/s ⁷⁰	0.70	0.27	1.14
h	Feil et al 12wk (Group1) 180°/s ⁷⁰	0.78	0.34	1.22
i	Feil et al 24wk (Group1) 180°/s ⁷⁰	0.73	0.30	1.17
j	Feil et al 6wk (Group 2) 180°/s ⁷⁰	-0.12	-0.53	0.30
k	Feil et al 12wk (Group2) 180°/s ⁷⁰	0.03	-0.39	0.44
l	Feil et al 24wk (Group2) 180°/s ⁷⁰	0.07	-0.35	0.48
m	Fitzgerald et al 12wk ⁷¹	0.47	-0.13	1.08
n	Fitzgerald et al 16wk ⁷¹	0.47	-0.13	1.08
o	Liber et al ⁶⁷	-0.37	-1.00	0.25
p	Sisk et al 7wks ⁷²	0.08	-0.82	0.98
q	Sisk et al 8wks ⁷²	-0.17	-1.03	0.69
r	Sisk et al 9wks ⁷²	0.04	-0.84	0.92
s	Stevens-Lapsley et al 3.5wks ⁵³	0.79	0.25	1.31
t	Stevens-Lapsley et al 6.5wks ⁵³	0.38	-0.14	0.89
u	Stevens-Lapsley et al 13wks ⁵³	0.46	-0.06	0.98
v	Stevens-Lapsley et al 26wks ⁵³	0.26	-0.26	0.77
w	Stevens-Lapsley et al 52wks ⁵³	0.33	-0.21	0.86

x	Wigerstad-Lossing et al ⁷³	1.03	0.15	1.91
y	Williams et al 120°/s ⁷⁴	0.83	-0.09	1.74
z	Williams et al 180°/s ⁷⁴	0.89	-0.04	1.81
aa	Williams et al 240°/s ⁷⁴	0.83	-0.09	1.75
bb	Williams et al 300°/s ⁷⁴	0.65	-0.25	1.56

Every time point at which post-operative quadriceps strength was measured is presented.

All comparisons were between NMES and control groups, except Feil which had a control group and 2 NMES groups G1: Group 1 (Kneehab), G2: Group 2 (Polystim). (-) = Information not provided.

Figure 2.3: Effect of neuromuscular electrical stimulation (NMES) on post-operative quadriceps strength over time.



Time represents the different time points at which each study measured post-operative quadriceps strength.

Chapter 3: Utilization of an Adaption of the Health Belief Model to Influence Rehabilitation Adherence in Athletic Training

Athletic trainers commonly treat physical factors such as strength and range-of-motion limitations identified through clinician-based measures.⁹³ Clinician-based measures are objective evaluations of how a patient is progressing in treatment.⁹⁴ While addressing physical deficits is important to return a patient to activity, consideration should also be given to the patient's psychological response to the injury.^{95,96} Athletes have been reported to suffer from emotional disturbances and negative mental states such as depression, anger, and decreased self-esteem after an injury.⁹⁷⁻⁹⁹ The ability to cope with the injury can positively or negatively impact the progress of the rehabilitation treatment and return to activity.^{100,101} Athletic trainers can utilize patient-based measures, such as patient reported outcome measures (PROMs), to evaluate a patient's mental state. Patient-based measures are self-report outcome measures that measure different aspects of rehabilitation (i.e.: function, quality of life, symptoms) from the patients' perspective.⁹⁴ A favorable rehabilitation plan should include attention to the physical and psychosocial factors experienced to optimize outcomes. However, psychosocial factors impacting a patient are not always readily apparent.¹⁰² Implementation of a disablement model provides an athletic trainer with a framework to evaluate the impact of an injury on a patient's overall health status.⁹³

Recently there has been an increased focus in athletic training on providing physically active patient centered care.⁹³ Part of providing physically active patient centered care is including the patient's beliefs, expectations, and goals into the rehabilitation process. Identifying and incorporating these factors can influence the

health behavior of adherence and aid in the development of an individualized rehabilitation process.^{95,103} The Health Belief Model (HBM)^{104,105} provides a theoretical framework for designing an individualized rehabilitation plan in the athletic training setting. The HBM was initially developed to explain why individuals were not participating in disease preventative health behaviors related to smoking cessation and weight loss.¹⁰⁵ The model has since been advanced to explain and predict general health behaviors exhibited by individuals.¹⁰⁵ Athletic trainers can use an expanded adaptation of the health belief model (HBM)^{105,106} as a guide to identify situational and personal factors influencing the rehabilitation process and facilitate ongoing discussion with a patient. The athletic trainer and the patient can then work together using various psychosocial strategies to mitigate the factors affecting the rehabilitation process. The overarching goal is to facilitate an environment that fosters a patient's adherence to treatment. Therefore, the purpose of this chapter is two-fold: (1) to describe the HBM and its constructs as they relate to the injury rehabilitation process and (2) to discuss how psychosocial strategies can be implemented to address factors identified from the model.

Health Belief Model

The HBM is a model that explains the factors that may influence an individual's decision making process during a health change¹⁰⁶ such as an initiation of a rehabilitation program following injury. Conceptualization of the HBM, began with two premises proposed to explain an individual's willingness to initiate a health behavior: 1) the value that the individual places on the goal is associated with the health behavior, and 2) the individual's belief that the actions put forth will result in the desired goal.¹⁰⁵ Both of these premises emphasize the avoidance of a negative health consequence such as not

recovering from an illness or injury. The HBM framework is comprised of six constructs: perceived severity, perceived susceptibility, perceived benefit, perceived barriers, cues to action, and self-efficacy.¹⁰⁵⁻¹⁰⁷

Interactions that occur between the constructs may help explain an individual's choice of health behaviors and related actions. The constructs are depicted in Figure 3.1 which was modified from Rosenstock's original publication.¹⁰⁶ Rosenstock proposed that the combination of *susceptibility* and *severity* motivates an individual to make a health change.¹⁰⁶ However to initiate a health behavior change an individual must feel that the *perceived benefits* are greater than the *perceived barriers*.¹⁰⁶ Additionally, the belief in one's ability to perform the health change, *self-efficacy*, influences the motivation to perform this change which can result in a positive or negative effect.¹⁰⁷ Any previous experiences with success or failure can greatly influence an individual's self-efficacy. Finally, a *cue to action* (external or internal) stimulates individuals to think about the decision to initiate the health change or to adopt a specific health change action.¹⁰⁵

Application of the Health Belief Model for Physically Active Patients

An integrated model to explain an athlete's response to injury has been described by Wiese-Bjornstal et al and others.^{108,109} In their model, the response of an athlete is composed of an emotional response, behavioral response, and cognitive appraisal. Furthermore, each response or appraisal can be influenced by pre-existing or experienced situational and personal factors.¹⁰⁸⁻¹¹¹ Personal factors are personality traits or characteristics of the individual or injury.¹⁰⁸⁻¹¹⁰ Situational factors can be either social interactions or items within the physical environment.¹⁰⁸⁻¹¹⁰ The combination of all three

responses (emotional, behavioral, and cognitive) and the associated situational and personal factors can positively or negatively influence rehabilitation outcomes. In this model adherence to a rehabilitation program is considered to be a behavioral response. Adherence is defined as the degree to which a patient's behavior (attendance, engagement, fulfillment) aligns with the athletic trainer's recommendations.¹¹² While adherence to a rehabilitation program is considered to be a critical component of outcomes, the degree of adherence may be influenced by a multitude of personal, situational, and psychosocial factors.^{110,111} Examples of such factors are family obligations, desire to continue sport participation, existing social support system, and pain tolerance to list a few.^{110,111} Which specific factors are relevant and the degree to which those factors influence treatment outcomes will vary between patients.¹¹³ Identification of these responses and the factors associated with them allows an athletic trainer to develop an individualized rehabilitation environment with the goal of high adherence.

If a patient's desires and/or beliefs are not included in the design of a rehabilitation program athletic trainers risk embarking on a rehabilitation plan that does not align with the patient's values. Furthermore, an athletic trainer may fail to identify psychosocial factors that could influence a patients' behavior during a rehabilitation process. Subsequently athletic trainers may be caught off-guard if they encounter obstacles, such as non-adherence. A disablement model can assist an athletic trainer in avoiding such pitfalls. Disablement models are beneficial for 2 reasons: (1) they provide a framework to guide conversation between a health care professional and a patient and (2) they are flexible enough to be adapted to new research and assist a clinician in

interpreting and applying the results from new research consistently.⁹³ By shifting the focus in rehabilitation to a disablement model, athletic trainers are provided a framework that empowers athletic trainers to evaluate the entire patient as a whole.

We present a Physically Active Patient Centered Health Belief Model, an adaptation of the HBM specific to athletes and physically active patients, to further explain response in the rehabilitation process following an injury (Figure 3.2). In the Physically Active Patient Centered Health Belief Model specific situational and personal factors, as defined by the Integrated Model, have been merged with the HBM. The Physically Active Patient Centered HBM focuses on understanding the cognitive appraisal process with emphasis on influential situational and personal factors. Identification of factors influential to the cognitive appraisal provides the athletic trainer with knowledge of the psychosocial factors to address to avoid poor adherence. Examples of psychosocial factors that have been influential in adherence to a rehabilitation plan are education, communication, goal setting, threats/scare tactics, social support, treatment tailoring, financial concerns, and sport/career concerns.¹¹⁴⁻¹¹⁸

Motivation & Energy: Perceived Susceptibility & Severity

Immediately after injury, a patient's perceived susceptibility will likely be high due to the injury. An injury diagnosis or plan of treatment can sometimes take a day or two to be established, leaving a patient in a state of uncertainty.^{96,116} During this time a patient's level of perceived severity may fluctuate as different members of the inter-professional health care team evaluate the patient.¹¹⁶ However, once a patient is provided with a diagnosis and a treatment plan their perceived severity is expected to stabilize. Then, as the rehabilitation process progresses, a patient's perceived severity

and susceptibility may oscillate. Some patients may have concerns about the likelihood of re-injury^{116,119-121} or the skill level attainable when the rehabilitation process is complete^{116,120} thus potentially elevating the level of perceived severity and susceptibility. Conversely, some patients may have a desire to return to activity early^{119,120} or may expect a quick fix for the injury¹¹⁹ lowering the level of severity or susceptibility perceived by a patient and thereby potentially lowering engagement in the rehabilitation process¹²⁰. Understanding a patient's perception after an injury is critical for the athletic trainer to deliver appropriate psychosocial interventions in the rehabilitation process. In addition, this description suggests that perceptions are dynamic throughout the rehabilitation process.

Deterrents & Path of Action: Perceived Benefits, Barriers, & Self-Efficacy

Another attribute to address is the perception of benefits and barriers to the rehabilitation process and the patient's self-efficacy during the rehabilitation process. If the barriers in the rehabilitation process are greater than the perceived benefits, his or her desire to adhere to the protocol will be diminished.^{105,106} Similarly, confidence in accomplishing the tasks required during the rehabilitation process may influence adherence.^{122,123} Physically active patients may perceive barriers to accessing athletic training services such as transportation, location, or scheduling of rehabilitation sessions.^{95,114,124} After sustaining an injury, mobility may be temporarily hindered requiring assistance with tasks previously accomplished independently with ease. An athletic training facility in a remote location or with a difficult entrance, such as multiple stairs, may contribute to a patient's perceived barriers to the rehabilitation process. The availability of a support system to assist with transportation and improve access may help

reduce a patient's anxiety about perceived barriers. Furthermore, a rehabilitation process requires an additional time commitment beyond an already busy schedule, between family commitments, work, academics, athletic commitments, and social activities. This can add additional stress and constraints to a patient's schedule, which may affect adherence. By considering a patient's schedule and academic or work deadlines (i.e.: tests and projects) when arranging rehabilitation appointments stress due to time demands may be reduced and adherence increased.^{95,124,125} One solution to address the transportation and scheduling barriers would be to conduct the rehabilitation during practice and/or conditioning times or during treatment time prior to practice. An athlete will already have this time set aside in their schedule and should be able to receive assistance from teammates. In the work setting, rehabilitation can be scheduled around breaks (such as an extended lunch) or alternatively a health care provider can create a mobile clinic to treat a patient at his or her place of work. Depending on the patient's exposure to a rehabilitation process he/she may or may not have a comprehensive understanding of the specific benefits provided by a rehabilitation process beyond the necessity of a rehabilitation process for return to play. The athletic trainer can capitalize on this situation and educate the patient on how the body processes the injury and why certain decisions in a rehabilitation process, such as rest or immobilization, are made. Informing the patient about the justification for different treatments can have a positive influence on adherence.¹²⁶ This suggests that education about the benefits from a rehabilitation process is important for athletic trainers to complete. By fully informing patients about the rehabilitation process, for a specific injury, ATs have the potential to maximize outcomes.

The athletic trainer can implement the proposed Physically Active Patient Centered HBM framework during the initial and subsequent stages of injury. The model can be used as a visual method to initiate and maintain conversation with the patient regarding the injury and the rehabilitation process. Specifically, the conversation can provide the athletic trainer insight about a patient's perceptions of the rehabilitation process and how those may influence the overall process. Table 3.1 provides a guide, with probing questions unique to each construct, for how an athletic trainer can utilize the HBM constructs when working with a patient. These questions are meant to stimulate conversation about the patient's perceptions within each construct. While the questions listed in table 3.1 will assist that athletic trainer during the conversation, the list is not an exhaustive list of all questions that may be applicable. Athletic trainers are encouraged to adapt the questions, create his or her own questions, or use established patient reported outcomes (PROMs) tailored to the construct of interest for the specific patient. The information gathered from the initial consultation and subsequent conversations will allow the athletic trainer to investigate factors affecting the rehabilitation process for a specific patient. Once factors are identified, additional psychosocial strategies to be discussed below can then be implemented to modify the factors to positively influence the rehabilitation process.

Psychosocial Interventional Strategies to Improve Adherence

Employing psychosocial interventions, such as communication, education, social support, goal setting, and treatment efficacy may improve adherence.^{114,127} While each of these interventions has been found to have a positive impact on adherence, the appropriateness of the strategy may differ based upon the situational and personal factors

perceived by each patient. It is the athletic trainer's responsibility to decide which interventional strategies are most appropriate based upon the perceptions described or demonstrated by a patient. Table 3.2 summarizes how an athletic trainer can utilize psychosocial intervention strategies to address perceived influential factors identified. The table categorizes questions an injured patient may pose to an athletic trainer based upon the HBM constructs. Additionally, appropriate psychosocial strategies have been listed as tools for the athletic trainer. An athletic trainer can utilize this table as a guide when preparing to speak or speaking with an injured patient.

Communication

Athletic trainers and athletes view communication as one of the most influential factors in adherence to a rehabilitation plan.^{95,96,114,128} This finding is justified as effective communication is integral to a patient's recovery.¹²⁹ The implementation of the Physically Active Patient Centered HBM framework in a rehabilitation process directly facilitates communication between an athletic trainer and physically active patient. For example, the initial and subsequent consultation periods provide a one-on-one session where a patient can divulge their experiences regarding the injury and the rehabilitation process. During this time it is important to express compassion for a patient's situation, as a caring relationship between a patient and athletic trainer is one of the largest factors associated with a success.⁹⁵ Furthermore, one-on-one time is preferred by athletes, and enables a patient and athletic trainer to develop and strengthen rapport between one another.^{95,96,128} A strong rapport is beneficial because patients may feel more comfortable expressing perceptions of susceptibility or barriers if this bond exists.

Perceptions may change throughout the rehabilitation process. Therefore, it is important for the athletic trainer to maintain clear and controlled communication.¹³⁰ Maintaining communication throughout the rehabilitation process will increase the likelihood that an athletic trainer will identify any changes in that patient's perceptions. Poor communication may result in a negative effect on adherence.¹²⁸ Athletic trainers can use communication as a cue to action for a patient. Cues to action such as, a text message or phone call, can encourage progress or to remind a patient of an upcoming treatment session. Depending on athletic trainers' patient volume and resources, automative systems, such as Demandforce (Demandforce Inc., San Francisco, CA), are available for automatic appointment reminders and scheduling. Furthermore, continual communication will help inform the athletic trainer of the patient's perceptions during the rehabilitation process and enable them to adjust interventions as needed.

Lastly, effective communication can provide a solid foundation for the patient – athletic trainer relationship to flourish. Athletic trainers can use mutual communication strategies such as listening support¹³¹, education^{95,114}, or positive-self talk¹³². Engaging in positive communication between the athletic trainer and patient, as well as the patient with himself/herself can have a constructive effect on the process. Athletic trainers can provide feedback on exercise performance as this form of communication has been reported to positively influenced adherence.^{126,133} Additionally, athletic trainers can encourage patients to engage in positive self-talk. Patients who engaged in positive self-talk were found to have a quicker functional recovery (strength, range of motion, and level of tenderness).¹³⁴ Positive self-talk examples are “I can do it. I can beat the odds” or “It's feeling pretty good” or “I can do anything”.¹³⁴ Negative self-talk examples are

“dumb mistake” or “stupid fool” or “why me?”.¹³⁴ Through positive and continual communication the athletic trainer can demonstrate to a patient his or her investment in recovery.

Education

Athletes frequently have an incomplete understanding of the injury and the rehabilitation required.¹¹⁹ In particular, a patient may perceive a disproportionate level of severity regarding his or her injury in relation to the actual severity of the injury.¹²⁸ Furthermore, adherence levels may vary based on the perceived level of injury severity.¹²⁸ Therefore, a relationship between the actual injury severity and adherence to the rehabilitation process cannot be assumed. An initial consultation appointment is the optimal time to further educate a patient about the injury and the rehabilitation process. Providing specific information to prepare the athlete for the work and commitment necessary to participate in the rehabilitation process can improve adherence.^{95,96,103,126,128} When educating a patient, specific details regarding the rehabilitation process should be emphasized, as athletes reported a preference for educational information specific to the rehabilitation process rather than detailed information on the injury.⁹⁵ Education should focus on the benefits, the commitment required, and the specific exercises/modalities employed. Continuing to provide education regarding the purpose of the exercises demonstrate to a patient the benefit of the treatment plan¹²⁸ and increase the likelihood of attendance.¹¹⁷ By implementing ongoing education the athletic trainer can create a transparent rehabilitation process where the expectations and benefits have been clearly outlined.

Goal Setting

Setting goals is one of the most common rehabilitation strategies used by athletic trainers.^{127,129} Long and short-term goals provide a patient with an end product on which to focus. The act of establishing a goal results in an internal cue to action. The goal should be challenging enough to maintain interest but still be achievable. Individuals with low self-efficacy can be easily deterred if perceived failures or barriers are encountered.¹³⁵ Additionally, a patient may get disinterested if the exercises are not challenging.^{120,136} Documentation of immediate results and progress is an important factor in adherence to a rehabilitation process.⁹⁵ As a patient successfully accomplishes each short-term goal they are more apt to self-evaluate themselves to be highly effective.^{135,137} A positive self-evaluation after a skill acquisition provides self-satisfaction^{135,137} and reveals the benefits and effectiveness of the rehabilitation process to the patient. Positively improving a patient's belief in the efficacy of the treatment can result in improved adherence, as treatment efficacy is a significant predictor in a patient's attendance.^{117,138,139} Together these findings illustrate that it is important to implement strategic goal setting in the rehabilitation process.

Social Support

Social support is a strategy that can be utilized to address perceived barriers, benefit, and self-efficacy. Social support is derived from multiple sources within a physically active patient's life e.g.: coaches, parents, teammates, colleagues, bosses/managers, athletic trainers, and friends. Yet, after sustaining an injury, athletes report feelings of isolation and lack of attention from others.¹¹⁶ Social support has been observed to be statistically different between adherent and non-adherent athletes, with

adherent athletes having greater social support.¹²⁴ Effort should be made to negate these feelings and ensure a physically active patient is supported in the rehabilitation process. For severe injuries the perceived social support of an athletic trainer is positively correlated with athletes' beliefs of treatment efficacy and self-efficacy.¹³⁶ An athletic trainer can demonstrate support by showing interest in the individual athlete and identify barriers to a rehabilitation process and propose solutions to the barriers. Positive support can be further offered by creating one-on-one time during a rehabilitation process, such as by providing direct supervision during therapeutic exercises.^{95,128} Athletic trainers can measure perceived social support through informal (conversation) or formal (PROMs such as the Social Support Survey¹⁴⁰) methods.

Involving teammates and coaches or co-workers and bosses in the rehabilitation process can minimize perceived barriers while improving self-efficacy. In fact, a survey revealed that approximately 60% of athletes stated that support from teammates was influential in adherence to a rehabilitation process.⁹⁵ Healthy teammates are able to minimize barriers such as transportation by assisting the athlete. Additionally, injured teammates and previously injured teammates may be able to serve as peer models increasing an athlete's confidence that recovery is attainable.^{114,136} Integrating the coach is important as well because acknowledgement and interest shown by the coach may allow an athlete to feel supported¹³⁶, increasing confidence, and diminishing feelings of neglect¹¹⁶ that can occur after being removed from competition. The interest of the coach in the rehabilitation program can further assist to increase an athlete's adherence to a rehabilitation process.¹²⁸ However, maintaining a balance in the number of people

involved in a rehabilitation session is important because too many teammates in one place can deter and distract an athlete's adherence to a rehabilitation program.⁹⁵

Conclusion:

Adherence to a rehabilitation program is critical for success following injury. The application of a theoretical framework during ongoing clinician-patient conversations throughout the continuum of care provides a systematic way to evaluate factors influential to adherence during a rehabilitation process. The HBM framework is broad enough to be applied to every physically active patient, yet the structure of the framework provides a standard guide to detect influential factors involved in the cognitive appraisal during the rehabilitation process. Athletic trainers are encouraged to utilize tables 3.1 and 3.2 as guides on how to apply the Physically Active Patient Centered Health Belief Model presented. The tables provide the athletic trainer with specific scenarios and interventional strategies based upon the constructs from the Physically Active Patient Centered Health Belief Model. Once influential factors are identified, the psychosocial strategies presented can be implemented to avoid poor outcomes. The athletic trainer will need to utilize his or her expertise when determining what psychosocial strategies to implement because physically active patients will present with varying perceptions and therefore enabling or disabling factors related to rehabilitation will also vary. The combination of the HBM framework described here with responsive psychosocial strategies can further enable an athletic trainer to provide a physically active patient centered approach that fosters adherence and optimizes rehabilitation outcomes.

Figure 3.1: The Health Belief Model constructs associated with the health behavior of rehabilitation adherence.

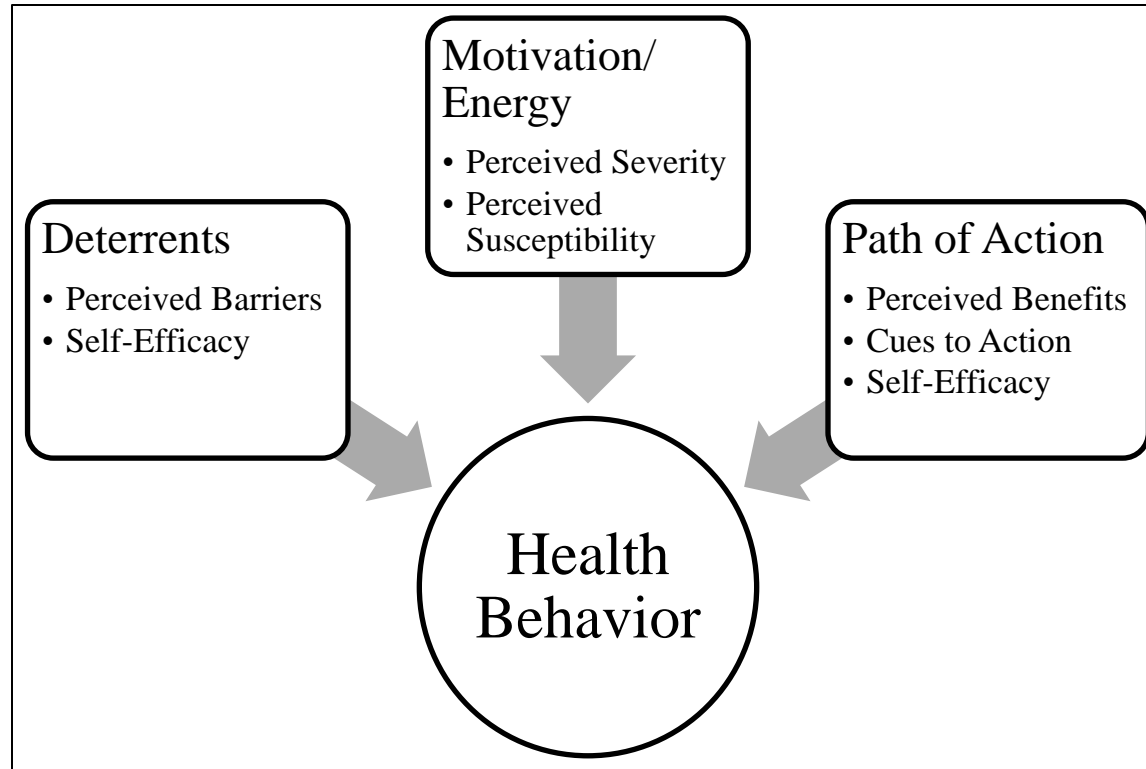
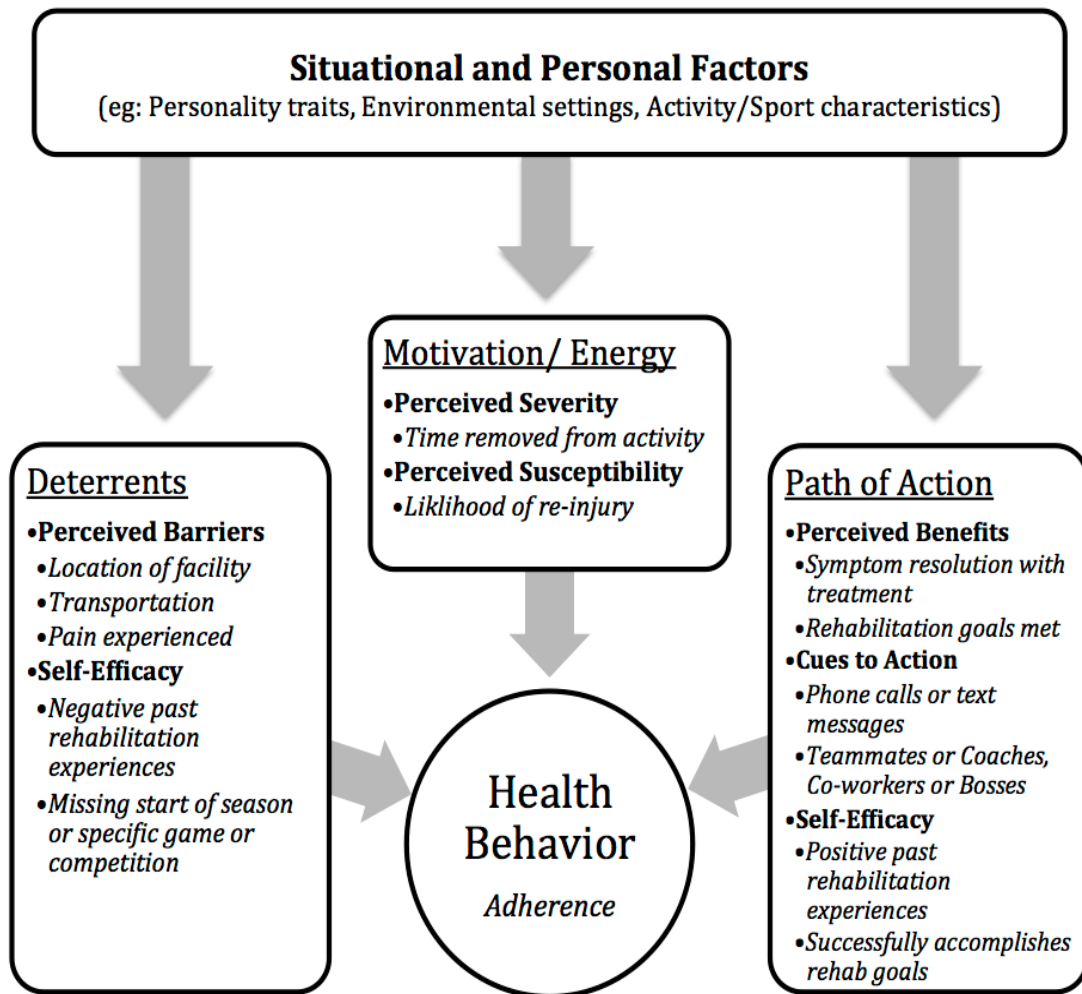


Figure 3.2: Depiction of the relationship between potential personal and situational factors encountered by a patient and the Health Belief Model (HBM) constructs.



Specific examples of personal and situational factors are listed below each HBM construct.

Table 3.1: Constructs within the Health Belief Model (HBM) framework and questions an athletic trainer can utilize when conducting a consultation with a patient.

HBM Constructs ^{105,106}	Definition	Questions to Identify Influential Situational and Personal Factors
Perceived Severity	The individual's interpreted seriousness of the injury	<ul style="list-style-type: none"> • Are there any long-term consequences from this injury that you believe may occur? • How has the injury impacted your normal day? • How do you feel the injury has impacted your ability to participate in activity?
Perceived Susceptibility	The individual's belief of vulnerability or risk to injury	<ul style="list-style-type: none"> • Are there other injuries you feel like you are at risk for experiencing? • Are you hesitant or fearful of doing certain activities due to your injury?
Perceived Barriers	The belief that there can be negative consequences that arise by changing the health behavior	<ul style="list-style-type: none"> • What do you believe will be an obstacle in the rehabilitation process? • Do you feel like anything negative can come from participating in the rehabilitation process?
Perceived Benefit	The individual's belief in the value of the actions required or the effectiveness of the treatment	<ul style="list-style-type: none"> • Do you feel that rehabilitation is required for you to return to activity? • How important is rehabilitation to you for regain your functional ability in both sport/physical activity and daily life? • What do you believe will be the most important factor in your recovery?
Self-Efficacy	The individual's belief in one's ability to control health change and execute health actions	<ul style="list-style-type: none"> • How confident are you in your ability to abide by the restrictions in rehabilitation? • To what degree do you feel you will be able to successfully complete the rehabilitation program? • How capable are you of actively participating in each rehabilitation session?

		<ul style="list-style-type: none"> • Have you participated in rehabilitation before? If so, how was your experience?
Cues to Action	Any factor stimulating an individual to action	<ul style="list-style-type: none"> • What are you most looking forward to in the rehabilitation process? • What are you least looking forward to in the rehabilitation process? • What motivates you achieve a goal? • How do you organize responsibilities and meetings? • Do you have any specific friends or family that are going to be assisting you during the rehabilitation process?

Table 3.2: Examples of potential patients' concerns within each construct of the HBM and psychosocial interventions an athletic trainer may implement to address each concern.

An Application of the Health Belief Model to the Rehabilitation of an Injured Athlete		
Construct	A Patient's Potential Questions	Interventional Strategies
Perceived Susceptibility	<ul style="list-style-type: none"> • Am I at risk for re-injury? • Will I have this pain for the rest of my life? • Why can't I return to activity earlier? 	<ul style="list-style-type: none"> • Education • Social Support
Perceived Severity	<ul style="list-style-type: none"> • Will I be able to return to my sport/desired activity? • Will I participate at the same level as before? • Other physically active patients have been able to return to activity prior to my return date. 	<ul style="list-style-type: none"> • Education • Social Support – Peer Modeling • Goal Setting
Perceived Benefits	<ul style="list-style-type: none"> • Will rehabilitation return me to the same activity level I was at prior to my injury? • How will these exercises do anything for me? • How can I return to activity for the beginning of season/competition date? 	<ul style="list-style-type: none"> • Education • Social Support • Goal Setting • Treatment Efficacy
Perceived Barriers	<ul style="list-style-type: none"> • How will I get to the athletic training facility? • I don't have the time to participate in a rehabilitation treatment due to other commitments. • My injury is too painful to do any rehabilitation. 	<ul style="list-style-type: none"> • Social Support • Communication

Self-Efficacy	<ul style="list-style-type: none"> • I don't know if I can do rehabilitation. • How confident am I in my ability to attend and participate in rehabilitation? • How confident am I in my ability to do exercises that may cause me discomfort? 	<ul style="list-style-type: none"> • Social Support • Goal Setting • Communication
Cues to Action	<ul style="list-style-type: none"> • How long do I have to wear my brace? • When can I wear high-heels again? • What will make the pain go away? • Can I participate in a pick-up game or recreational activity with my family and/or friends? • Did you tell coach/boss about my progression in rehabilitation? 	<ul style="list-style-type: none"> • Education • Communication • Goal Setting

Chapter 4: Patient Oriented, Strength, and Functional Outcomes Following the Implementation of a Home-Based Neuromuscular Electrical Stimulation Treatment in Articular Cartilage Repair Surgery Patients

Introduction

In a review of arthroscopic knee surgery, 60-63% of patients with a mean age of 43 had an articular cartilage defect.⁷ Patients with these defects frequently present with pain, swelling, and mechanical symptoms.³ Articular cartilage has a limited ability to self-heal² and when left untreated increases the risk for osteoarthritis (OA) progression.^{12,13} Osteoarthritis is a progressive joint degeneration disease that affects approximately 27 million people in the United States¹⁴¹, with the most common treatments for knee OA being a total knee arthroplasty (TKA), osteotomy, or unicompartmental replacement.¹⁴² In 2007 the total estimated cost of total knee arthroplasty surgeries performed in the U.S. was \$9.2 billion.¹⁶ Due to the limited longevity of the procedure, TKA surgery is frequently reserved for older patients with OA. For younger patients with articular cartilage defects surgical repair and restoration procedures (for example: autologous chondrocyte implantation, osteochondral allografts, and microfracture) are available to reduce the risk of OA progression and the symptoms associated with articular cartilage defects.

Surgical procedures to address articular cartilage defects have resulted in positive outcomes.¹⁴³⁻¹⁴⁵ However, a challenge with articular cartilage repair procedures is the extended non-weight bearing time after surgery, with the progression to full-weight bearing beginning around 6 weeks post operation.^{51,146} The extended period of time of non-weight bearing is necessary to protect the chondrocyte graft, but also results in significant muscle atrophy. Post-surgical quadriceps strength deficits as large as 33% after 1 year and 26% after 2 years when compared to preoperative values have been

documented after articular cartilage repair surgery.¹⁴⁷ In addition to deficits in quadriceps strength, lower extremity function has also been documented to be at a deficit both 1 and 2 years after articular cartilage repair surgery.^{44,148} Since muscle function as well as joint motion are critical factors to maintain joint health, a decline in muscle strength and mobility may result in a steep acceleration to the progression of posttraumatic OA.^{48,50} This progression creates an environment which potentially compromises the surgical procedure performed. Therefore, it is necessary to investigate clinically feasible techniques available to address post-operative quadriceps strength deficits.

Neuromuscular electrical stimulation (NMES) is a treatment modality that has been used to recover quadriceps muscle strength after surgery.⁶¹ The addition of electrical stimulation to the muscle allows a greater number of motor units to be activated that are otherwise inhibited during a post-surgical voluntary contraction.¹⁴⁹ Neuromuscular electrical stimulation treatments have commonly been administered in a clinic setting due in part to NMES unit size and cost. Recently new portable NMES devices with present-day technology, such as the Kneehab (Biomedical Research Ltd, Galway, Ireland) and the Phoenix, (Empi, DJO Global, St. Paul, Minnesota), have become available to health care providers. Portable NMES treatments offer health care providers the opportunity to prescribe an NMES treatment in a home setting, thus allowing patients to participate in a higher volume of exercise with the added benefit of electrical stimulation outside of the traditional supervised setting. In other patient populations (anterior cruciate ligament reconstruction and TKA patients) portable NMES units had a significant effect on post-operative quadriceps strength.^{53,70} It is important to determine if a portable NMES

treatment administered immediately post-operative during the non-weight-bearing phase of rehabilitation can be effective in articular cartilage patients.

Therefore, the primary purpose of this randomized controlled trial was to investigate the effect of a post-surgical, 12-week, home-based NMES treatment regimen on objective isometric quadriceps strength following articular cartilage repair surgery. The secondary purpose of the study was to investigate the effect of the home-based NMES treatment regimen on lower extremity function (Y-balance test) and patient reported outcomes (Knee Injury and Osteoarthritis Outcome Score). Lastly, we explored the longitudinal treatment effect of the home-based NMES treatment program on isometric quadriceps strength, lower extremity function and subjective function over 1 year post-surgery. The results of this study will provide clinicians with an intervention to target muscle weakness commonly documented after articular cartilage surgery. We hypothesize that a post-operative home-based NMES treatment will result in greater isometric quadriceps strength improvements at 3-months when compared to the current standard of care treatment.

Methods

Participants

Patients between the ages of 10-60 years with an articular cartilage defect in the knee were recruited from an active cartilage center in an orthopedic sports medicine clinic between August 2014 and December 2016. Patients were included if they underwent a surgical procedure to repair an articular cartilage defect in the knee and were willing to complete a prescribed home-treatment program. Participants were excluded if they had a pacemaker, diagnosis or family history of a neurological disorder, or currently

were utilizing a home NMES device. Prior to participation participants completed an informed consent form approved by a university institutional review board. After a warm-up on a stationary bicycle patients completed isometric quadriceps strength, lower extremity function (Y-balance test), and patient reported outcome assessments preoperatively and post-operatively at 3-months, 6-months, and 1 year. The first author (CEWC) conducted all testing, however due to limited resources the tester was not blinded to group assignments. Nevertheless all outcome measures were standardized with objective values recorded upon testing completion and the order of testing was counterbalanced. For all assessments the non-surgical limb was tested first followed by the surgical limb.

Randomization and Interventions

A block randomization scheme stratified by surgical procedures was utilized to randomize the patients into either an NMES treatment groups or a standard of care treatment group. Randomization was concealed utilizing sealed envelopes. Group placement was assigned after the patients had consented and completed preoperative testing. Patients were provided instructions (verbal and a paper copy (Appendix A & B)) and shown how to perform the designated home treatment program (the NMES or the standard of care quadriceps set exercises) after randomization.

Patients in the standard of care group were instructed to generate a strong isometric quadriceps muscle contraction for 4 seconds followed by a 10 second rest for a 15 minute treatment duration while in full knee extension. The home-treatment program began on the 3rd post-operative day and continued for 12 weeks post-operatively. The treatment was prescribed for 5 days a week, 3 times a day, for 15 minutes a session.

A portable NMES device, Phoenix, (Empi, DJO Global) was implemented for the home NMES treatment. The patients were instructed to perform an isometric quadriceps contraction with the onset of the electrical stimulus. A square biphasic waveform was utilized at a frequency of 75Hz, a pulse duration of 300us, and a duty cycle of 4 seconds on and 10 seconds off. Patients were positioned in full knee extension due to post-operative restriction and instructed to actively contract with the stimulation. The patients in the NMES treatment group were prescribed the same dosage of treatment as the standard of care group. The home-treatment program began on the 3rd post-operative day and continued for 12 weeks post-operatively. The treatment was to be performed 5 days a week, 3 times a day, for 15minutes a session. Patients in the NMES treatment group were required to demonstrate correct device set-up, the ability to turn on the machine, and increase the intensity. Patients were instructed to continually increase the intensity of the NMES treatment both during a session and over the treatment length. Furthermore, patients were informed that the intensity level should be uncomfortable but not to a level requiring the patient to increase pain medication.

Patients were to record treatment adherence with a provided home diary log (NMES treatment Appendix A, Standard of Care treatment Appendix B). Furthermore, a compliance monitor within the NMES device recorded treatment adherence for the patients in the NMES treatment group. All patients were prescribed post-operative physical therapy and provided a standardized physical therapy protocol during their first post-operative clinic visit. The home-treatment program was conducted as an adjunct to the standard physical therapy prescription.

Outcome Measures

Lower Extremity Function

The Y balance test (YBT) is a commercially available product created to measure lower extremity dynamic stability.¹⁵⁰ The test is reliable^{150,151} and has been used to assess a wide variety of patient populations¹⁵²⁻¹⁵⁵. Each participant was instructed to stand on a block in the middle of 3 PVC pipes that are constructed to resemble a “Y” (Figure 4.1). The participant maintained stance on the center block and with the reach leg pushed a box as far as possible in one of the specific direction. The 3 directions were: anterior (ANT), posteromedial (PM), and posterolateral (PL). After attaining maximum reach distance in the specific direction the participant then returned the reach leg to the beginning position while maintaining his/her balance. Four practice repetitions per direction were provided followed by 3 test repetitions per direction. The order of the reach directions was ANT, PM, and PL. The participant was required to stand with his/her hands on his/her hips. A repetition was discarded and repeated if the participant removed his/her hands from his/her hips, elevated the stance heel, touched down on the ground with the reach leg, placed weight on top of the slide block, or kicked the block. To account for differences in leg length the reach distance was normalized to the participant’s leg length.¹⁵⁶ The maximum reach for the three trials (normalized to leg length) was recorded for each direction (ANT, PM, PL).

Isometric Knee Extensor Strength

Isometric quadriceps strength was assessed using the portable BTE Evaluator digital dynamometer (BTE Technologies, Baltimore MD).^{157,158} The protocol previously published required the patients to be in a seated position with his/her arms across the chest and a strap across the pelvis to stabilize the hips. The patients’ knee was at 90° and

hips were at 85° degrees of flexion.^{157,158} The portable load cell was attached via an ankle strap proximal to the malleoli and secured to a box behind the patient (Figure 4.2). The patients were provided 3 practice repetitions for familiarization. Participants were instructed to contract approximately 20% of perceived maximum initially, then 50% of perceived maximum, and lastly with maximal force. The participants were encouraged to gradually attain a maximum contraction force during the first second and discouraged from immediately exploding into the contraction. Following the practice trials, participants were instructed to perform three maximal voluntary isometric contractions (MVIC's) for five seconds with a 15 second rest between each trial. Verbal encouragement and a visual display (BTE data collection screen) were provided to give participants feedback during the test. Peak torque of the three trials for the surgical and the non-surgical limb was recorded. To convert all values to Newton-meters (Nm), the shank was measured from the lateral condyle to the mid-point of the ankle strap.

Patient Reported Outcome

Self-reported function was assessed through the Knee Injury and Osteoarthritis Outcome Score (KOOS) (Appendix C). The KOOS contains questions about the participants' knee function and how their function affects their daily life and activity level. The KOOS includes 5 individually scored sections: symptoms, pain, function in daily living, function in sport and recreation, and knee-related quality of life. The KOOS is a reliable and responsive instrument in cartilage patients.^{22,37} The form was completed electronically as part of a larger patient registry.

Statistical Analysis

A sample size of 40 was determined to be necessary based upon a prospective power analysis. The difference in the primary endpoint, isometric quadriceps peak torque

strength at 3 months, between groups was tested using an effect size of .60.⁷⁰ A sample size of 17 per group was necessary to detect an interaction between groups over time at 80% power and an alpha level of 0.05. To account for potential participant drop out the sample size was increased to 20 per group.

Normality was assessed with a Shapiro-Wilks test. All variables were normally distributed except for normalized quadriceps strength on the surgical limb, KOOS activities of daily living score, and KOOS sport and recreation score. After assessing the Q-Q plots for the variables that violated normality it was determined that a pattern was not present. Therefore, parametric tests were utilized for statistical analysis. Independent t-tests were utilized to compare baseline demographics between groups. Additionally, change scores between baseline and 3-months were calculated between each dependent variable. Change scores were calculated to determine if the patients had exceeded the minimal clinically important difference for the KOOS instrument.

For the primary purpose of the study, a repeated measures ANOVA was used to compare each dependent variable (isometric quadriceps strength, YBT, KOOS) between baseline and 3-months. A second repeated measures ANOVA was performed to compare each dependent variable (isometric quadriceps strength, YBT, KOOS) across time (baseline, 3-months, 6-months, and 12-months). This analysis was conducted to determine the longitudinal treatment effect recognizing that fewer subjects would be available for the analysis.

To evaluate treatment adherence, the number of hours the patients recorded performing the treatment (patient diary log and NMES compliance monitor) was divided by the total treatment minutes prescribed and was multiplied by 100 for a percentage. The

percentage of self-reported adherence was compared between the groups using an independent t-test. Statistical significance for all analyses was set to $p < 0.05$ a priori. IBM SPSS Statistics version 23 (IBM, Corp., Armonk, NY, USA) was utilized for all statistical analyses.

Results

Forty-seven patients were screened for the study (Figure 4.3). A total of 17 patients were excluded from the study: 6 patients were enrolled in a different clinical trial, 1 patient had a neurological disorder, 3 patients had previous use of the interventional NMES device and had intentions to use the device after surgery, finally 7 patients declined participation due to the time commitment. A total of 30 patients were consented and enrolled in the study. One patient never underwent surgery or completed baseline testing resulting in a total of 29 patients. From the time of baseline testing to 3-months, 3 patients were lost to follow-up and 1 is currently within the 3-month testing window. Therefore, a total of 25 patients were included for analysis at 3-months. At 3-months 3 patients had not achieved weight bearing and were unable to perform the YBT functional testing. Patient demographics and baseline testing variables are presented in Table 4.1 and Table 4.2 respectively. There were no significant differences between the groups for any demographic or baseline variables.

Change scores for each dependent variable at 3-months are presented between groups in Table 4.3. At 3-months post-operative we did not find any statistical differences between groups for any dependent variable (Table 4.4). There was a main effect for time for 4 dependent variables. Both the surgical limb normalized quadriceps strength ($p < 0.00$) and the quadriceps strength limb symmetry index ($p < 0.00$) decreased significantly and the non-surgical limb anterior reach distance increased significantly

($p=0.02$) between baseline and 3-months. Lastly, the patients had a statistically significant improvement in KOOS pain scores between baseline and 3-months.

To explore the effect across 12-months a 2x4 repeated measures ANOVA was run to compare each dependent variable between the independent variables of group (NMES, Control) and time (baseline, 3-months, 6-months, 12-months). These results are presented in Figures 4.2 – 4.6. There was no group effect for any dependent variable. There was a statistical improvement over time for the surgical limb normalized quadriceps strength ($p=0.03$) (Figure 4.4), limb symmetry index ($p=0.05$) (Figure 4.6), surgical limb YBT posteromedial reach ($p=0.02$) (Figure 4.7), KOOS symptoms ($p=0.01$), KOOS pain ($p=0.02$), KOOS activities of daily living ($p=0.04$), and KOOS knee related quality of life ($p<0.001$) (Figure 4.8). Change scores for the KOOS at all time points are presented in Table 4.5.

Self-report adherence documented through patient diary logs for all patients was calculated overall and between groups. Twenty-three patients completed the patient diary logs (12 NMES, 11 Control). The overall average self-reported adherence to the prescribed treatment was $55.89\pm 34.53\%$ (NMES $60.00\pm 37.75\%$, Control $48.13\pm 37.00\%$) ($p=0.56$). Documented adherence from the patients in the NMES groups is presented as a mean and standard deviation. We also present the median and the range because we noted that the data was positively skewed. The NMES compliance monitor was $25.49\pm 25.32\%$ and median 13.78% (2.64%, 72.14%) ($n=11$). NMES adherence values are categorized in Table 4.6.

Discussion:

The primary purpose of our study was to determine the effect of a 12-week home NMES treatment on isometric quadriceps strength at 3-months post surgery in articular

cartilage knee patients. Our hypothesis that quadriceps strength would increase in the NMES group was not supported. There were no between group differences for isometric quadriceps strength. For our secondary purposes, there was no group effect to explain the effect of a 12-week home NMES treatment on lower extremity function (YBT) and patient reported outcomes (KOOS) 3-months post surgery in articular cartilage knee patients.

Isometric Quadriceps Strength

There was no effect for time or group for the non-surgical limb at 3-months or when analyzed across the first post-operative year. Preoperative average strength for the non-surgical limb quadriceps strength was $2.32 \pm 0.8 \text{ Nm/kg}$ decreasing slightly to $2.13 \pm 0.55 \text{ Nm/kg}$ at 3-months. These values were found to be similar to the preoperative value of $2.29 \pm 0.5 \text{ Nm/kg}$ in patients with articular cartilage defects reported by Thoma et al.¹⁵⁹ Similar findings were reported in a group of ACI patients who were followed longitudinally for 1 year. There was no statistical difference between preoperative and 1 year isokinetic strength values on the non-surgical limb.⁴⁶ This suggests that the non-surgical limb remains relatively stable across the first post-operative year.

While no difference in surgical limb strength was found between groups there was a difference across time. When compared to previous research, the preoperative surgical limb average quadriceps strength in our cohort was slightly higher with the quadriceps strength being $1.77 \pm 0.8 \text{ Nm/kg}$ when compared to $1.65 \pm 0.7 \text{ Nm/kg}$ reported by Thoma et al.¹⁵⁹. When compared to other patient populations our preoperative surgical limb values are a third less than what has been reported preoperatively for anterior cruciate ligament patients ($2.6 \pm 0.6 - 2.8 \pm 1.1$)^{160,161} but approximately 25% stronger than patients undergoing a TKA surgery ($1.33 \pm 0.6 \text{ Nm/kg}$).⁵³ Quadriceps strength of the

surgical limb was statistically lower at 3-months when compared to preoperative values and 12-month values. Additionally, quadriceps strength at 6-months was statistically different than strength values at 12-months. However, we found no statistical difference between baseline values when compared to 6-months values and 12-months values. This suggests that patients progressively increased quadriceps strength after 3-months post-surgery. It is interesting to note that patients do not exceed baseline scores during the first post-operative year. The loss of quadriceps strength at 3-months and the gradual progression in strength makes intuitive sense due to the rehabilitation restrictions placed on patients. Specifically that weight bearing is strictly controlled during the first 3-months post-operatively.⁵¹ During this time patients progressively increase the amount of weight they can bear in their surgical limb until they reach full weight bearing. Full weight bearing is commonly seen between 7 – 12 weeks post-surgery.⁵¹ Furthermore, strength progression during the first year is consistent with other post-operative strength evaluations in articular cartilage patients.^{42,46} Patients undergoing either a microfracture or an ACI demonstrated isokinetic quadriceps strength deficits at 6-months post-operatively while progressively increasing at 9-months, 12-months, and 24 months post-operative.⁴² Similarly, matrix-induced autologous chondrocyte implantation (MACI) patients were found to have no statistical difference between preoperative and 1 year measures of isokinetic quadriceps strength on either the surgical limb or the non-surgical limb.⁴⁶ Subsequently, the MACI patients continued to experience an increase in quadriceps strength for both the surgical and non-surgical limb at 2 years post-operatively.⁴⁶ Thus, quadriceps strength on the surgical limb is slow to improve during the first post-surgical year. However, while not documented in our study, patients may

surpass preoperative strength values by 2-years post-operative. In summary, the progression of post-surgical quadriceps strength is reduced at 3-months post-surgery and subsequently improved at 6-months, but approaches baseline values at 12-months post-surgery.

When evaluating limb symmetry index values the same trend over time found in the surgical limb values was evident. There was a statistical difference in the overall limb symmetry index (LSI) between baseline (76.44%) and 3-month testing (53.86%), with the 3-month value dipping below baseline values. There was an improvement at 6-months and values approached baseline at 12-months. The average preoperative LSI value in our patients (82.67%) was slightly higher when compared to previously reported LSI values in ACI patients (78%)^{42,46}. This difference may be attributed to the method of strength testing; our study utilized isometric testing compared to an isokinetic protocol for ACI patients in the previous studies^{42,46}. Research shows that as velocity increases during strength testing torque decrease.¹⁶² Thus it is not surprising that the patients in this study were able to generate greater peak torque values during an isometric contraction when compared to an isokinetic contraction. Nevertheless, a LSI value of 82% is still below the clinically desired level of 90%³⁹ suggesting the participants in this study were weak before the surgery and remained weak after the surgery.

A main finding in this study was the overall trend of persistent quadriceps weakness documented during the first post-operative year in the surgical limb and the LSI. Clinically it is desired to have a quadriceps strength limb symmetry index above 90%.³⁹ Strength deficits below a 90% threshold have been associated with functional impairments such as deficiencies in gait mechanics¹⁶³, and lower single leg hop

performance.¹⁶⁴ In our sample of patients, while strength values improved, overall limb symmetry indices did not exceed 80% after surgery. Persistent quadriceps strength deficits have been documented up to 5 – 7 years^{46,165} after articular cartilage surgery with peak isokinetic values^{42,46} and total work values¹⁶⁵ not exceeding 80% until 2 years after surgery. The inability to regain quadriceps strength earlier in the post-operative recovery is potentially concerning for the longevity of the cartilage repair. Women with low quadriceps strength, defined as a hamstring to quadriceps ratio of >0.6 , were found to be at increased risk for joint space narrowing compared to women with high quadriceps strength.¹⁶⁶ Furthermore in a different cohort a combination of a loss in quadriceps strength and lower Cincinnati knee scores were found as a risk factor for symptomatic radiographic OA.¹⁶⁷ Thus, the very patients who underwent surgery to address a cartilage defect are potentially at risk for damaging the surgical site or the surrounding cartilage due to post-surgical strength deficits.

Lower Extremity Function

Functional performance on the YBT statistically improved in the anterior reach direction on the non-surgical limb when the preoperative and 3-month time points were compared in the 2x2 ANOVA. Additionally, the reach distance on the non-surgical limb at 3-months was similar to values reported in a healthy population.¹⁵¹ Evaluating anterior reach performance on the nonsurgical limb across time (preoperative, 3-months, 6-months, and 12-months) in the 2x4 ANOVA a statistical difference between preoperative values and 3-month values was not found however a trend was seen ($p=0.07$). The lack of statistical significance in the longitudinal analysis may be attributed to the decreased sample size in the analysis. The improved reach distance at 3-months may be attributed to the patients depending more on the non-surgical limb during the restricted weight

bearing period the first 3-months after surgery. However, this does not explain why the reach distance in the posteromedial or the posterolateral directions on the non-surgical limb were not different at 3-months.

While there was no statistical difference in the non-surgical limb anterior reach distance across 12-months there was a statistical difference in the surgical limb posteromedial direction. Patients reached further at 12-months than at preoperative, 3-month, and 6-months. Additionally, reach distance at 6-months trended higher than the 3-month value ($p=0.06$). Furthermore, visual (Figure 4.7) assessment of the patients' performance in the posteromedial direction on the surgical limb mirrors the trend seen in surgical isometric quadriceps strength values and LSI values across 12-months. These findings suggest that while patient performance may decrease at 3-months, by 6-months patients will continually improve from preoperative values in the posteromedial reach distance on the surgical limb.

To our knowledge this is the first report of the YBT performance in this population. Previous research supports a similar recovery trend with a dip at 3-months followed by improvements to baseline scores at later time points. For example a similar trend was reported for other low impact performance testing (step-up and-over and forward lunge)⁴⁴ and in 6-minute walk times in ACI patient¹⁶⁸. When compared to preoperative values it was reported patients increased the lift-up force when performing a step-up and-over task at 3-months, 6-months, and 12-months.⁴⁴ Similarly 3-month impact index values (%BW) during a forward lunge task decreased when compared to preoperative values. Impact values then returned to preoperative values by 6-months and exceed preoperative values by 12-months.⁴⁴ For the 6-minute walk test the distance

patients were able to walk in 6-minutes dropped from 492m preoperatively to 434m at 3-months.¹⁶⁸ This distance improved at 6-months and surpassed the preoperative distance by 12-months post-operative. Similar to our YBT reach distance results for the surgical limb posteromedial direction, both studies demonstrated that performance on low impact lower extremity functional tasks falls below preoperative values and does not approach or exceed preoperative values until 1 year after surgery. Based upon our results the posteromedial direction of the YBT may be another low-impact functional task clinicians can use to document post-surgical progress during the first year in this population.

In a higher impact one-leg hop functional test battery a deficit similar to what we found for low impact function task performance is seen in ACI patients.⁴² During a single leg cross over hop and a single leg hop preoperative mean limb symmetry index of 88% dropped to 81% for the cross over hop and to 73% for the single leg hop 6-months after surgery.⁴² Similarly for a single leg timed hop preoperative values were documented to have a mean limb symmetry index of 86% which dropped to 78% at 6-months after surgery.⁴² While values for all the hop tests improved at 9-months and at 12-months, only 77% of patients exceeded the desired 85% LSI value at 2 years after surgery, and this was only for the crossover hop and the timed hop.⁴² Furthermore, performance on the crossover hop and the timed hop tests did not exceed preoperative values until 2 years after surgery for the ACI patients.⁴² Deficits were still present 2 years post-operative for the single leg hop with mean limb symmetry index values reaching 83%.⁴² Overall, at 2 years only 68% of the ACI patients exceeded the 85% LSI goal.⁴² In comparison, the recovery in performance on the higher impact hop test

battery⁴² showed deficits for a longer period of time after surgery when compared to the surgical limb YBT posteromedial performance documented in this study.

Due to the differences in functional performance between low and high impact assessments a clinician may wish to keep a patient's goals in mind when selecting functional tests to evaluate recovery. It is possible deficits present on higher impact tests may not reflect activities in a patient's daily life because some patients may not have participated in such task preoperatively for reasons other than the joint injury. Thus high impact testing assessment may not be as clinically meaningful when evaluating progression in rehabilitation for that patient. The surgical limb performance in the posteromedial direction on the YBT provides clinicians with a clinically available low-impact assessment to track a patients' recovery. This information may assist clinicians in the selection of a functional test to document a patients' post-surgical recovery.

Performance of a single limb anterior reach has been reported to require the greatest activation of the quadriceps muscle when compared to other reach directions.¹⁶⁹ Thus, it was initially anticipated that in the anterior reach direction we would see a decrease in performance at 3-months that would gradually improve until 12-months post-operative. However, we did not find any differences over time for reach distance in the anterior direction. A potential explanation for this may be that patients self-selected alternative movement patterns when performing the specific task. When performing the functional task patients self-reported feeling hesitant to "unlock" the knee and go into more knee flexion for fear of the knee "giving out". Similarly patients reported believing they could reach further if they felt more comfortable "unlocking" the knee. This observation aligns with documented performance on the star excursion balance test, a test

similar to the YBT, in anterior cruciate ligament reconstruction patients.¹⁷⁰ When performing the anterior reach direction on the SEBT anterior cruciate ligament patients were found to have less knee flexion, less hip flexion, and more hip adduction when compared to a healthy control group.¹⁷⁰ Furthermore, a similar finding of decreased knee flexion during a preoperative functional task was reported in a cohort of patients with articular cartilage defects.¹⁵⁹ During stair ascent it was reported that the patients had less knee flexion in the knee with the articular cartilage defect than the uninvolved knee.¹⁵⁹ Furthermore knee extension moment was reduced in the involved knee when compared to the uninvolved knee and the knee of a matched control.¹⁵⁹ The authors suggested that this difference in the knee moment may highlight an avoidance strategy used by the patients to decrease the demand on the involved limb's quadriceps muscle.¹⁵⁹ This pattern of self-selecting alternative movement patterns on the injured limb when performing a functional task may be similar to the quad avoidance pattern seen in gait after anterior cruciate ligament surgery.^{163,171} While there was no difference in walking velocity, at peak knee flexion anterior cruciate ligament patients categorized as weak (<80% LSI) were found to have a reduce knee moment and a trend for reduced knee angle compared to a control group.¹⁶³ Thus patients are able to accomplish the task of walking to the same degree as a control group, however different strategies are utilized to accomplish the task. In our study the self-reported hesitation to go into a larger degree of knee flexion may have been because of a reduction in stability due to quadriceps weakness resulting in compensatory strategies with patients depending more on a hip strategy. However, since we did not systematically measure kinematic motions when performing the YBT we cannot confirm this theory. Further investigation into movement

strategies utilized during functional tasks will assist in identifying the differences in movement strategies and there in turn compensations clinicians can address in rehabilitation.

Patient Reported Outcomes

Patient reported outcomes measured by the KOOS improved over time for four of the five subscales. Specifically we found improvements from preoperative values in the pain, symptoms, activities of daily living, and knee related quality of life subscales at 6-months and at 12-month. Additionally, symptoms improved from 3-months to 6-months and activities of daily living improved from 6-months and 12-months. When limiting the analysis to only a comparison between preoperative and 3-month values there was a statistical improvement in pain between preoperative scores and 3-month scores ($p=0.02$). This may suggest that pain scores improve significantly within the first three months after surgery.

Our values were similar to what has been reported in ACI populations by Ebert et al¹⁷² and Robertson et al¹⁶⁸. However the symptoms score in this study appeared to be lower, meaning more symptomatic, at all time points and our sport and recreation scores appear to be higher, meaning a higher perceived function level, at all time points. In the symptoms subscale, preoperatively our value of 53 was similar to the 50.4 reported by Robertson et al¹⁶⁸ but lower than the 68 in the traditional weight bearing group and the 78 in the accelerated weight bearing group reported by Ebert et al¹⁷². However, our score of 72 at 12m is similar to the score of 72 reported at 4 years in a group of ACI patients with prior microfracture surgery¹⁷³ and approached the score of 79 at 12-months reported by Robertson et al¹⁶⁸. However, our score at 12m was still lower than 83 reported in the tradition weight bearing group and 81 reported in the accelerated weight bearing group

by Ebert et al.¹⁷² From these data it would appear that while our patients reported more symptoms initially after by 12 months post-surgery they recovered to a level similar to other ACI patient populations.

Our sport and recreation score was higher than what was reported by Robertson et al¹⁶⁸. This difference was most pronounced at the 3-month time point. Slight similarities are seen between our reported preoperative values of 36 and the preoperative value of 29 and 22 reported by Ebert et al¹⁷². However, at 3-months our patients reported a score of 32 while Ebert et al¹⁷² reported a score of 11 and 6 and Robertson et al¹⁶⁸ reported a 4.3. Furthermore, while our 12-month values trended closer to the values reported by Ebert et al¹⁷² and Robertson et al¹⁶⁸ they were still elevated. Our patients reported a sport and recreation score of 57 at 12-months whereas Ebert et al¹⁷² does not report a score of that magnitude (55 and 61) until 2 years after surgery and Robertson et al¹⁶⁸ never reported a score of that magnitude. This subscale of the KOOS requires the patient to rate their level of difficulty squatting, running, jumping, twisting on the knee, and kneeling. These are motions that are more commonly associated with sporting activity. It is possible that the differences in the sport and recreation scores are due to differences in the reported average age of the patients. We had an average age of 29 years while both Ebert et al¹⁷² and Robertson et al¹⁶⁸ reported an average age over 36. While the mean age between the studies is close, it may be possible that the younger aged patients were more active and potentially participating more frequently in sport activities.

The overall improvement seen in our patients from preoperative scores to 6-months and from preoperative scores to 12-months exceeded the minimal clinically importance difference suggested for the KOOS (8 – 10 points).³⁵ Symptoms improved by

22 points at 6-months and 23 points at 12-months. Pain improved by 10 points at 6-months and 14 points at 12-months, activities of daily living improved by 8 points at 6-months and 13 points at 12-months. Sports and recreation improved by 11 points at 6-months and 23 points at 12-months. Lastly, knee related quality of life improved by 12 points at 6-months and 21 points at 12-months. Furthermore, while the differences from preoperative values and 6-months and 12-months exceed the suggested 8 – 10 point range³⁵, the differences for symptoms, pain, and activities of daily living at the different time points also exceeded recently suggested minimal clinically importance difference for the KOOS in articular cartilage patients (symptoms 9, pain 14, and activities of daily living 10 respectively).¹⁷⁴ Specifically, symptoms exceeded a 9 point change at both 6-months and 12-months, pain exceeded a 14 point change at 12-months, and activities of daily living exceeded a 10 point change at 12-months. This suggests that the differences in our patients at 6-months and 12-months are improvements that are clinically meaningful and demonstrate change beyond that of chance. While we did not find differences between groups, these findings support that overall patients' perceptions for symptoms, pain, and activities of daily living were improved following the surgery and subsequent rehabilitation.

The changes in the KOOS subscale between preoperative and 12-month values found in our study are in the range reported in other articular cartilage surgery patients. Five years after an ACI surgery a 17 point change in symptoms, a 19 point change in pain, a 16 point change in activities of daily living, a 33 point change in sports and recreation and a 32 point change in knee related quality of life were reported.¹⁷⁵ Overall the amount of change we found in each KOOS subscale score was less than the ACI

cohort¹⁷⁵ with the exception of the symptoms score. The change we saw in our pain subscale and activities of daily living subscale was slightly less compared to the change reported in the ACI cohort¹⁷⁵. While the change we found for both sport and recreation and the knee related quality of life was 10 points less than what was reported in the ACI cohort¹⁷⁵. Lastly, our reported change in symptoms was slightly greater than the ACI cohort¹⁷⁵. One explanation for this may be found in the preoperative symptoms score reported by our patients. When comparing to others in the literature our values were slightly lower implying that our patients were more symptomatic than comparative cohorts^{168,172}. Therefore, if our patients had a lower symptom score to start there may be more room for them to improve over time without having a ceiling effect. When we compared our results to Vanlauwe et al¹⁷⁵, time from surgery was potentially an explanation for why we found a smaller degree of change in KOOS scores. Our patients were tested at 12-months post-surgery compared 5 years post-surgery¹⁷⁵. It is interesting to note that the progression of KOOS scores over 5 years post ACI implantation supports a continual improvement in scores over time.¹⁷⁶ Thus, it would be expected that patients 5 years out of surgery would have a greater amount of change when compared to preoperative values than patients 12-months out of surgery.

While all KOOS subscale improved when preoperative values were compared to 6-months post-operative (except for sport and recreation) this was not the case for the strength assessment and YBT assessment. Strength values did not reach or approach preoperative values until at least 12-months after surgery and the surgical limb posteromedial YBT direction did not reach preoperative values until 6-months after surgery. Improvements in patient reported outcome scores before functional performance

is an observation that has been previously reported by others in the literature. Howard et al⁴⁴ reported improvements from preoperative values in the IKDC, SF-36, Lysholm, and WOMAC patient measures at 6-months. However, values on several performance-based measures (weight bearing squat, step-up and over, and lung) did not approach preoperative values in many instances until 12-months post-surgical.⁴⁴ Similarly improvements for a 6-minute walk task did not reach preoperative values until 12-months post-surgical as reported in the study by Robertson et al¹⁶⁸ However, preoperative value improvements on all KOOS subscales were presented when seen 6-months post-operative.¹⁶⁸ This trend suggests that after knee surgery patients perceive improvements in patient reported outcomes; however these improvements may not be identifiable on function and strength assessments. In a lengthy rehabilitation program as required for articular cartilage rehabilitation this information is valuable. This information can be used to educate the patients on what to expect in rehabilitation. Specifically, patients can be informed that they may start to feel better before they are actually able to perform tasks better or at a level they are accustomed to.

Adherence

A central factor potentially contributing to the lack of group differences in this study is the treatment adherence of the patients. A high level of adherence has been defined as 80% of the prescribed treatment.⁵³ However, documentation of treatment adherence is limited in many if not most post-surgical studies. In our study, we collected adherence through two measures: traditional patient self-report diaries and an objective compliance monitor within the NMES device. According to our patient diary our overall treatment adherence was 55.85% with the NMES group reporting a slightly higher level of adherence (60.00%) than the control group (48.13%). Adherence to our home

treatment program was lower than what has been reported in patients being treated for low back pain.¹⁷⁷ In the patients treated for low back pain adherence to a 4-week home exercise treatment was 71.6%.¹⁷⁷ However our adherence level was closer to the adherence level of 62% that was reported for patients prescribed a home treatment program while in supervised physical therapy for various injuries.¹⁷⁸ Nevertheless, when compared to the desired 80% adherence level previously described both of our groups largely missed this threshold.

We had the luxury of having the NMES equipped with an internal timer so that we could objectively monitor adherence. We were able to document the amount of time that the device was active. Active was defined such that the electrode pads needed to be in contact with the skin and resistance was low enough that a current could be delivered, i.e. the device could not just be left on and time be recorded. The adherence level on the NMES device was much lower than the adherence level reported on the patient diary. The NMES group reported on the patient diary performing an average of 60% of the treatment that was prescribed. However, the average adherence recorded on the NMES device was 25.49%, approximately 34% less than what was reported on the patient diary log. The finding of patients overestimating the level of adherence to a prescribed program is not uncommon. Medication adherence was measured in cardiac failure patients by a patient diary and an electronic monitoring device in the cap on the medication bottle.¹⁷⁹ In patients that reported high medication adherence on a patient diary 14% – 54% of the patients were found to actually adhere less than 80% of the time when examining the objective adherence monitor.¹⁷⁹ This is of interest for in this study there was no objective measure to document treatment adherence in the standard of care

exercise group. Therefore, based upon the disagreement in subjective and objective adherence in the NMES it is presumed that this group also overestimated their treatment adherence.

Due to the lack of patient adherence to the prescribed treatment, conclusions regarding the treatment effectiveness are limited. However, home NMES treatments have been shown in the literature to have a positive effect on post-surgical quadriceps strength. After a 6-week home NMES treatment in total knee arthroplasty (TKA) patients were reported to have increase in quadriceps post-surgical strength at 3.5 weeks, 6.5 weeks, 13 weeks, and 52 week, respectively.⁵³ However in this study the authors reported that 77.4% of patients completed 80% or more of the prescribed treatment. Furthermore, lowering the adherence threshold to 50%, 96.8% of patients completed 50% or more of the prescribed treatment.⁵³ In our study only 14.3% of patients completed 50% or more of the prescribed NMES treatment and none of our patients completed over 80% of the prescribed treatment. The differences in levels of adherence between our study and the reported adherence in the TKA study may be an explanation for the different findings regarding the effect of post-surgical NMES.

What is unknown is what factors resulted in a lower level of adherence in our patients. An explanation between the levels of adherence between the TKA study⁵³ and ours may be the treatment supervision. In the TKA study patients had 3 days of inpatient physical therapy followed by 2 weeks of home physical therapy.⁵³ The supervised treatment in the home setting appeared to keep patients accountable, for 83.9% of patients completed 80% or more of the treatment during the first two weeks post-operative.⁵³ Once supervision was reduced, the level of adherence then dropped to 77.4%

for week 3 and continued to drop under 65% for the remainder of the treatment time.⁵³ The level of adherence reported once supervision was reduced is similar to the adherence level of 75.5% reported for a 12-week home NMES treatment study.⁷⁰ While patients in the 12-week treatment study were not supervised it was not reported if any measures were implemented to influence adherence such as phone calls, home visits, or clinic visits.⁷⁰ In our study patients were contacted bi-weekly either by phone or in-person at scheduled clinic visits. However, no patients crossed the 80% threshold and only 14.3% of patients completed between 50-80% of the prescribed treatment. It is possible that if the patients were visited in the home setting similar to the TKA study adherence levels may have been greater.

Another factor that may have contributed to the level of adherence in our study is the length of the prescribed treatment. Our treatment time was the first 12 weeks after post while the TKA study that found a treatment effect for NMES had a prescribed treatment length of 6-weeks after surgery⁵³. However, our prescribed treatment time was similar to the 12-week treatment time utilized by Feil et al⁷⁰ in ACL patients that reported a treatment effect for a home NMES treatment. Nevertheless, patients in our study reported finding time to perform the treatment difficult once they went back to work, increased the number of physical therapy visits, or increased their number of activities during the day as rehabilitation progressed. This aligns with a theme reported in a qualitative study examining ACL patient's experiences during post-surgical recovery. Patients in this cohort reported that the recovery process at times became secondary to other life priorities.¹⁸⁰ Our treatment time was initially selected to match the weight-bearing restriction placed on the patients post-operatively. The goal of our study was to

provide a therapeutic intervention to target the quadriceps muscle during this time with the hopes of improving strength outcomes. However, it is possible that the length of the treatment may have instead had a negative effect on treatment adherence. Further research is needed to determine what barriers to treatment adherence our patients experience and if steps can be taken by clinicians to increase treatment adherence in this population. Lastly, the implementation of patient education should be explored. Specifically, education should be tailored to inform the patient about the benefits of the prescribed treatment.

Our study sought to minimize the quadriceps strength loss documented after surgery by implementing a home NMES treatment. However, adherence to the prescribed treatment limited us from finding a group difference. The issue of adherence warrants further investigation. Specifically, future research should investigate what specific factors may contribute to post-surgical treatment adherence in this population. Furthermore, based upon the strength deficits documented on the surgical limb future research should also evaluate the most appropriate intervention treatments to improve this strength deficit in this patient population.

Limitations:

This study is not without limitations. One potential limitation to the study was the lack of blinding. The participants were not blinded to group allocation. Due to the stimulation sensation experienced by the NMES treatment, treatment group blinding was not feasible. A sham device could have been implemented; however, it was the desire of the researchers to compare two treatments in a realistic clinic setting. Secondly, the investigator measuring the outcomes after group allocation was not blinded. However,

steps were taken to address this limitation by utilizing outcome measures that objectively documented patient performance. Finally, a major limitation in this study was the lack of adherence to the prescribed home-treatment program potentially influencing the ability to find a difference between groups.

Conclusion:

Based upon our findings recovery in strength, function, and patient reported outcome scores after articular cartilage surgery is a slow process. After articular cartilage surgery patients have large quadriceps strength deficits on the surgical limb that persist at least a year after surgery. However, quadriceps strength does slowly improve over this period of time. Functional deficits in the posteromedial direction when performing a single-limb functional task on the surgical limb are seen initially after surgery followed by a gradual improvement. KOOS scores for pain, symptoms, activities of daily living and knee related quality of life improve by 6-months post-operatively. Lastly, there was no effect for a NMES home treatment program. However, more importantly patients minimally adhere to a prescribed homes NMES treatment program.

Funding:

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Table 4.1: Patient demographics for all the included participants.

	Total	NMES	Control	p-value
Number of Participants	N=29	n=14	n=15	
Gender (M/F)				
Males	17 (59%)	7 (50%)	10 (67%)	p=0.462
Females	12 (41%)	7 (50%)	5 (33%)	
Age (yrs)	29±10	30±11	29±9	p=0.906
BMI	28±6	28±6	27±6	p=0.720
Defect Size (cm ²)	5.53±2.87 cm ²	5.53±3.24cm ²	5.69±2.70 cm ²	p=0.992
Lesion Location				p=0.803
Medial Femoral Condyle	14 (48%)	6 (43%)	8 (53%)	
Lateral Femoral Condyle	10 (35%)	6 (43%)	4 (27%)	
Patella/Trochlea	3 (10%)	1 (7%)	2 (13%)	
Multiple Sites	2 (7%)	1 (7%)	1 (7%)	
Procedure				p=0.572
Autologous Chondrocyte Implant	11 (38%)	6 (43%)	5 (33%)	
Osteochondral Allograft	17 (59%)	8 (57%)	9 (60%)	
Particulated Juvenile Cartilage	1 (3%)	0 (0%)	1 (7%)	

Values presented as means±sd or number (%) where appropriate.

Table 4.2: Baseline mean and standard deviation values for all outcome variables.

	Total	NMES	Control	p-value
Isometric Quadriceps Strength (Nm/kg)				
Number of Participants	N=28	n=14	n=14	
Surgical	1.77±0.80	1.65±0.76 ^a	1.88±0.69	p=0.42
Non-Surgical	2.32±0.80	2.27±0.69 ^a	2.37±0.81	p=0.77
LSI (%)	76.49±18.04	71.39±15.34 ^a	81.23±19.59	p=0.16
Y-Balance Test				
Number of Participants	N=27 ^b	n=13	n=14	
Surgical Anterior Direction	58.49±10.00	57.46±6.59	59.45±12.55	p=0.61
Non-Surgical Anterior Direction	62.15±9.43	62.44±9.08	61.85±10.11	p=0.87
Surgical Posteromedial Direction	93.40±12.59	92.01±10.00	94.69±14.87	p=0.59
Non-Surgical Posteromedial Direction	101.97±15.07	99.41±16.37	102.98±14.03	p=0.54
Surgical Posterolateral Direction	88.18±13.71	84.95±11.13	91.18±15.54	p=0.25
Non-Surgical Posterolateral Direction	96.02±12.60	93.68±12.08	98.35±13.12	p=0.34
KOOS Questionnaire				
Number of Participants	N=28	n=14	n=14	
Symptoms	54.46±18.71	52.00±16.16	56.93±21.28	p=0.50
Pain	64.68±18.38	65.14±14.20	64.21±22.36	p=0.90
Activities of Daily Living	72.61±20.14	70.86±14.64	74.35±24.93	p=0.65
Sport and Recreation	36.07±29.86	29.29±25.26	42.86±33.38	p=0.24
Knee Related Quality of Life	30.64±18.70	26.79±19.48	34.50±17.74	p=0.28

^aOne patient's values were unable to be converted to Nm due to missing the shank length, NMES n=13. ^bDue to one patient being unable to perform baseline measuring on their surgical limb Total N=27, NMES surgical limb n=13.

Table 4.3: Change scores between baseline and three-month post-surgical for all outcome variables.

	Total	NMES	Control
Number of Participants	N=25	n=13	n=12
Isometric Quadriceps Strength (Nm/kg)			
Surgical	-0.63±0.67	-0.47±0.67	-0.80±0.66
Non-Surgical	-0.13±0.44	-0.13±0.51	-0.12±0.37
LSI (%)	-26.88±25.03	-18.56±20.69	-35.90±27.01
Y-Balance Test ^a			
Surgical Anterior Direction	-2.31±5.84	-0.15±4.31	-4.47±6.54
Non-Surgical Anterior Direction	3.67±5.41	4.10±6.04	3.25±4.95
Surgical Posteromedial Direction	-1.50±9.96	-0.65±9.62	-2.33±10.69
Non-Surgical Posteromedial Direction	2.32±8.75	1.65±8.25	3.00±9.59
Surgical Posterolateral Direction	-1.34±11.78	-0.10±14.53	-2.58±8.77
Non-Surgical Posterolateral Direction	1.50±7.72	-0.20±9.05	3.20±6.09
KOOS Questionnaire			
Symptoms	6.22±19.6	5.00±21.72	7.55±18.07
Pain	8.17±15.19	5.92±14.53	10.64±16.21
Activities of Daily Living	6.36±17.27	7.58±15.73	4.90±19.73
Sport and Recreation	-4.31±31.75	1.25±26.98	-11.00±37.03
Knee Related Quality of Life	5.17±17.17	3.67±15.00	6.82±19.90

Values presented as means and standard deviations. ^aDue to patients being unable to complete YBT testing Total N==22, N=11 for the surgical limb testing and N=11 for the non-surgical limb testing.

Table 4.4: Repeated measures ANOVA results comparing baseline and three-month post-surgical values for all outcome variables.

	Baseline	3-Months	p-value
Number of Participants	N=25	N=25	
Isometric Quadriceps Strength (Nm/kg)			
Surgical	1.72±0.70	1.09±0.58	p=0.18
Non-Surgical	2.26±0.76	2.13±0.55	p<0.00*
LSI (%)	76.44±18.78	49.56±17.05	p=0.00*
Y-Balance Test ^a			
Surgical Anterior Direction	58.02±10.64	55.71±9.21	p=0.07
Non-Surgical Anterior Direction	62.79±9.44	66.46±9.65	p=0.01*
Surgical Posteromedial Direction	93.19±13.34	91.70±13.05	p=0.50
Non-Surgical Posteromedial Direction	104.45±12.51	106.77±10.96	p=0.24
Surgical Posterolateral Direction	88.03±14.75	86.69±13.54	p=0.61
Non-Surgical Posterolateral Direction	96.90±11.39	98.41±12.78	p=0.37
KOOS Questionnaire			
Symptoms	53.57±18.76	59.78±19.48	p=0.15
Pain	64.83±20.12	73.00±19.28	p=0.02*
Activities of Daily Living	74.05±21.96	80.41±20.59	p=0.11
Sport and Recreation	36.36±30.79	32.05±29.69	p=0.48
Knee Related Quality of Life	32.77±17.51	36.78± 18.12	p=0.22

Values presented as means and standard deviations. P values presented are for time effect; *denotes significant differences between baseline and 3 months. Group effect p-values did not exceed 0.05 therefore are not presented. ^aDue to patients being unable to complete testing Total N=22, N=11 for the surgical limb testing and N=11 for the healthy limb testing.

Table 4.5: Change scores for the KOOS subscales during the first post-operative year.

Number of Participants	n=14	n=14	n=14
Time points	Preoperative – 3-months	3-months – 6-months	6-months – 12-months
KOOS Questionnaire Subscales			
Symptoms	8.43±18.84*	13.28±19.98*†	1.21±14.41
Pain	6.29±12.24	3.64±12.16	4.43±11.32
Activities of Daily Living ^a	4.77±11.13	3.46±7.69	4.50±7.56
Sport and Recreation ^a	-5.00±31.29	16.15±35.36*	12.50±26.00*
Knee Related Quality of Life	7.64±19.61*	3.93±15.24	9.07±20.11*
Time points	Preoperative – 3-months	Preoperative – 6-months	Preoperative – 12-months
KOOS Questionnaire Subscales			
Symptoms	8.43±18.84*	21.71±30.98*†	22.93±20.58*†
Pain	6.29±12.24	9.92±14.91*	14.36±12.79*†
Activities of Daily Living ^a	4.77±11.13	9.71±12.50*	14.21±12.18*†
Sport and Recreation ^a	-5.00±31.29	11.07±37.27*	23.57±35.16*
Knee Related Quality of Life	7.64±19.61*	11.57±16.75*	20.64±14.59*

Values presented as means and standard deviations. ^aN=13 for the activities of daily living and sport and recreation subscale.
 *Exceeded suggested MCID of 8 -10 points, †Exceeded recently suggested MCID values Symptoms=9 points, Pain=14 points,
 Activities of Daily Living=10 points, Sport and Recreation=28 points, Knee Related Quality of Life=28 points.

Table 4.6: Adherence to the prescribed treatment documented by the neuromuscular electrical stimulation device.

	n (%)	Percentage of Treatment Completed
Adherent (>80%)	0 (0%)	–
Moderately Adherent (50 – 80%)	2 (14.3%)	65%, 72%
Minimally Adherent (20 – 50%)	4 (28.6%)	14%, 22%, 39%, 41%
Non – Adherent (<10%)	5 (35.7%)	2%, 3%, 6%, 7%, 8%
Not Reported	3 (21.4%)	–

– denotes no patients within that adherence category.

Figure 4.1: Y-Balance Test (YBT) reach directions: (A) anterior direction, (B) posteromedial direction, (C) posterolateral direction

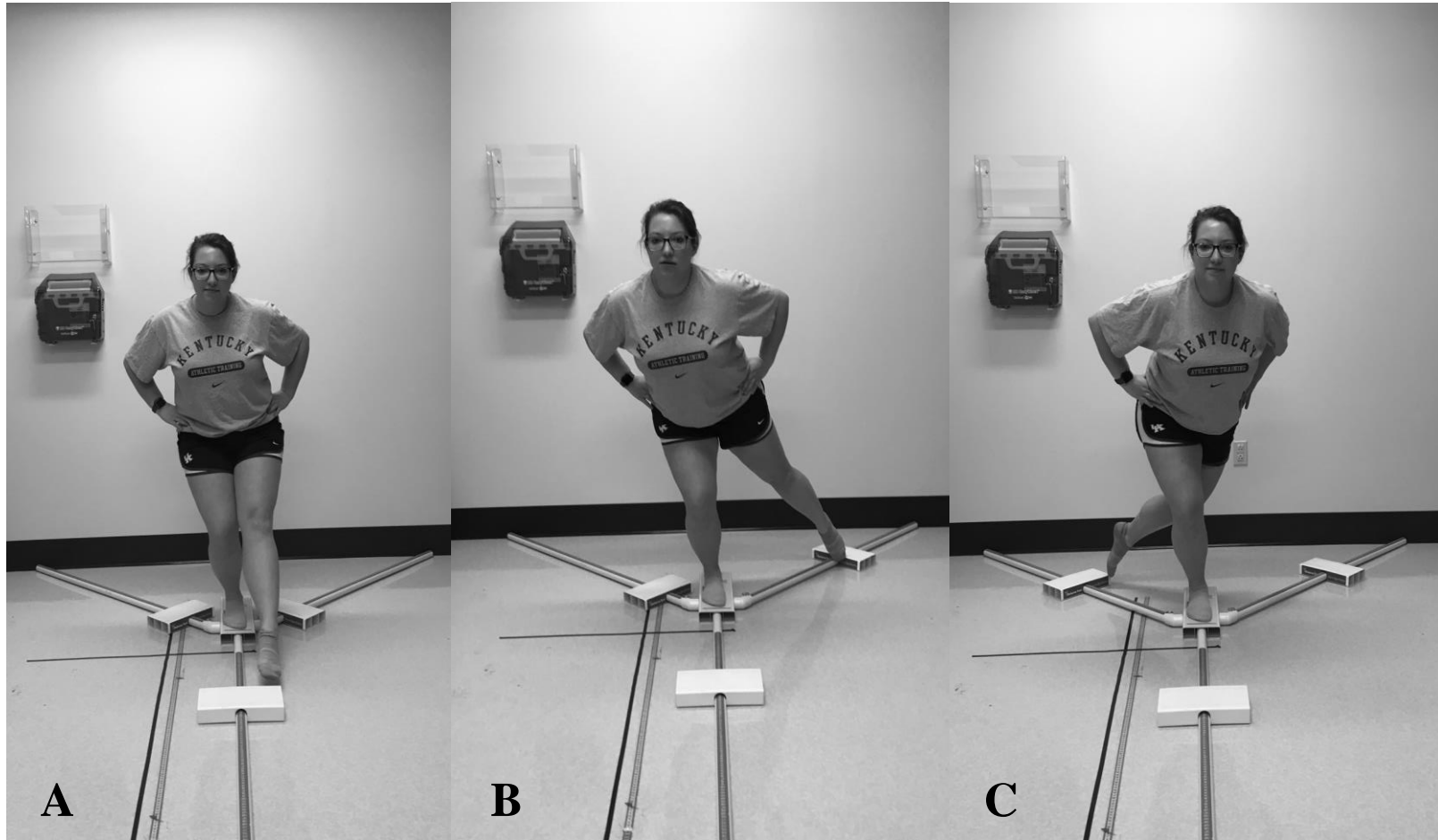
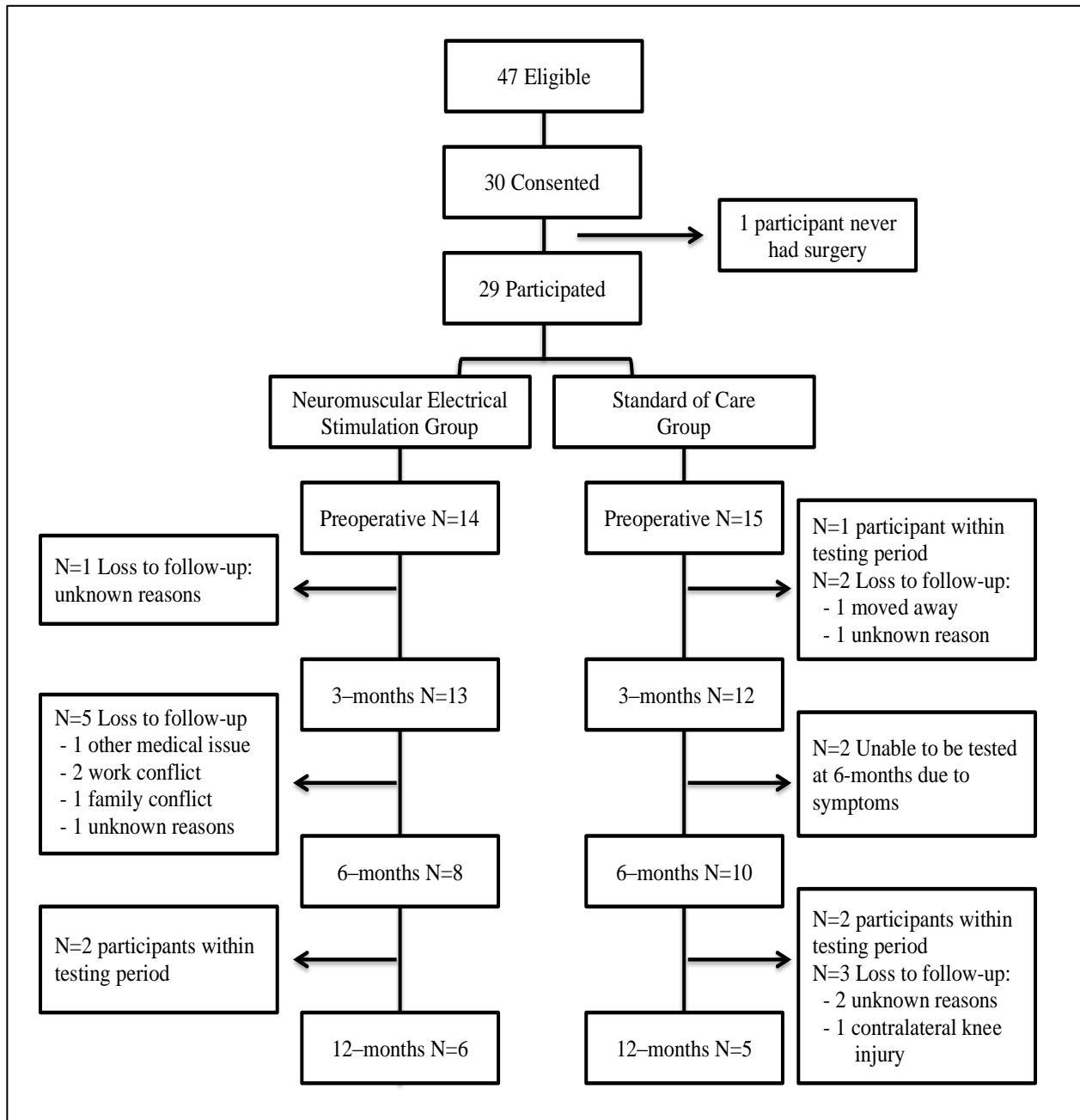


Figure 4.2: Seated isometric quadriceps strength testing set-up with a portable dynamometer.

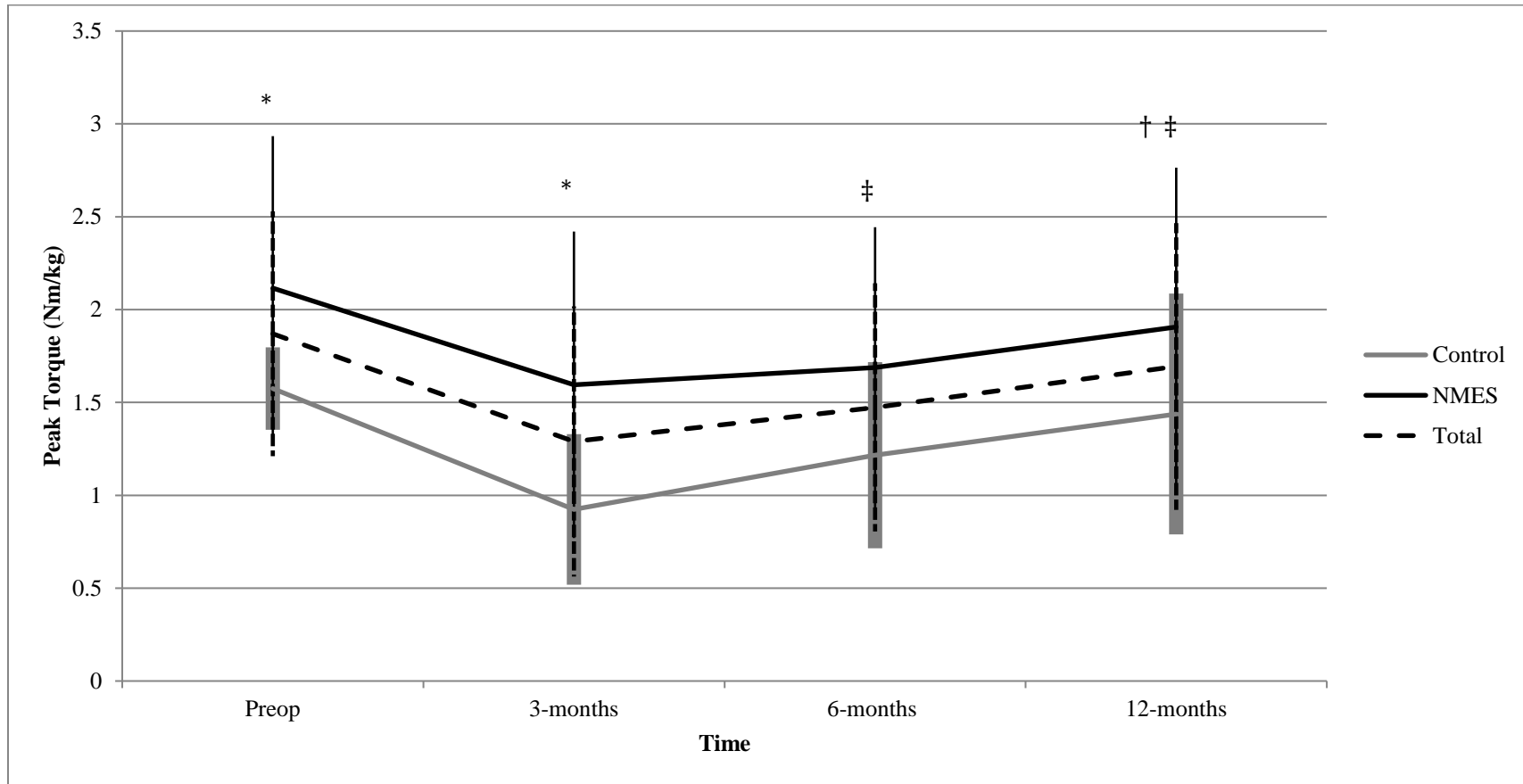


Figure 4.3: Recruitment and enrollment chart for all patients.



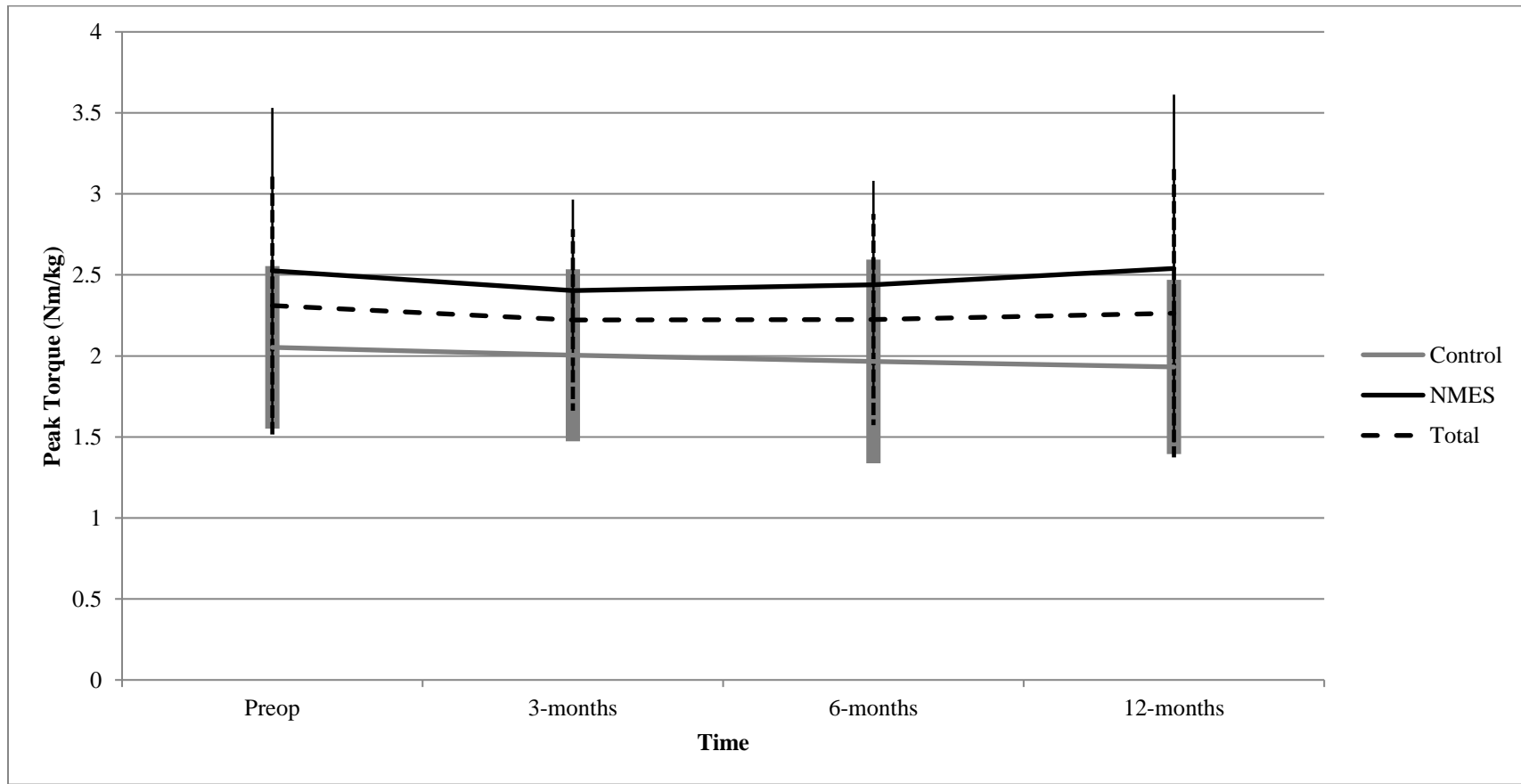
The number of patients that were a loss to follow-up are presented in the side boxes between time points.

Figure 4.4: Isometric quadriceps strength normalized to body weight for the surgical limb across time.



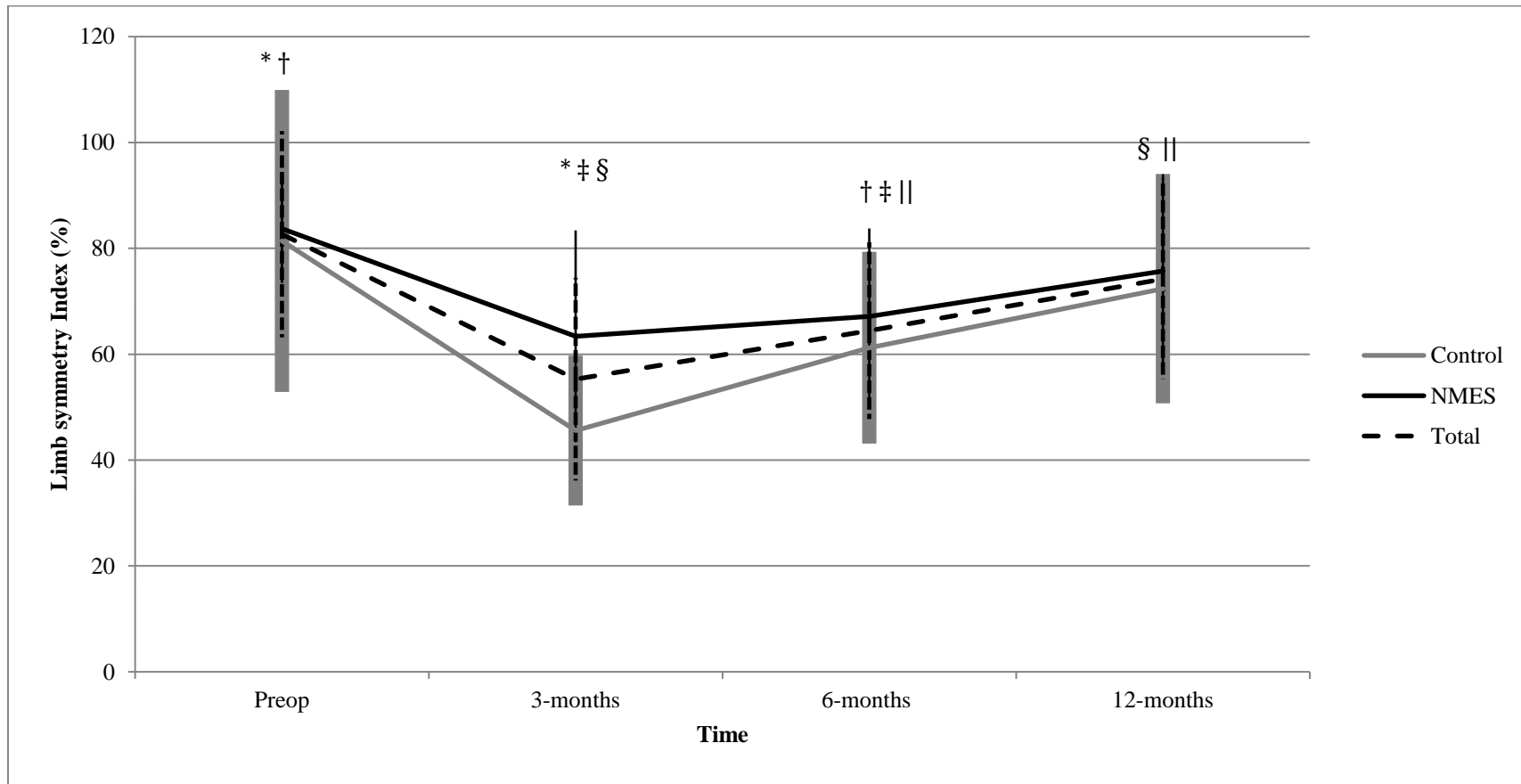
There was no effect for group ($p=0.82$) but there was an effect for time ($p=0.03$). *preoperative (preop) compared to 3-months (3m), †3-months compared to 12-months (12m), and ‡6-months (6m) compared to 12-months. n: Control 5, NMES 6.

Figure 4.5 Isometric quadriceps strength normalized to body weight for the non-surgical limb across time.



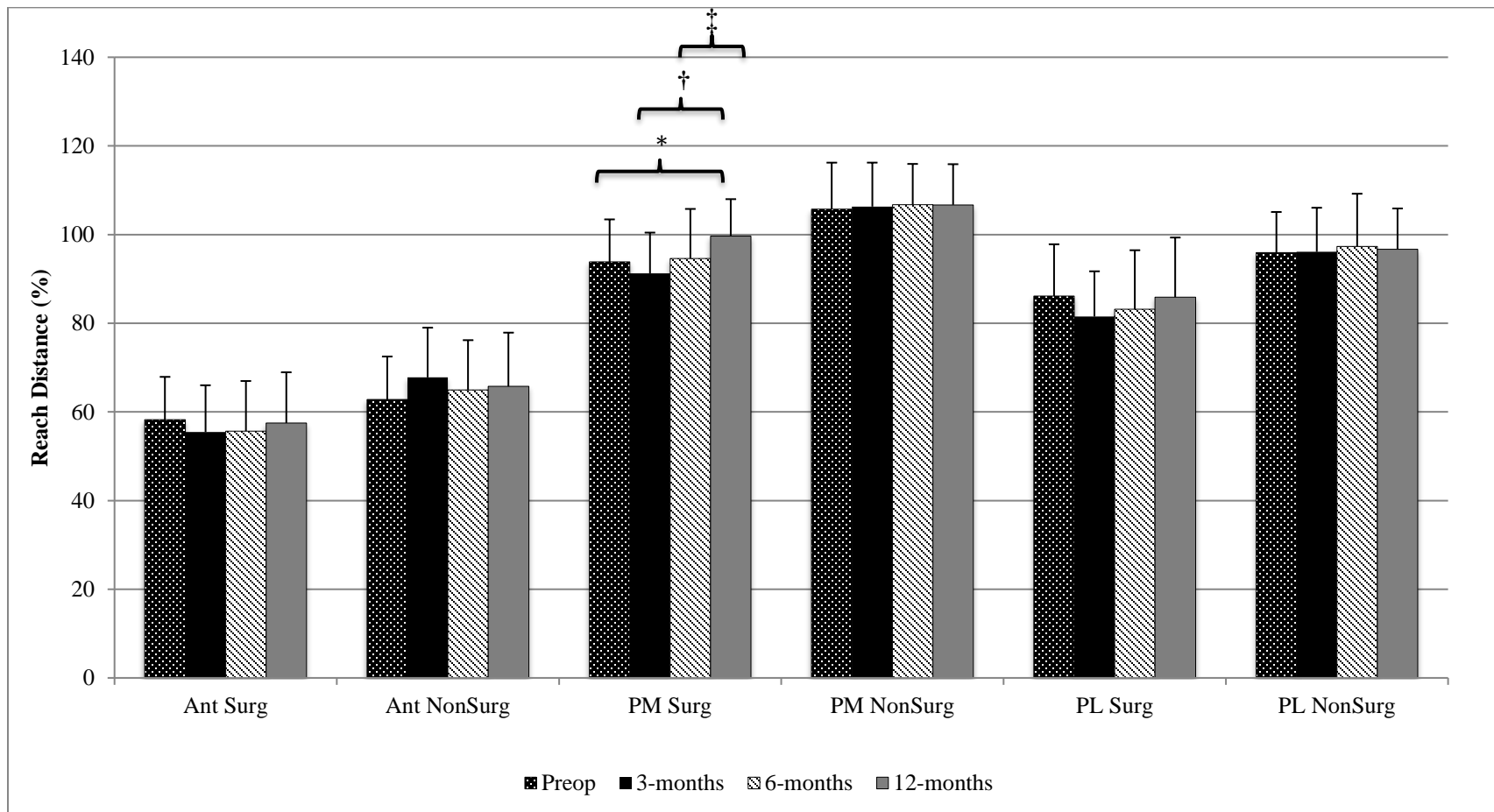
There was no effect for group ($p=0.92$) or time ($p=0.97$). N: Control 5, NMES 6

Figure 4.6: Limb symmetry index for isometric normalized quadriceps strength across time.



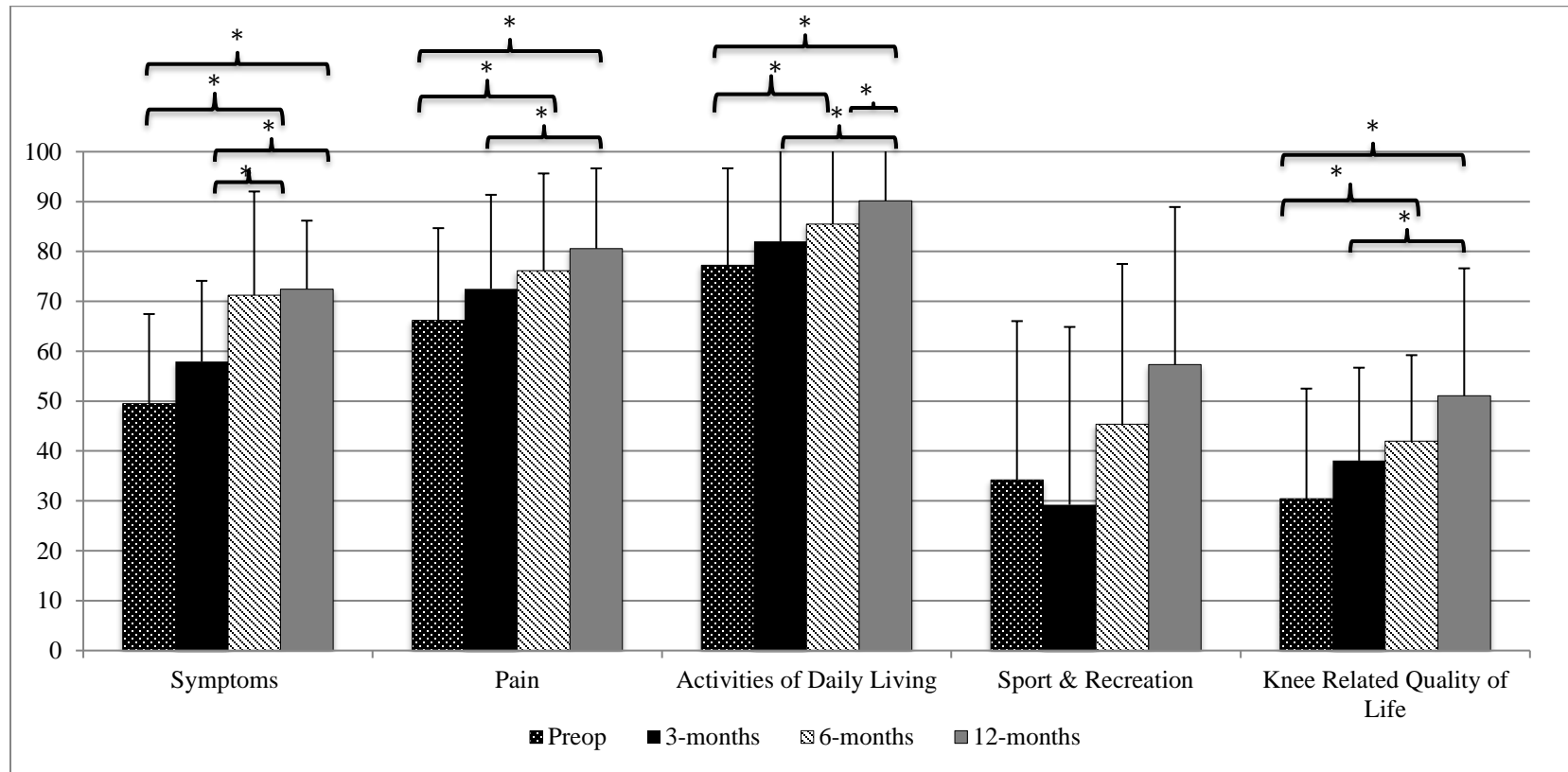
There was no effect for group ($p=0.55$) but there was an effect for time ($p=0.05$). N: Control 5, NMES 6. *preoperative (preop) compared to 3-months (3m), †preoperative compared to 6-months, ‡3-months to 6-months, §3-months to 12-months, and || 6-months to 12-months.

Figure 4.7: Y-balance test (YBT) performance in the anterior (ANT), posteromedial (PM), and posterolateral (PL) directions across time for both the surgical (Surg) and non-surgical (NonSurg) limbs.



There was a statistical significant effect for time in the surgical posteromedial direction, *preoperative (preop) compared to 12-months, †3-months compared to 12-months, and ‡6-months compared to 12-months. N: Control 4, NMES 6.

Figure 4.8: Knee Injury and Osteoarthritis Outcome Score (KOOS) sub-scales across time.



Statistical significant time effect for symptoms, pain, activities of daily living (ADL), and knee related quality of life (QL), *denotes significance between time points for the respective subscales. Symptoms, pain, ADL, & QL were statistically different between preoperative and 6m, preoperative and 12m, and 3m and 12m. Additionally statistical differences were present for symptom between 3m and 6m and for ADL between 6m and 12m. N: Control 7, NMES 7.

Chapter 5: Summary

The primary purpose of this group of studies was to investigate available rehabilitation treatment options for addressing post-surgical quadriceps weakness after articular cartilage surgery and to develop a model to explain a patients' adherence to a health care provider's prescriptions. The specific aims of the study were as follows:

- Specific Aim 1: To determine the most effective neuromuscular electrical stimulation (NMES) treatment parameters for post-operative quadriceps strength.
- Specific Aim 2: To propose a theoretical framework for influencing adherence to a post-surgical rehabilitation. From this aim we will (1) provide health care providers with a set of guidelines to systematically identify situational and personal factors that may contribute to the rehabilitation process and (2) propose interventions to address the factors identified.
- Specific Aim 3: To evaluate the effect of a 12-week home-based neuromuscular electrical stimulation treatment program compared to the standard of care on isometric quadriceps strength, functional performance, and subjective function at 3-month post-surgery in articular cartilage patients. *We hypothesize that a post-operative home-based NMES treatment will result in greater isometric quadriceps strength, improved lower extremity function and reported subjective function at 3-months when compared to the current standard of care treatment.*

Summary

Based upon our findings multiple conclusions can be made regarding post-surgical quadriceps weakness after articular cartilage surgery:

First, in specific aim 1 we found level B evidence to summarize and better explain the NMES parameters associated with large effect sizes for post-surgical quadriceps weakness. Specifically, we made recommendations for treatment intensity level, electrode size, frequency, initiation time of the treatment and the occurrence of treatment sessions. The parameter selection for waveform shape, pulse duration, current, and duty cycle were heterogeneous between studies. Therefore, a clear consensus on the effect of waveform shape, pulse duration, current, and duty cycle on post-surgical quadriceps strength could not be made. Nevertheless, our recommendations are the best available evidence at this time to choose the following parameters when utilizing NMES for post-surgical quadriceps strength: treatment intensity level, electrode size, frequency, initiation time of the treatment and the occurrence of treatment sessions.

Secondly, in specific aim 2 the health belief model was referenced to build a theoretical framework to identify factors that may influence patient adherence, the Physically Active Patient Centered Health Belief Model. To increase the clinical application of this model we presented interventional strategies that could be implemented to address treatment adherence. Influential factors were categorized under the specific constructs of the health belief model (perceived severity, perceived susceptibility, perceived barriers, perceived benefits, self-efficacy, and cues to action). Based upon these constructs we have presented questions a health care clinician can ask patients to facilitate and maintain clinician-patient conversation related to adherence. This framework provided by the Physically Active Centered Health Belief Model offers clinicians a guideline to systematically investigate factors influential to adherence. Additionally, the application of the adapted health belief model may assist health care

providers improve the clinician-patient conversation concerning treatment adherence and subsequently what interventional strategies that may be applied.

Lastly, in specific aim 3 we did not find a treatment effect for a 12-week NMES home treatment program on post-surgical quadriceps strength, lower extremity function, or patient reported outcome scores in articular cartilage patients. It is possible that the non-significant finding was due to a lack of patient adherence. Adherence objectively recorded on the NMES device suggested that overall patients did less than 26% of the prescribed treatment. Nevertheless, from our data we were able to describe quadriceps strength, lower extremity function, and KOOS patient reported outcome score recovery over the first post-operative year. Specifically, we found that post-surgical quadriceps strength on the surgical limb and the limb symmetry index values at 3-months drop below baseline values. However, after 3-months these values positively improved approaching baseline values 12-months post surgery. Secondly, we found that performance on the YBT did not change over time for the anterior direction or posterolateral direction on the surgical limb. The lack of a significant finding in YBT performance over time can be attributed to compensation movement strategies substituted by patients. We did find changes in the posteromedial direction with performance surpassing baseline values by 12-months after surgery. Lastly, we found that the values for symptoms, pain, activities of daily living and knee related quality of life statistically improved surpassing baseline values at 6-months. Out of the dependent variables utilized in our study to document outcomes after surgery the KOOS was the outcome to show the earliest post-surgical improvement. Specifically, the KOOS scores highlighted progress before improvements were documented in function performance and strength values. This suggests that

patients may perceive progress before improvement is documented through objective measurements of function and strength.

Future Research

Multiple future research directions were born out of this series of studies. The first direction is exploration of factors influential to a patients' adherence to treatment and interventions, such as patient education, that may be implemented to minimize non-adherence in this population. The second direction is investigation of alternative treatments that could assist in recovering quadriceps strength after surgery. A final direction is the investigation of movement compensation strategies adopted by patients after articular cartilage surgery.

A primary area of future research focus would be to focus on patients' adherence to a home-treatment program. Many factors can contribute to a patients' level of adherence thus it is difficult to explain our level of non-adherence to one specific variable. Theories such as the Health Belief Model have been created to help health care providers identify factors unique to a patient that may contribute to a patient's level of adherence. The implementation of such a theory during the rehabilitation process may help clinicians and patients identify and address potential factors that would influence adherence. Specifically, when examining our prescribed treatment, the length of the prescribed NMES treatment may have influenced patients' level of adherence. Patients in our study reported it difficult to find time to perform the home treatment once they went back to work, increased the number of physical therapy visits, or increased their number of activities during the day as rehabilitation progressed. A qualitative study on patient experiences after an ACI procedure found a similar theme in the patient's

recovery. Patients in this cohort reported that the recovery process at times became a secondary focus compared to other life priorities.¹⁸⁰ While it is impossible to avoid all factors influencing adherence implementing such a theoretical model continually through the rehabilitation process may help a patient identify life priorities that may deter treatment adherence.

Another area of future research should focus on the parameters of patient education and the role of expectations. The trend of early improvement seen in the patient reported outcome scores over the first post-operative year could assist clinicians in educating patients what to expect during the post-operative recovery and rehabilitation. Specifically the knowledge that many patients initially experience reductions in perception of pain followed by improvements in symptoms, activities of daily living and knee related quality of life at 6-months can be conveyed to patients to educate them on the longevity of the rehabilitation progress. Patients have reported that they expected the rehabilitation process to progress quicker.¹⁸⁰ Furthermore, the length of the rehabilitation process was noted as a source of frustration for patients in turn reducing motivation making adherence to home programs difficult.¹⁸⁰ Providing patient education explaining the recovery process may help patients modulate expectations after surgery.

Patients in this study were found to present with persistent quadriceps weakness on the surgical limb after surgery. While strength values did improve over time patients did not approach baseline values until one year after surgery. This finding is similar to what has been reported in the literature for strength recovery after articular cartilage surgery. While the intervention we selected did not have a treatment effect it is possible other interventions, such as blood flow restrictive therapy, may be beneficial. Blood flow

restrictive therapy has been shown to have a moderate to high effect on post-surgical strength while performing low-intensity exercises.¹⁸¹ Future research should evaluate treatment interventions that can be implemented to address the quadriceps weakness documented.

Lastly, the movement strategies patients utilized to accomplish functional tasks after articular cartilage surgery are not well understood. In our study it was found that patients' performance relatively did not change over time for the Y-balance test with the exception of the posteromedial reach on the surgical limb. It is theorized that this non-significant finding may be due to compensatory movement strategies implemented by the patient, specifically, a quad avoidance movement strategy. Future research should investigate the movement strategies implemented in this patient population. This information will assist clinicians in both evaluating patients progression in rehabilitation through appropriate test assessment selection and in the identification of deficits to target in rehabilitation.

Appendix A: Neuromuscular electrical stimulation home treatment diary

Name: _____

Instructions:

- ❑ **Step 1** Perform the quadriceps exercises with the garment prescribed to you for the research study. You will perform this treatment on program 2 (P2) for 20 minutes. The first 2 minutes of the treatment is a warm-up period to get you accustomed to the stimulation. After the warm-up period, a 15-minute exercise-period will
- ❑ **Step 2** After you have completed the 20-minute treatment, please perform the home exercises prescribed by your therapist. (If you have already completed the prescribed exercises today please proceed to step 3).
- ❑ **Step 3** If you desire to apply ice, Cryocuff, or Game Ready to your knee please do so once you have completed all of your exercises.

Additional Information:

If your physical therapist has prescribed you to do the same exercise you currently perform for the research study. Please perform each set of exercises separately.

It is possible that the amount of exercises prescribed by your therapist will be different than the amount prescribed by the study. Please treat each exercise program individually.

Please don't hesitate to call if you have any questions (859) 218-0578

Thank you for your time!

Treatment Session 1			Treatment Session 2			Treatment Session 3			Completion of PT prescribed exercises (Y/N)
Time	Intensity	Pain	Time	Intensity	Pain	Time	Intensity	Pain	

Week 1

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 2

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 3

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Treatment Session 1			Treatment Session 2			Treatment Session 3			Completion of PT prescribed exercises (Y/N)
Time	Intensity	Pain	Time	Intensity	Pain	Time	Intensity	Pain	

Week 4

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 5

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 6

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

	Treatment Session 1			Treatment Session 2			Treatment Session 3			Completion of PT prescribed exercises (Y/N)
	Time	Intensity	Pain	Time	Intensity	Pain	Time	Intensity	Pain	
Week 7										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										
Week 8										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										
Week 9										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										

Treatment Session 1			Treatment Session 2			Treatment Session 3			Completion of PT prescribed exercises (Y/N)
Time	Intensity	Pain	Time	Intensity	Pain	Time	Intensity	Pain	

Week 10

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 11

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 12

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Appendix B: Standard of care home treatment diary

Name: _____

Instructions:

- Step 1** Perform the quadriceps exercise prescribed to you for the research study. You will perform the exercise for a total of 15 minutes, holding the quadriceps contraction for 23 seconds followed by a rest time of 10 seconds between each contraction. This will be done 5 days a week, 3 times a day.
- Step 2** After you have completed the 15 minutes of your study exercises please perform the home exercises prescribed by your therapist. *If you have already completed the prescribed exercises today please proceed to step 3).*
- Step 3** If you desire to apply ice, Cryocuff, or Game Ready to your knee please do so once you have completed all of your exercises.

Additional Information:

If your physical therapist has prescribed you to do the same exercise you currently perform for the research study. Please perform each set of exercises separately.

It is possible that the amount of exercises prescribed by your therapist will be different than the amount prescribed by the study. Please treat each exercise program individually. Please document in the left hand column whether you were able to complete the home exercises prescribed by your physical therapist.

Please don't hesitate to call if you have any questions (859) 218-0578

Thank you for your time!

	Treatment Session 1			Treatment Session 2			Treatment Session 3			Completion of PT prescribed exercises (Y/N)
	Time	Number Performed	Pain	Time	Number Performed	Pain	Time	Number Performed	Pain	
Week 1										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										
Week 2										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										
Week 3										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										

Treatment Session 1			Treatment Session 2			Treatment Session 3			Completion of PT prescribed exercises (Y/N)
Time	Number Performed	Pain	Time	Number Performed	Pain	Time	Number Performed	Pain	

Week 4

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 5

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 6

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

	Treatment Session 1			Treatment Session 2			Treatment Session 3			Completion of PT prescribed exercises (Y/N)
	Time	Number Performed	Pain	Time	Number Performed	Pain	Time	Number Performed	Pain	
Week 1										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										
Week 2										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										
Week 3										
Day 1										
Day 2										
Day 3										
Day 4										
Day 5										

Treatment Session 1			Treatment Session 2			Treatment Session 3			Completion of PT prescribed exercises (Y/N)
Time	Number Performed	Pain	Time	Number Performed	Pain	Time	Number Performed	Pain	

Week 10

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 11

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Week 12

Day 1									
Day 2									
Day 3									
Day 4									
Day 5									

Appendix C: Knee Osteoarthritis and Injury Outcome Score

S15 Koos Knee Score

Patient Name _____ Side Right Left

Date of Review: ___/___/___ Follow-up Period: Pre-Op OR ___ weeks/months/years (circle one)

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 do 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 slowness 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?

Never Monthly Weekly Daily Always

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

P2. Twisting/pivoting on your knee

None Mild Moderate Severe Extreme

P3. Straightening knee fully

None Mild Moderate Severe Extreme

P4. Bending knee fully

None Mild Moderate Severe Extreme

Pain, continued

P5. Walking on flat surface	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
P6. Going up or down stairs	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
P7. At night while in bed	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
P8. Sitting or lying	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
P9. Standing upright	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme

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	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A2. Ascending stairs	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A3. Rising from sitting	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A4. Standing	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A5. Bending to floor/pick up an object	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A6. Walking on flat surface	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A7. Getting in/out of car	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A8. Going shopping	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A9. Putting on socks/stockings	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A10. Rising from bed	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A11. Taking off socks/stockings	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A12. Lying in bed (turning over, maintaining knee position)	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme
A13. Getting in/out of bath	<input type="checkbox"/> None	<input type="checkbox"/> Mild	<input type="checkbox"/> Moderate	<input type="checkbox"/> Severe	<input type="checkbox"/> Extreme

For each of the following activities please indicate the degree of difficulty you have experienced in the **last week** due to your knee.

A14. Sitting

None Mild Moderate Severe Extreme

A15. Getting on/off toilet

None Mild Moderate Severe Extreme

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 life style 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.

References

1. Harris JD, Flanigan DC. Management of knee articular cartilage injuries. *Modern arthroscopy, InTech, New York*. 2011:103-128.
2. Hunter W. Of the structure and diseases of articulating cartilages, by William Hunter, surgeon. *Philosophical Transactions*. 1742;42(462-471):514-521.
3. Brittberg M, Lindahl A, Nilsson A, Ohlsson C, Isaksson O, Peterson L. Treatment of Deep Cartilage Defects in the Knee with Autologous Chondrocyte Transplantation. *N Engl J Med*. 1994;331(14):889-895.
4. Hjelle K, Solheim E, Strand T, Muri R, Brittberg M. Articular cartilage defects in 1,000 knee arthroscopies. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. 2002;18(7):730-734.
5. Lattermann C, Kang RW, Cole BJ. What's new in the treatment of focal chondral defects of the knee? *ORTHOPEDICS-NEW JERSEY*. 2006;29(10):898.
6. Widuchowski W, Widuchowski J, Trzaska T. Articular cartilage defects: study of 25,124 knee arthroscopies. *The Knee*. 2007;14(3):177-182.
7. Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: a review of 31,516 knee arthroscopies. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. 1997;13(4):456-460.
8. Årøen A, Løken S, Heir S, et al. Articular cartilage lesions in 993 consecutive knee arthroscopies. *Am J Sports Med*. 2004;32(1):211-215.
9. Kleemann R, Krockner D, Cedraro A, Tuischer J, Duda G. Altered cartilage mechanics and histology in knee osteoarthritis: relation to clinical assessment (ICRS Grade). *Osteoarthritis Cartilage*. 2005;13(11):958-963.
10. Outerbridge RE. The Etiology of Chondromalacia Patellae. *J Bone Joint Surg Br*. 1961;43-B(4):752-757.
11. Brittberg M, Winalski CS. Evaluation of cartilage injuries and repair. *The Journal of Bone & Joint Surgery*. 2003;85(suppl_2):58-69.
12. Schinhan M, Gruber M, Vavken P, et al. Critical-size defect induces unicompartmental osteoarthritis in a stable ovine knee. *J Orth Res*. 2012;30(2):214-220.
13. Peterson L. Articular cartilage injuries treated with autologous chondrocyte transplantation in the human knee. *Acta Orthop Belg*. 1996;62:196.
14. Messner K, Maletius W. The long-term prognosis for severe damage to weight-bearing cartilage in the knee: a 14-year clinical and radiographic follow-up in 28 young athletes. *Acta Orthop Scand*. 1996;67(2):165-168.
15. Centers for Disease Control and Prevention. *Arthritis: Data and Statistics* <https://www.cdc.gov/nchs/products/databriefs/db210.htm>. Accessed January 10, 2014.
16. Stranges E, Russo CA, Friedman B. Procedures with the most rapidly increasing hospital costs, 2004–2007. 2009.
17. Lim H-C, Bae J-H, Song S-H, Park Y-E, Kim S-J. Current Treatments of Isolated Articular Cartilage Lesions of the Knee Achieve Similar Outcomes. *Clinical Orthopaedics and Related Research*®. 2012;470(8):2261-2267.

18. Demange M, Gomoll AH. The use of osteochondral allografts in the management of cartilage defects. *Current reviews in musculoskeletal medicine*. 2012;5(3):229-235.
19. Harris JD, Siston RA, Pan X, Flanigan DC. Autologous Chondrocyte Implantation A Systematic Review. *J Bone Jt Surg Am*. 2010;92(12):2220-2233.
20. Chahal J, Gross AE, Gross C, et al. Outcomes of Osteochondral Allograft Transplantation in the Knee. *Arthroscopy: The Journal of Arthroscopic & Related Surgery*. 2013;29(3):575-588.
21. Roos EM, Engelhart L, Ranstam J, et al. ICRS Recommendation Document Patient-Reported Outcome Instruments for Use in Patients with Articular Cartilage Defects. *Cartilage*. 2011;2(2):122-136.
22. Bekkers JEJ, de Windt TS, Raijmakers NJH, Dhert WJA, Saris DBF. Validation of the Knee Injury and Osteoarthritis Outcome Score (KOOS) for the treatment of focal cartilage lesions. *Osteoarthritis Cartilage*. 2009;17(11):1434-1439.
23. Engelhart L, Nelson L, Lewis S, et al. Validation of the Knee Injury and Osteoarthritis Outcome Score Subscales for Patients With Articular Cartilage Lesions of the Knee. *Am J Sports Med*. 2012;40(10):2264-2272.
24. Greco NJ, Anderson AF, Mann BJ, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form in comparison to the Western Ontario and McMaster Universities Osteoarthritis Index, modified Cincinnati Knee Rating System, and Short Form 36 in patients with focal articular cartilage defects. *Am J Sports Med*. 2010;38(5):891-902.
25. Kocher MS, Steadman JR, Briggs KK, Sterett WI, Hawkins RJ. Reliability, validity, and responsiveness of the Lysholm knee scale for various chondral disorders of the knee. *The Journal of Bone & Joint Surgery*. 2004;86(6):1139-1145.
26. Beard DJ, Knezevic K, Al-Ali S, Dawson J, Price AJ. The use of outcome measures relating to the knee. *Orthopaedics and Trauma*. 2010;24(4):309-316.
27. Beaton DE. Understanding the relevance of measured change through studies of responsiveness. *Spine*. 2000;25(24):3192-3199.
28. Copay AG, Subach BR, Glassman SD, Polly DW, Schuler TC. Understanding the minimum clinically important difference: a review of concepts and methods. *The Spine Journal*. 2007;7(5):541-546.
29. Jaeschke R, Singer J, Guyatt GH. Measurement of health status: ascertaining the minimal clinically important difference. *Control Clin Trials*. 1989;10(4):407-415.
30. Collins NJ, Misra D, Felson DT, Crossley KM, Roos EM. Measures of knee function: International Knee Documentation Committee (IKDC) Subjective Knee Evaluation Form, Knee Injury and Osteoarthritis Outcome Score (KOOS), Knee Injury and Osteoarthritis Outcome Score Physical Function Short Form (KOOS-PS), Knee Outcome Survey Activities of Daily Living Scale (KOS-ADL), Lysholm Knee Scoring Scale, Oxford Knee Score (OKS), Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), Activity Rating Scale (ARS), and Tegner Activity Score (TAS). *Arthritis Care Res*. 2011;63(S11):S208-S228.
31. Howard JS, Lattermann C, Hoch JM, Mattacola CG, McKeon JMM. Comparing Responsiveness of Six Common Patient-Reported Outcomes to Changes

- Following Autologous Chondrocyte Implantation A Systematic Review and Meta-Analysis of Prospective Studies. *Cartilage*. 2013;4(2):97-110.
32. Hambly K, Griva K. IKDC or KOOS? Which measures symptoms and disabilities most important to postoperative articular cartilage repair patients? *Am J Sports Med*. 2008;36(9):1695-1704.
 33. Irrgang JJ, Anderson AF, Boland AL, et al. Development and validation of the international knee documentation committee subjective knee form. *Am J Sports Med*. 2001;29(5):600-613.
 34. Irrgang JJ, Anderson AF, Boland AL, et al. Responsiveness of the International Knee Documentation Committee Subjective Knee Form. *Am J Sports Med*. 2006;34(10):1567-1573.
 35. Roos EM, Lohmander LS. The Knee injury and Osteoarthritis Outcome Score (KOOS): from joint injury to osteoarthritis. *Health Qual Life Outcomes*. 2003;1(1):64.
 36. Roos EM, Roos HP, Lohmander LS, Ekdahl C, Beynon BD. Knee Injury and Osteoarthritis Outcome Score (KOOS)—development of a self-administered outcome measure. *J Orthop Sports Phys Ther*. 1998;28(2):88-96.
 37. Ebert JR, Smith A, Wood DJ, Ackland TR. A Comparison of the Responsiveness of 4 Commonly Used Patient-Reported Outcome Instruments at 5 Years After Matrix-Induced Autologous Chondrocyte Implantation. *Am J Sports Med*. 2013;41(12):2791-2799.
 38. Schmitt LC, Quatman CE, Paterno MV, Best TM, Flanigan DC. Functional Outcomes After Surgical Management of Articular Cartilage Lesions in the Knee: A Systematic Literature Review to Guide Post-Operative Rehabilitation. *J Orthop Sports Phys Ther*. 2014:1-53.
 39. Barber-Westin SD, Noyes FR. Factors used to determine return to unrestricted sports activities after anterior cruciate ligament reconstruction. *Arthroscopy*. 2011;27(12):1697-1705.
 40. Noyes FR, Barber SD, Mangine RE. Abnormal lower limb symmetry determined by function hop tests after anterior cruciate ligament rupture. *Am J Sports Med*. 1991;19(5):513-518.
 41. Thomeé R, Kaplan Y, Kvist J, et al. Muscle strength and hop performance criteria prior to return to sports after ACL reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2011;19(11):1798-1805.
 42. Van Assche D, Staes F, Caspel D, et al. Autologous chondrocyte implantation versus microfracture for knee cartilage injury: a prospective randomized trial, with 2-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2010;18(4):486-495.
 43. Ebert JR, Robertson WB, Lloyd DG, Zheng MH, Wood DJ, Ackland T. Traditional vs accelerated approaches to post-operative rehabilitation following matrix-induced autologous chondrocyte implantation (MACI): comparison of clinical, biomechanical and radiographic outcomes. *Osteoarthritis Cartilage*. 2008;16(10):1131-1140.
 44. Howard J, Mattacola C, Mullineaux D, English R, Lattermann C. Patient Oriented and Performance Based Outcomes Following Knee Autologous Chondrocyte Implantation: A Time Line for the 1st Year of Recovery. *J Sport Rehabil*. 2014.

45. Perrin DH. Reliability of isokinetic measures. *Athletic training*. 1986;21(319-321):3.
46. Ebert JR, Smith A, Edwards PK, Ackland TR. The Progression of Isokinetic Knee Strength After Matrix-Induced Autologous Chondrocyte Implantation: Implications for Rehabilitation and Return to Activity. *J Sports Rehabil*. 2014;23(3).
47. Kreuz PC, Müller S, Freymann U, et al. Repair of Focal Cartilage Defects With Scaffold-Assisted Autologous Chondrocyte Grafts Clinical and Biomechanical Results 48 Months After Transplantation. *Am J Sports Med*. 2011;39(8):1697-1705.
48. McAlindon T, Cooper C, Kirwan J, Dieppe P. Determinants of disability in osteoarthritis of the knee. *Ann Rheum Dis*. 1993;52(4):258-262.
49. Schmitt LC, Rudolph KS. Influences on knee movement strategies during walking in persons with medial knee osteoarthritis. *Arthritis Care Res*. 2007;57(6):1018-1026.
50. Slemenda C, Brandt KD, Heilman DK, et al. Quadriceps weakness and osteoarthritis of the knee. *Ann Intern Med*. 1997;127(2):97-104.
51. Hambly K, Bobic V, Wondrasch B, Van Assche D, Marlovits S. Autologous Chondrocyte Implantation Postoperative Care and Rehabilitation Science and Practice. *Am J Sports Med*. 2006;34(6):1020-1038.
52. Snyder-Mackler L, Delitto A, Stralka SW, Bailey SL. Use of electrical stimulation to enhance recovery of quadriceps femoris muscle force production in patients following anterior cruciate ligament reconstruction. *Phys Ther*. 1994;74(10):901-907.
53. Stevens-Lapsley JE, Balter JE, Wolfe P, Eckhoff DG, Kohrt WM. Early neuromuscular electrical stimulation to improve quadriceps muscle strength after total knee arthroplasty: a randomized controlled trial. *Phys Ther*. 2012;92(2):210-226.
54. Mizner RL, Petterson SC, Stevens JE, Vandenborne K, Snyder-Mackler L. Early quadriceps strength loss after total knee arthroplasty. *The Journal of Bone & Joint Surgery*. 2005;87(5):1047-1053.
55. Palmieri-Smith RM, Thomas AC, Wojtys EM. Maximizing quadriceps strength after ACL reconstruction. *Clin Sports Med*. 2008;27(3):405-424.
56. Louboutin H, Debarge R, Richou J, et al. Osteoarthritis in patients with anterior cruciate ligament rupture: a review of risk factors. *The Knee*. 2009;16(4):239-244.
57. Reed B. The physiology of neuromuscular electrical stimulation. *Pediatric Physical Therapy*. 1997;9(3):96-102.
58. Kramer JF. Effect of electrical stimulation current frequencies on isometric knee extension torque. *Phys Ther*. 1987;67(1):31-38.
59. Rooney JG, Currier DP, Nitz AJ. Effect of variation in the burst and carrier frequency modes of neuromuscular electrical stimulation on pain perception of healthy subjects. *Phys Ther*. 1992;72(11):800-806.
60. Kim K-M, Croy T, Hertel J, Saliba S. Effects of neuromuscular electrical stimulation after anterior cruciate ligament reconstruction on quadriceps strength, function, and patient-oriented outcomes: a systematic review. *J Orthop Sports Phys Ther*. 2010;40(7):383.

61. Snyder-Mackler L, Delitto A, Bailey S, Stralka S. Strength of the quadriceps femoris muscle and functional recovery after reconstruction of the anterior cruciate ligament. *J Bone Joint Surg Am.* 1995;77(8):1166-1173.
62. Bax L, Staes F, Verhagen A. Does Neuromuscular Electrical Stimulation Strengthen the Quadriceps Femoris? *Sports Med.* 2005;35(3):191-212.
63. The Oxford 2011 levels of evidence. Oxford Centre for Evidence-Based Medicine; 2011.
64. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther.* 2003;83(8):713-721.
65. Database PE. PEDro statistics. 2014; <http://www.pedro.org.au/english/downloads/pedro-statistics/>. Accessed April 13, 2014.
66. Ebell MH, Siwek J, Weiss BD, et al. Strength of recommendation taxonomy (SORT): a patient-centered approach to grading evidence in the medical literature. *J Am Board Fam Pract.* 2004;17(1):59-67.
67. Lieber R, Silva P, Daniel D. Equal effectiveness of electrical and volitional strength training for quadriceps femoris muscles after anterior cruciate ligament surgery. *J Orth Res.* 1996;14(1):131-138.
68. Myers NL, Sciascia AD, Westgate PM, Kibler WB, Uhl TL. Increasing Ball Velocity in the Overhead Athlete: A Meta-analysis of Randomized Controlled Trials. *The Journal of Strength & Conditioning Research.* 2015;29(10):2964-2979.
69. Cohen J. Statistical power analysis for the behavioral sciences Lawrence Earlbaum Associates. *Hillsdale, NJ.* 1988:20-26.
70. Feil S, Newell J, Minogue C, Paessler HH. The Effectiveness of Supplementing a Standard Rehabilitation Program With Superimposed Neuromuscular Electrical Stimulation After Anterior Cruciate Ligament Reconstruction A Prospective, Randomized, Single-Blind Study. *Am J Sports Med.* 2011;39(6):1238-1247.
71. Fitzgerald G, Piva SR, Irrgang JJ. A modified neuromuscular electrical stimulation protocol for quadriceps strength training following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 2003;33(9):492.
72. Sisk TD, Stralka SW, Deering MB, Griffin JW. Effect of electrical stimulation on quadriceps strength after reconstructive surgery of the anterior cruciate ligament. *Am J Sports Med.* 1987;15(3):215-220.
73. Wigerstad-Lossing I, Grimby G, Jonsson T, Morelli B, Peterson L, Renström P. Effects of electrical muscle stimulation combined with voluntary contractions after knee ligament surgery. *Med Sci Sports Exerc.* 1988;20(1):93-98.
74. Williams RA, Morrissey MC, Brewster CE. The effect of electrical stimulation on quadriceps strength and thigh circumference in meniscectomy patients. *J Orthop Sports Phys Ther.* 1986;8(3):143-146.
75. Mikesky AE, Meyer A, Thompson KL. Relationship between quadriceps strength and rate of loading during gait in women. *J Orth Res.* 2000;18(2):171-175.
76. Keays SL, Newcombe PA, Bullock-Saxton JE, Bullock MI, Keays AC. Factors involved in the development of osteoarthritis after anterior cruciate ligament surgery. *Am J Sports Med.* 2010;38(3):455-463.

77. da Silva VZM, Durigan JLQ, Arena R, de Noronha M, Gurney B, Cipriano Jr G. Current evidence demonstrates similar effects of kilohertz-frequency and low-frequency current on quadriceps evoked torque and discomfort in healthy individuals: a systematic review with meta-analysis. *Physiotherapy theory and practice*. 2015;31(8):533-539.
78. Kittelson AJ, Stackhouse SK, Stevens-Lapsley JE. Neuromuscular electrical stimulation after total joint arthroplasty: a critical review of recent controlled studies. *European journal of physical and rehabilitation medicine*. 2013;49(6):909-920.
79. Stevens-Lapsley JE, Balter JE, Wolfe P, et al. Relationship Between Intensity of Quadriceps Muscle Neuromuscular Electrical Stimulation and Strength Recovery After Total Knee Arthroplasty. *Phys Ther*. 2012;92(9):1187-1196.
80. Marmon AR, Snyder-Mackler L. Quantifying Neuromuscular Electrical Stimulation Dosage after Knee Arthroplasty. *Journal Of Life Sciences (Libertyville, Ill)*. 2011;5(8):581-583.
81. Smith GV, Alon G, Roys SR, Gullapalli RP. Functional MRI determination of a dose-response relationship to lower extremity neuromuscular electrical stimulation in healthy subjects. *Exp Brain Res*. 2003;150(1):33-39.
82. Adams GR, Harris RT, Woodard D, Dudley GA. Mapping of electrical muscle stimulation using MRI. *J Appl Physiol*. 1993;74(2):532-537.
83. Maffiuletti NA, Bramanti J, Jubeau M, Bizzini M, Deley G, Cometti G. Feasibility and efficacy of progressive electrostimulation strength training for competitive tennis players. *The Journal of Strength & Conditioning Research*. 2009;23(2):677-682.
84. Pietrosimone BG, McLeod MM, Lepley AS. A theoretical framework for understanding neuromuscular response to lower extremity joint injury. *Sports Health: A Multidisciplinary Approach*. 2012;4(1):31-35.
85. Thomas AC, Stevens-Lapsley JE. Importance of attenuating quadriceps activation deficits after total knee arthroplasty. *Exerc Sport Sci Rev*. 2012;40(2):95-101.
86. Jenkins WM, Merzenich MM, Ochs MT, Allard T, Guic-Robles E. Functional reorganization of primary somatosensory cortex in adult owl monkeys after behaviorally controlled tactile stimulation. *J Neurophysiol*. 1990;63(1):82-104.
87. Johnston MV. Plasticity in the developing brain: implications for rehabilitation. *Developmental disabilities research reviews*. 2009;15(2):94-101.
88. Delitto A, Rose SJ. Comparative comfort of three waveforms used in electrically eliciting quadriceps femoris muscle contractions. *Phys Ther*. 1986;66(11):1704-1707.
89. Gorgey AS, Dudley GA. The role of pulse duration and stimulation duration in maximizing the normalized torque during neuromuscular electrical stimulation. *J Orthop Sports Phys Ther*. 2008;38(8):508.
90. Bowman BR, Baker LL. Effects of waveform parameters on comfort during transcutaneous neuromuscular electrical stimulation. *Ann Biomed Eng*. 1985;13(1):59-74.
91. Laufer Y, Ries JD, Leininger PM, Alon G. Quadriceps femoris muscle torques and fatigue generated by neuromuscular electrical stimulation with three different waveforms. *Phys Ther*. 2001;81(7):1307-1316.

92. De Ruiter C, Kooistra R, Paalman M, De Haan A. Initial phase of maximal voluntary and electrically stimulated knee extension torque development at different knee angles. *J Appl Physiol.* 2004;97(5):1693-1701.
93. Snyder AR, Parsons JT, McLeod TCV, Bay RC, Michener LA, Sauers EL. Using disablement models and clinical outcomes assessment to enable evidence-based athletic training practice, part I: disablement models. *J Athl Train.* 2008;43(4):428.
94. McLeod TCV, Snyder AR, Parsons JT, Bay RC, Michener LA, Sauers EL. Using disablement models and clinical outcomes assessment to enable evidence-based athletic training practice, part II: clinical outcomes assessment. *J Athl Train.* 2008;43(4):437.
95. Fisher AC, Hoisington LL. Injured athletes' attitudes and judgments toward rehabilitation adherence. *J Athl Train.* 1993;28(1):48.
96. Fisher AC, Mullins SA, Frye PA. Athletic trainers' attitudes and judgments of injured athletes' rehabilitation adherence. *J Athl Train.* 1993;28(1):43.
97. Roh JLC, Perna FM. Psychology/counseling: a universal competency in athletic training. *J Athl Train.* 2000;35(4):458.
98. Appaneal RN, Levine BR, Perna FM, Roh JL. Measuring postinjury depression among male and female competitive athletes. *J Sport Exerc Psychol.* 2009;31(1):60-76.
99. Leddy MH, Lambert MJ, Ogles BM. Psychological consequences of athletic injury among high-level competitors. *Res Q Exerc Sport.* 1994;65(4):347-354.
100. Morrey MA, Stuart MJ, Smith AM, Wiese-Bjornstal DM. A longitudinal examination of athletes' emotional and cognitive responses to anterior cruciate ligament injury. *Clin J Sport Med.* 1999;9(2):63-69.
101. McDonald SA, Hardy CJ. Affective response patterns of the injured athlete: an exploratory analysis. *Sport Psychol.* 1990;4(3):261-274.
102. Parsons JT, McLeod TCV, Snyder AR, Sauers EL. Change is hard: adopting a disablement model for athletic training. *J Athl Train.* 2008;43(4):446.
103. Pizzari T, McBurney H, Taylor NF, Feller JA. Adherence to anterior cruciate ligament rehabilitation: a qualitative analysis. *J Sport Rehabil.* 2002;11(2):90-103.
104. Rosenstock IM. The health belief model and preventive health behavior. *Health Educ Behav.* 1974;2(4):354-386.
105. Janz NK, Becker MH. The health belief model: A decade later. *Health Educ Behav.* 1984;11(1):1-47.
106. Rosenstock IM. Historical origins of the health belief model. *Health Educ Behav.* 1974;2(4):328-335.
107. Rosenstock IM, Strecher VJ, Becker MH. Social learning theory and the health belief model. *Health Educ Behav.* 1988;15(2):175-183.
108. Wiese-Bjornstal D, Smith A, LaMott E. A model of psychologic response to athletic injury and rehabilitation. *Athletic training: Sports Health Care Perspectives.* 1995;1(1):17-30.
109. Wiese-bjornstal DM, Smith AM, Shaffer SM, Morrey MA. An integrated model of response to sport injury: Psychological and sociological dynamics. *J Appl Sport.* 1998;10(1):46-69.

110. Wagman D, Khelifa M. Psychological issues in sport injury rehabilitation: current knowledge and practice. *J Athl Train.* 1996;31(3):257.
111. Andersen MB, Williams JM. A model of stress and athletic injury: Prediction and prevention. *J Sport Exerc Psychol.* 1988;10(3):294-306.
112. WHO. Adherence to long-term therapies: evidence for action. Geneva: World Health Organization. 2003.
113. Clement D, Arvinen-Barrow M, Fetty T. Psychosocial Responses During Different Phases of Sport-Injury Rehabilitation: A Qualitative Study. *J Athl Train.* 2015;50(1):95-104.
114. Fisher AC, Scriber KC, Matheny ML, Alderman MH, Bitting LA. Enhancing athletic injury rehabilitation adherence. *J Athl Train.* 1993;28(4):312.
115. Theodorakis Y, Mallion P, Papanionnon A, Beneca A, Filactakidon A. The effect of personal goals, self-efficacy, and self-satisfaction on injury rehabilitation. *J Sport Rehabil.* 1996;5:214-223.
116. Gould D, Udry E, Bridges D, Beck L. Stress sources encountered when rehabilitating from season-ending ski injuries. *Sport Psychol.* 1997;11(4):361-378.
117. Duda JL, Smart AE, Tappe MK. Predictors of adherence in the rehabilitation of athletic injuries: An application of personal investment theory. *J Sport Exerc Psychol.* 1989;11(4):367-381.
118. Brewer BW. The role of psychological factors in sport injury rehabilitation outcomes. *Int Rev Sport Exerc Psychol.* 2010;3(1):40-61.
119. Ford IW, Gordon S. Perspectives of Sport Trainers and Athletic Therapists on the Psychological Content of Their Practice and Training. *J Sport Rehabil.* 1998;7:79-94.
120. Bianco T, Malo S, Orlick T. Sport injury and illness: elite skiers describe their experiences. *Res Q Exerc Sport.* 1999;70(2):157-169.
121. Kvist J, Ek A, Sporrstedt K, Good L. Fear of re-injury: a hindrance for returning to sports after anterior cruciate ligament reconstruction. *Knee Surg Sports Traumatol Arthrosc.* 2005;13(5):393-397.
122. Bandura A. Human agency in social cognitive theory. *Am Psychol.* 1989;44(9):1175-1184.
123. Jack K, McLean SM, Moffett JK, Gardiner E. Barriers to treatment adherence in physiotherapy outpatient clinics: a systematic review. *Man Ther.* 2010;15(3):220-228.
124. Byerly PN, Worrell T, Gahimer J, Domholdt E. Rehabilitation compliance in an athletic training environment. *J Athl Train.* 1994;29(4):352.
125. Fields J, Murphey M, Horodyski MB, Stopka C. Factors associated with adherence to sport injury rehabilitation in college-age recreational athletes. *J Sport Rehabil.* 2010;4(3).
126. Marshall A, Donovan-Hall M, Ryall S. An exploration of athletes' views on their adherence to physiotherapy rehabilitation after sport injury. *J Sport Rehabil.* 2012;21(1):18.
127. Wiese DM, Weiss MR, Yukelson DP. Sport psychology in the training room: a survey of athletic trainers. *Sport Psychol.* 1991;5(1):15-24.

128. Granquist MD, Podlog L, Engel JR, Newland A. Certified Athletic Trainers' Perspectives on Rehabilitation Adherence in Collegiate Athletic Training Settings. *J Sport Rehabil.* 2014;23(2):123-133.
129. Larson GA, Starkey C, Zaichkowsky LD. Psychological aspects of athletic injuries as perceived by athletic trainers. *Sport Psychol.* 1996;10:37-47.
130. Wiese-Bjornstal DM, Smith AM. Counseling strategies for enhanced recovery of injured athletes within a team approach. In: Pargman D, ed. *Psychological Bases of Sport Injuries.* Morgantown, WV: Fitness Information Technology, Inc; 1999:149-183.
131. Barefield S, McCallister S. Social support in the athletic training room: athletes' expectations of staff and student athletic trainers. *J Athl Train.* 1997;32(4):333.
132. Scherzer CB, Brewer BW, Cornelius AE, et al. Psychological skills and adherence to rehabilitation after reconstruction of the anterior cruciate ligament. *J Sport Rehabil.* 2001;10(3):165-173.
133. Levy AR, Polman RC, Borkoles E. Examining the relationship between perceived autonomy support and age in the context of rehabilitation adherence in sport. *Rehabil Psychol.* 2008;53(2):224.
134. Ievleva L, Orlick T. Mental links to enhanced healing: An exploratory study. *Sport Psychol.* 1991;5(1):25-40.
135. Bandura A. Social cognitive theory of self-regulation. *Organ Behav Hum Decis Process.* 1991;50(2):248-287.
136. Bone JB, Fry MD. The influence of injured athletes' perceptions of social support from ATCs on their beliefs about rehabilitation. *J Sport Rehabil.* 2006;15(2):156-167.
137. Bandura A. Health promotion by social cognitive means. *Health Educ Behav.* 2004;31(2):143-164.
138. Brewer BW, Cornelius AE, Van Raalte JL, et al. Protection motivation theory and adherence to sport injury rehabilitation revisited. *Sport Psychol.* 2003;17(1):95-103.
139. Taylor AH, May S. Threat and coping appraisal as determinants of compliance with sports injury rehabilitation: an application of protection motivation theory. *J Sports Sci.* 1996;14(6):471-482.
140. Richman JM, Rosenfeld LB, Hardy CJ. The social support survey: A validation study of a clinical measure of the social support process. *Res Social Work Prac.* 1993;3(3):288-311.
141. Lawrence RC, Felson DT, Helmick CG, et al. Estimates of the prevalence of arthritis and other rheumatic conditions in the United States: Part II. *Arthritis Rheum.* 2008;58(1):26-35.
142. Kurtz S, Mowat F, Ong K, Chan N, Lau E, Halpern M. Prevalence of primary and revision total hip and knee arthroplasty in the United States from 1990 through 2002. *The Journal of Bone & Joint Surgery.* 2005;87(7):1487-1497.
143. Peterson L, Vasiliadis HS, Brittberg M, Lindahl A. Autologous chondrocyte implantation. *Am J Sports Med.* 2010;38(6):1117-1124.
144. Bentley G, Biant L, Carrington R, et al. A prospective, randomised comparison of autologous chondrocyte implantation versus mosaicplasty for osteochondral defects in the knee. *J Bone Joint Surg Br.* 2003;85(2):223-230.

145. Harris J, Siston R, Brophy R, Lattermann C, Carey J, Flanigan D. Failures, re-operations, and complications after autologous chondrocyte implantation—a systematic review. *Osteoarthritis Cartilage*. 2011;19(7):779-791.
146. Hirschl A, Baur H, Braun S, Kreuz P, Südkamp N, Niemeyer P. Rehabilitation After Autologous Chondrocyte Implantation for Isolated Cartilage Defects of the Knee. *Am J Sports Med*. 2011;39(12):2686-2696.
147. Van Assche D, Staes F, Van Caspel D, et al. Autologous chondrocyte implantation versus microfracture for knee cartilage injury: a prospective randomized trial, with 2-year follow-up. *Knee Surg Sports Traumatol Arthrosc*. 2010;18(4):486-495.
148. Van Assche D, Van Caspel D, Vanlauwe J, et al. Physical Activity Levels After Characterized Chondrocyte Implantation Versus Microfracture in the Knee and the Relationship to Objective Functional Outcome With 2-year Follow-up. *Am J Sports Med*. 2009;37(1 suppl):42S-49S.
149. Maffiuletti NA. Physiological and methodological considerations for the use of neuromuscular electrical stimulation. *Eur J Appl Physiol*. 2010;110(2):223-234.
150. Pilsky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. *North American Journal of Sports Physical Therapy/Volume*. 2009;4(2):92.
151. Shaffer SW, Teyhen DS, Lorenson CL, et al. Y-balance test: a reliability study involving multiple raters. *Mil Med*. 2013;178(11):1264-1270.
152. Butler RJ, Lehr ME, Fink ML, Kiesel KB, Plisky PJ. Dynamic Balance Performance and Noncontact Lower Extremity Injury in College Football Players An Initial Study. *Sports Health: A Multidisciplinary Approach*. 2013;5(5):417-422.
153. Teyhen DS, Riebel MA, McArthur DR, et al. Normative Data and the Influence of Age and Gender on Power, Balance, Flexibility, and Functional Movement in Healthy Service Members. *Mil Med*. 2014;179(4):413-420.
154. Mayer SW, Queen RM, Taylor D, et al. Functional Testing Differences in Anterior Cruciate Ligament Reconstruction Patients Released Versus Not Released to Return to Sport. *Am J Sports Med*. 2015;43(7):1648-1655.
155. Benis R, Bonato M, Torre AL. Elite Female Basketball Players' Body-Weight Neuromuscular Training and Performance on the Y-Balance Test. *J Athl Train*. 2016.
156. Gribble PA, Hertel J. Considerations for normalizing measures of the Star Excursion Balance Test. *Measurement in physical education and exercise science*. 2003;7(2):89-100.
157. Kollock RO, Onate JA, Van Lunen B. The Reliability of Portable Fixed Dynamometry During Hip and Knee Strength Assessments. *J Athl Train*. 2010;45(4):349-356.
158. Toonstra J, Mattacola CG. Test-retest Reliability and Validity of Isometric Knee Flexion and Extension Measurement Using Three Methods of Assessing Muscle Strength. *J Sport Rehabil*. 2012.
159. Thoma LM, Flanigan DC, Chaudhari AM, Siston RA, Best TM, Schmitt LC. Quadriceps femoris strength and sagittal-plane knee biomechanics during stair

- ascent in individuals with articular cartilage defects in the knee. *J Sport Rehabil.* 2014;23(3):259-269.
160. Lepley LK, Wojtys EM, Palmieri-Smith RM. Combination of eccentric exercise and neuromuscular electrical stimulation to improve quadriceps function post-ACL reconstruction. *The Knee.* 2015;22(3):270-277.
 161. Lepley AS, Ericksen HM, Sohn DH, Pietrosimone BG. Contributions of neural excitability and voluntary activation to quadriceps muscle strength following anterior cruciate ligament reconstruction. *The Knee.* 2014;21(3):736-742.
 162. Kannus P. Isokinetic evaluation of muscular performance: implications for muscle testing and rehabilitation. *Int J Sports Med.* 1994;15:S11-18.
 163. Lewek M, Rudolph K, Axe M, Snyder-Mackler L. The effect of insufficient quadriceps strength on gait after anterior cruciate ligament reconstruction. *Clin Biomech.* 2002;17(1):56-63.
 164. Schmitt LC, Paterno MV, Hewett TE. The impact of quadriceps femoris strength asymmetry on functional performance at return to sport following anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 2012;42(9):750-759.
 165. Løken S, Ludvigsen T, Høysveen T, Holm I, Engebretsen L, Reinholt F. Autologous chondrocyte implantation to repair knee cartilage injury: ultrastructural evaluation at 2 years and long-term follow-up including muscle strength measurements. *Knee Surg Sports Traumatol Arthrosc.* 2009;17(11):1278-1288.
 166. Segal NA, Glass NA, Torner J, et al. Quadriceps weakness predicts risk for knee joint space narrowing in women in the MOST cohort. *Osteoarthritis Cartilage.* 2010;18(6):769-775.
 167. Øiestad BE, Holm I, Gunderson R, Myklebust G, Risberg MA. Quadriceps muscle weakness after anterior cruciate ligament reconstruction: A risk factor for knee osteoarthritis? *Arthritis Care Res.* 2010;62(12):1706-1714.
 168. Robertson WB, Fick D, Wood DJ, Linklater JM, Zheng MH, Ackland TR. MRI and clinical evaluation of collagen-covered autologous chondrocyte implantation (CACI) at two years. *The Knee.* 2007;14(2):117-127.
 169. Earl JE, Hertel J. Lower-extremity muscle activation during the Star Excursion Balance Tests. *J Sport Rehabil.* 2001;10(2):93-104.
 170. Delahunt E, Chawke M, Kelleher J, et al. Lower limb kinematics and dynamic postural stability in anterior cruciate ligament-reconstructed female athletes. *J Athl Train.* 2013;48(2):172.
 171. Andriacchi TP, Birac D. Functional testing in the anterior cruciate ligament-deficient knee. *Clin Orthop.* 1993;288:40-47.
 172. Ebert JR, Robertson WB, Lloyd DG, Zheng M, Wood DJ, Ackland T. A Prospective, Randomized Comparison of Traditional and Accelerated Approaches to Postoperative Rehabilitation following Autologous Chondrocyte Implantation 2-Year Clinical Outcomes. *Cartilage.* 2010;1(3):180-187.
 173. Pestka JM, Bode G, Salzmann G, Südkamp NP, Niemeyer P. Clinical Outcome of Autologous Chondrocyte Implantation for Failed Microfracture Treatment of Full-Thickness Cartilage Defects of the Knee Joint. *Am J Sports Med.* 2012;40(2):325-331.

174. Howard JS WCC, Mattacola CG, Lattermann C. Minimal Clinically Important Differences for the Knee Injury and Osteoarthritis Outcomes Score (KOOS) among Knee Cartilage Patients. Paper presented at: 13th World Congress of the International Cartilage Repair Society 2016; Sorrento, Italy.
175. Vanlauwe J, Saris DB, Victor J, et al. Five-Year Outcome of Characterized Chondrocyte Implantation Versus Microfracture for Symptomatic Cartilage Defects of the Knee Early Treatment Matters. *Am J Sports Med.* 2011;39(12):2566-2574.
176. Ebert JR, Robertson WB, Woodhouse J, et al. Clinical and magnetic resonance imaging-based outcomes to 5 years after matrix-induced autologous chondrocyte implantation to address articular cartilage defects in the knee. *Am J Sports Med.* 2011;39(4):753-763.
177. Kolt G, McEvoy J. Adherence to rehabilitation in patients with low back pain. *Man Ther.* 2003;8(2):110-116.
178. Sluijs EM, Kok GJ, van der Zee J. Correlates of exercise compliance in physical therapy. *Phys Ther.* 1993;73(11):771-782.
179. Wu J-R, Moser DK, Chung ML, Lennie TA. Objectively Measured, but Not Self-Reported, Medication Adherence Independently Predicts Event-Free Survival in Patients With Heart Failure. *J Card Fail.* 2008;14(3):203-210.
180. Toonstra JL, Howell D, English RA, Lattermann C, Mattacola CG. Patient Experiences of Recovery After Autologous Chondrocyte Implantation: A Qualitative Study. *J Athl Train.* 2016.
181. Loenneke JP, Wilson JM, Marín PJ, Zourdos MC, Bembem MG. Low intensity blood flow restriction training: a meta-analysis. *Eur J Appl Physiol.* 2012;112(5):1849-1859.

EDUCATION

Doctorate of Philosophy

University of Kentucky, Lexington, KY (August 2012 – May 2017)

Successful Doctoral Defense Date: April 17, 2017, Graduation August 2017

Doctorate of Philosophy - Rehabilitation Sciences

Dissertation: Effect Of A 12-Week Home-Based Neuromuscular Electrical Stimulation Treatment On Clinical Outcomes Following Articular Cartilage Knee Surgery

Graduate Certificate in Clinical Research Skills

University of Kentucky, Lexington, KY (August 2012 – August 2015)

Master of Science

University of Arkansas, Fayetteville, AR (May 2012)

Master of Science - Kinesiology

Thesis: The Relationship between Hip Abductor Strength and Functional Performance in Division I Female Soccer Athletes

Bachelors of Science

University of Florida, Gainesville, FL (May 2010)

Bachelor of Science - Athletic Training (*Cum Laude*)

LICENSURE INFORMATION

Licensed Athletic Trainer: State of Kentucky (August 2012 – Current)

Licensure Number: AT1039

Licensed Athletic Trainer: State of Arkansas (May 2010 – June 2012)

Licensure Number: AT 490

CERTIFICATION

Certified Athletic Trainer - Board of Certification

Certification Number 2000003239 (May 2010 - Current)

BLS Health Care Provider and First Aid Certification (April 2013 – Current)

PROFESSIONAL EXPERIENCE

University of Kentucky, Lexington, KY

Orthopedic Surgeon Research Assistant – Department of Orthopedic Surgery
and Sports Medicine
June 2012 – Current

**Bluegrass Invitational High School Volleyball Tournament,
Lexington, KY**
Athletic Trainer
August 2016

KHSAA Boys Basketball Sweet 16 Tournament, Lexington, KY
Athletic Trainer
March 2016

University of Arkansas, Fayetteville, AR
Approved Clinical Instructor
June 2011 – June 2012

University of Arkansas, Fayetteville, AR
Clinical Instructor
June 2010 – June 2011

University of Arkansas, Fayetteville, AR
Graduate Assistant Athletic Trainer - Women's Soccer and Softball
June 2010 – May 2012

Ozark Juniors Volleyball Club, Fayetteville, AR
Athletic Trainer for Home Tournaments
Spring 2011

University of Arkansas, Fayetteville, AR
Athletic Trainer for Team Summer Camps
June – July (2010 – 2011)

PEER REVIEWED PUBLICATIONS

Hines AS, **Whale Conley CE**, Burnham JM, Malempati CS, JS Howard, C
Lattermann, CA Jacobs. Return to Sport Significantly Worse Following
Patellofemoral Articular Cartilage Procedures than Tibiofemoral Procedures: A
Systematic Review. KSSTA – *Submitted*

Whale Conley CE, Olson AD, Howard JS, Dressler EV, Lattermann C,
Mattacola CG. Utilization of the Health Belief Model to Influence Rehabilitation
Adherence in Athletic Training. *ATSHC – Submitted*

Jochimsen KN, **Whale Conley CE**, Malempati CS, Jacobs CA, Mattacola CG, Lattermann C. Meniscus Transplantation: A Systematic Review of Return to Play. *ATSHC – Submitted*

Howard JS, Toonstra JL, Meade A, **Whale Conley CE**, Mattacola CG. Feasibility of Conducting a Web-Based Survey of Patient-Reported Outcomes and Rehabilitation Progress. *Digital Health*. 2016; 2:1-10

Whale, CE, Pass, AN, Tripp, PM. Chronic Groin Pain in a Collegiate Football Running Back. *IJATT*. 2012;17:41-44.

PEER REVIEWED SCIENTIFIC AND PROFESSIONAL PRESENTATIONS

Understanding and Influencing Rehabilitation Adherence in Athletic Training Rehabilitation Setting – Special Topic Presentation

Whale Conley CE, Howard JS, Mattacola CG

2017 National Athletic Trainers' Association Annual Meeting, Houston, Tx

Lower VR-12 Mental Component Scores Associated with Lower Return-to-Work Rates after Patellofemoral Autologous Chondrocyte Implantation (ACI)

Whale Conley CE, Burnham JM, Jacobs CA, Howard JS, King P, Jochimsen KN, Malenpati CS, Mattacola CG, Lattermann C.

2016 International Cartilage Repair Society 13th World Congress, Sorrento Italy

Implementation of Knee Specific Patient Reported Outcomes in the Rehabilitation Setting – Special Topic Presentation

Whale CE, Howard JS, Mattacola CG

2015 National Athletic Trainers' Association Annual Meeting, St. Louis, MO

Special Tests – What is the Evidence?

Howard JS *Lab Assistant*: **Whale, CE**

2014 Annual Wildcat Sports Medicine Symposium, Lexington, KY

Finding the Root Cause(s) of an Abnormal Running Gait Pattern

Mokha M, Colas M *Lab Assistant*: **Whale CE**

2013 National Athletic Trainers' Association Annual Meeting Las Vegas, NV

Predictive Value of the Jump Task for Injury among Division-I Female Soccer Athletes

Whale CE, Oliver GD, Tripp PM

2012 ACL Research Retreat VI, Greensboro, NC

Abstract Presentations (mentored student)

Effect of Preoperative Sport Participation on Post-Operative Outcomes in Patients undergoing Knee Cartilage Surgery

Whale, CE, Howard JS, Jacobs CA, Lattermann C, Mattacola CG
2017 National Athletic Trainers' Association Annual Meeting, Houston, TX –
Accepted

Relationship Between Defect Size and Pre-Operative Strength, Function, and Patient Reported Outcomes.

Mattacola CG, **Whale Conley CE**, Howard JS, Jochimsen KN, Jacobs CA, Lattermann C.

2016 International Cartilage Repair Society 13th World Congress, Sorrento Italy

Effect of Previous Cartilage Surgery Failure on 3-month Strength Outcomes in Osteochondral Allograft Patients.

Whale Conley CE, Mattacola CG, Howard JF, Jochimsen KN, Jacobs CA, Lattermann C.

2016 International Cartilage Repair Society 13th World Congress, Sorrento Italy

Effects of Rehabilitation Attendance on Three-Month Patient Reported Outcome Measures in Articular Cartilage Restoration Patients

Goldstein SG, **Whale Conley CE**, Lattermann C, Howard JS, Gribble P, Mattacola CG

2016 National Athletic Trainers' Association Annual Meeting, Baltimore, MD

Effect of Pre-Operative Quadriceps Strength on 3-month Outcomes in Articular Cartilage Repair and Restoration Patients

Whale, CE, Howard JS, Lattermann C, Mattacola CG

2016 National Athletic Trainers' Association Annual Meeting, Baltimore, MD

Doctoral Poster Award Finalist Nomination

An Analysis of the Impact of Outreach Athletic Trainers on of ACL Surgical Referrals

Whale, CE, Mattacola CG, Slavova SS, Lattermann C, Howard JS

2015 National Athletic Trainers' Association Annual Meeting, St. Louis, MO

Comparison of Individuals Who Do and Do Not Return-to-Play following ACL Reconstruction.

Howard JS, **Whale CE**

2015 National Athletic Trainers' Association Annual Meeting, St. Louis, MO

Reliability of a Novel Step-Down-To-Fatigue Test.

Chamberlain AM, **Whale CE**, Howard JS

2015 National Athletic Trainers' Association Annual Meeting, St. Louis, MO

Effect of Previous Cartilage Surgery Failure on Short-term Patient Reported Outcomes following Knee Osteochondral Allograft

Whale, CE, Mattacola CG, Starnes CP, Lattermann C, Howard JS

2015 International Cartilage Repair Society 12th World Congress, Chicago, IL

An Analysis of the Impact of Outreach Athletic Trainers on of ACL Surgical Referrals

Whale, CE, Mattacola CG, Slavova SS, Lattermann C, Howard JS
2014 Kentucky Athletic Trainers Society Annual Meeting and Symposium,
Lexington, KY

Chronic Groin Pain in a Collegiate Football Running Back

Whale, CE, Pass, AN, Tripp, PM
2010 Southeast Athletic Trainers' Association Student Workshop, Atlanta, GA

PEER-REVIEWED BOOK CHAPTER

Whale, CE, Mattacola, CG. To what extent do foot orthotics help treat impairments associated with ankle sprains?. *Quick Questions in Ankle Sprains: Expert Advice in Sports Medicine*. Patrick O McKeon, Erik Wikstrom. Slack Incorporated. 2015. 135-138.

NON PEER REVIEWED PUBLICATIONS

Lattermann C., **Whale Conley CE**. Rehabilitation after Articular Cartilage Repair in the Knee. *International Cartilage Repair Society Winter Newsletter*. 2016;22:32-33.

ADVISING ACTIVITY

Master's Degree – Graduates:

Goldstein, Sarah (May 2016) – Doctoral Student Advisor

Thesis: *The Effect of a Home-based Neuromuscular Electrical Stimulation Program on Formalized Rehabilitation Adherence in Patients Following Cartilage Defect Repair*

Chamberlain, Amanda (May 2015) – Doctoral Student Advisor

Thesis: *Development of a Lower Extremity Functional Endurance Test*

Frank, Sharon (May 2014) – Doctoral Student Advisor

Thesis: *Epidemiological Analysis of Women's Soccer Injuries*

FUNDED/IN REVIEW GRANT ACTIVITY:

Co-Investigator: \$41,400.00 DJO Research Grant Application, DJO Global, Vista, CA, January 2014.

Effect of a Superimposed Electrical Stimulation Knee Garment on Strength, Function, and Patient Reported Outcomes after Knee Surgery

Whale, C.E., Mattacola, C.G.

Co-Investigator: \$4,000.00 Center for Clinical and Translational Science, University of Kentucky, Lexington, KY November 2014.
Effectiveness of a Post-Surgical 12-week Home-Based Neuromuscular Electrical Stimulation Treatment on Isometric Quadriceps Strength, Function, and Patient Reported Outcomes after Articular Cartilage Repair Surgery
Whale, C.E., Mattacola, C.G., VanMeter Dressler, E.M., Lattermann, C.

Administrator: \$660 Graduate Student Travel Grant, University of Arkansas, Fayetteville, AR March 2012.
Predictive Value of the Jump Task for Injury among Division-1 Female Soccer Athletes
Whale, C.E., Oliver, G., Tripp, P.M.

PROFESSIONAL ACTIVITY

Reviewer, Journal of Strength and Conditioning Research (2016 – current)
Reviewer, International Journal of Athletic Training & Therapy (2016 – current)
Reviewer, Journal of Sport Rehabilitation (2013 – current)

TEACHING RESPONSIBILITIES

PAS 610 *Summer 1 May 2017* Instructor

KHP 340 Introduction to Athletic Training *January 2014–May 2017* Instructor
This is a 2-credit introduction to athletic training course. Lecture and laboratory experience will emphasize prevention, treatment and rehabilitation of injuries. Films and other visuals will be used to supplement instruction. The student will have an opportunity to gain practical experience in the field of athletic training.

PT 686 Principles of Athletic Taping Elective *Summer 2013–2016* Co-Instructor
This one credit course is designed to be an introduction to taping techniques for orthopedic and sports-related pathologies. The student will become proficient in taping psychomotor skills and will learn appropriate taping techniques for a given pathology or injury. Students will also learn current evidence supporting various taping techniques.

AT 740 Musculoskeletal Anatomical Dissection *Summer 2013–2016* Teaching Assistant
This course is a 3-credit cadaver anatomy laboratory course, which will include examination and dissection of the human cadaver. Lectures and laboratory experience will emphasize the musculoskeletal, articular, nervous, and vascular systems particularly as they relate to athletic injury mechanism and evaluation.

SERVICE ACTIVITIES

Camp Horsin' Around Camp Out Fundraiser (September 2015, 2016)
Assisted with the online auction and registration

UKHealth Care Booth Kentucky Bank Tennis Championships (July 2016)
Assisted with UKHealth Care Sports Medicine Promotional Booth

Lexington Habitat for Humanity ReStore (April 2016)
Assisted with donation acceptance, donation sorting, and item pricing for the local Habitat for Humanity store, ReStore. All the proceeds from the sales within the store are utilized to support the Lexington Habitat for Humanity organization.

UKHealth Care Annual Physicals (Summer 2013, 2014)
Assisted with the Fayette County Annual Sports Physical for high school athletes

Annual Dog Paddle (September 2013)
Assisted with the annual Friends of the Dog Park fundraiser. The event raised money for the local organization Friends of the Dog Park to maintain the city's dog parks.

MEMBERSHIP IN SCIENTIFIC/PROFESSIONAL ORGANIZATIONS

Member, National Athletic Trainers' Association (December 2010 – Current)
Member, Southeaster Athletic Trainers' Association (June 2012 – Current)
Member, Southwest Athletic Trainers' Association (December 2010 – December 2011)
Member, Athletic Trainers' Association of Arkansas (December 2010 – December 2011)
Member, Student Athletic Training Organization (December 2009 – December 2010)

HONORS AND AWARDS

Research Assistantship University of Kentucky (August 2012 – Current)
Graduate Assistantship University of Arkansas Athletics (June 2010 – June 2012)
Golden Key International Honour Society (October 2011)
Dr. Shaara Memorial Scholarship Recipient (December 2009-May 2010)
Description: An award given to an outstanding athletic training student in memory of former University of Florida team physician Dr. Richard Shaara. The athletic training student must represent him or herself in a way that would positively reflect the values and principles Dr. Shaara implemented and expressed each day
College of Health and Human Performance Dean's List (January 2009- May 2009)
College of Health and Human Performance Dean's List (August 2008- December 2008)
University of Florida, 2008 Rec Sports Fitness Supervisor of the Year
College of Health and Human Performance Dean's List (January 2007- May 2007)
Florida Undergraduate (Bright Futures) Scholarship (May 2006 – May 2010)