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The Effect of Astym Treatment on Muscle Performance

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THE EFFECT OF ASTYM® TREATMENT ON MUSCLE PERFORMANCE

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By

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ABSTRACT

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December 2014

Dissertation Supervised by RobRoy L. Martin PhD, PT

Purpose: Astym® treatment is a manual therapy intervention performed to stimulate tissue regeneration and treat pain, limited mobility, and muscle weakness for patients with musculoskeletal pathology. The purpose of this study was to determine if Astym® treatment administered to the lower extremity of individuals with lower extremity musculoskeletal injuries would result in an immediate change of maximal force output during a unilateral isometric squat test.

Subjects: Forty-five subjects (14males; 31females) aged between 18-65 years participated in this study. Criteria for inclusion in the study were: a lower extremity musculoskeletal injury with a resulting deficit of at least 10% in isometric squat strength of the involved limb; and a lower extremity functional score of 40-70 out of 80 points.

Materials/Methods: Subjects were randomized into 3 treatment groups (15 subjects per group): 1) Control – received no treatment 2) Placebo – received a sham Astym® treatment 3) Astym® Treatment – received Astym® treatment to the lower extremity. Subjects were blinded to whether they received the Astym® treatment or placebo treatment intervention. After a 5-minute warm-up on a lower body ergometer the subjects were familiarized to the operations of a computerized leg press machine that measured the maximum force output (Newtons) during a unilateral isometric squat test. A baseline measure of maximal force output (pre-test) was determined by the average of 3 trials with a 30 second rest period between the trials. The subjects then received the designated treatment intervention. Immediately following the treatment intervention the subjects were retested (post-test) using identical testing procedures by an investigator blinded to the treatment intervention received by the subject. The percent change of maximal force output from pre-test to post-test measures was compared using a one-way analysis of variance with alpha set at 0.05. A Tukey's post-hoc analysis determined statistical differences between the groups.

Results: A significant effect was observed on the percent change of maximal force output at the $p<0.05$ level for the Astym®, placebo, and control treatment interventions [$F(2,42) = 7.91$, $p = 0.001$]. Tukey's post hoc analysis demonstrated that the percent change of maximal force output was significantly greater in the Astym® group (15 ± 18%change) compared to the placebo (-6 ± 11%change) and control(-1 ± 17%change) groups. No significant difference ($p=0.68$) was noted between the control and placebo groups.

Conclusions: Astym® treatment to the involved lower extremity increases maximum force output during an isometric squat test immediately following treatment. A placebo treatment and a control treatment did not change maximal force output of the lower extremity.

Clinical Relevance: The results of this study suggest that Astym® treatment can be used as a treatment intervention for the immediate improvement of muscle performance for patients presenting with a muscle strength deficit caused by a musculoskeletal injury to the lower extremity. This may expand the use of Astym® treatment for patients with muscular weakness in an effort to improve functional activities or athletic performance. The longevity of the effect of Astym® treatment on muscle performance, however, remains unknown.

DEDICATION

This work is dedicated to my grandmother, Grin, for her constant love and encouragement, to my parents, Rick and Gayle, who taught me to work hard to achieve my goals, and finally to my amazing wife, Kim, whose unconditional love and support has allowed me to pursue my dreams.

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Chapter 1

Introduction

1.1 Background

Physical therapists treat individuals with various types of injuries to the musculoskeletal system. This includes soft-tissue injuries affecting muscles, tendons, fascia, joint capsules, and ligaments. To treat soft-tissue injuries, physical therapists may employ various types of therapeutic interventions such as electrical stimulation, ultrasound, infrared laser, cryotherapy, strengthening exercises, and soft-tissue mobilization techniques. However, injuries to soft-tissue structures can be challenging to resolve and resilient to traditional therapeutic interventions.[1] New soft-tissue mobilization techniques have evolved that utilize specialized instruments, tools, or devices to facilitate healing and address the impairments associated with soft-tissue injuries.[2] Astym® treatment is an innovative instrument assisted soft-tissue mobilization technique that has been shown to stimulate soft-tissue regeneration and address common impairments such as pain, limitations in mobility, and muscle weakness that may accompany soft-tissue injury.[1,3-11]

Astym® treatment is a manual therapy technique applied with the use of specialized handheld instruments (Figure 1).[1] The instruments are guided across the surface of an individual's skin, parallel to the fiber orientation of the underlying soft-tissue structures.[1] These underlying ligamentous, deep fascial, muscular, and tendinous

tissues present with a different texture than the skin and superficial fascia. This difference in texture can be felt through the Astym® instruments by the therapist.[12] The therapist will judge the appropriate amount of pressure to apply with the instruments based on feeling the distinct texture of the ligamentous, deep fascial, muscular, and tendinous tissues with the Astym instruments.[12] Individuals that are lean will require less pressure through the instruments to contact the target tissues.[12] Individuals that have greater adipose in the superficial fascia will require greater pressure applied through the instruments in order to feel the change of the tissue textures necessary to mechanically stimulate underlying ligamentous, deep fascial, muscular, and tendinous tissues.[12] Mechanical stimulation of the soft-tissue structures initiates the body's innate mechanisms of healing [13,14] and may reduce pain while improving mobility and muscle strength.[1,3-11] Astym® treatment differs from other methods of soft-tissue mobilization techniques in that the treatment is administered to an entire limb segment with a specific, sequential protocol. Thus a typical session of Astym® treatment incorporates treatment to soft-tissue structures proximal and distal to the focal area of injury or pathology. Each Astym® treatment session lasts approximately 15 minutes and is accompanied by stretching and strengthening exercises determined by the physical therapist.[12]

The indications for Astym® treatment are pain, limited mobility, and impaired muscle performance as the result of common musculoskeletal pathologies. [5,11] Astym® treatment is believed to alter the recipient's perception of pain through mechanical stimulation of soft tissues. In cases of chronic pain caused by soft-tissue dysfunction, Astym® treatment is thought to help the body absorb dysfunctional soft tissue and return it to a healthy, pain-free state.[13-15] Several case studies have shown that Astym®

treatment can reduce pain caused by common musculoskeletal pathologies including epicondylosis [5], carpal tunnel syndrome,[16] Achilles tendinopathy,[8] hamstring tendinopathy [9] and patellar tendinopathy.[17] Astym® treatment has also been successfully used to improve joint mobility as a result of excessive soft-tissue scarring and fibrosis.[4,6,7,10] In two separate case studies, Henry et al.[6,7] demonstrated clinically significant changes in knee joint range of motion in response to Astym® treatment when previous conservative and surgical interventions had failed. Astym® treatment was also used successfully to restore the range of motion to pre-injury levels in 2 separate cases of patients with ankle joint dysfunction caused by excessive fibrosis.[10,11] Davies and Backopp [4] documented improvements in shoulder mobility in response to Astym® treatment for a series of patients with limited mobility of the shoulder after mastectomy surgery.

Anecdotally, therapists have noted Astym® treatment invokes immediate improvements of muscle performance. Muscle performance is described as the combination of the strength, power, and endurance of a muscle or group of muscles necessary to execute a specific task or functional activity.[18] Because of the potential effects of Astym® treatment on muscular performance, athletes have begun receiving Astym® treatment before training sessions and competitions.[19] However, only a few documented case studies have substantiated the influences of Astym® treatment on measures of muscle performance.[5,9] The impact of Astym® treatment on muscle performance is an area that needs to be studied in clinically controlled trials.

Figure 1. Astym® Instruments

Muscular strength is a component of muscle performance. Muscular strength can be defined as the amount of maximal volitional force produced by the contraction of a single muscle or a group of muscles.[20] Determining the effect of Astym® treatment on force output may impact how physical therapists implement a treatment program for a patient presenting with deficits in muscular strength due to common musculoskeletal pathologies. Lower extremity muscular strength that is measured in the closed kinetic chain (ex. squat or leg press), is closely associated with the functional abilities of an individual.[21] Unilateral squat strength has been associated with an individual's ability to walk and negotiate stairs.[22] A deficit of lower extremity muscular strength has been shown to be a risk factor associated with falls in an elderly population.[23] In a younger, active population, squat strength is associated with athletic performance. Comfort et al.[24] demonstrated a significant negative correlation (r= -0.60) of squat strength to timed sprint speed in athletes and recreationally active, young men. Parchmann & McBride[25] also demonstrated a relationship in maximal squat strength of collegiate athletes to sprint time

at 10 meters (r=-0.81) and 20 meters (r=-0.87), respectively. The authors also found a strong relationship of maximal squat strength to vertical jump height (r=0.87) and agility test time (r=-0.76). [25] Based on the literature cited above, there is evidence to suggest that lower extremity muscular strength plays a moderate role in a wide variety of functional activities.

To date, there is limited evidence to show that patients experience an increase in muscular performance as a result of Astym® treatment. [5,9] Anecdotally, physical therapists have noted post-treatment improvements of muscular strength quantified by handheld dynamometry of the musculotendinous structures treated with the Astym® instruments. Patients have also reported an immediate improvement of functional activities that require significant lower extremity muscular strength such as transitioning from sit to stand or climbing stairs. However, none of these anecdotal findings have been studied in a randomized clinical trial. This research project will determine if Astym® treatment improves immediate muscular performance for patients presenting with muscle weakness due to a musculoskeletal condition. The information gained from this research project will help determine if Astym® treatment has clinical application to improve muscle performance. Specifically, it will determine if Astym® treatment has a role in acutely improving muscular strength in an effort to enhance patient function.

1.2 Operational Definitions

Astym® treatment – An instrument assisted soft-tissue mobilization technique that is applied using specialized instruments and a specific sequential protocol to stimulate

tissue regeneration and for the treatment of pain, limited mobility, and muscle weakness related to common musculoskeletal conditions.

Control group – The group of subjects that were randomized to receive no treatment intervention.

Placebo group – The group of subjects that were randomized to receive a sham Astym® treatment that was performed using light pressure with the non-treatment edge of the Astym® instruments.

Isometric Squat Test - A closed-kinetic chain physical performance test performed unilaterally on a leg press machine that records the force output produced from a static, pre-determined position of knee flexion and hip extension.

Therapeutic soft-tissue mobilization - Manual therapy interventions directed to soft-tissue structures to increase joint range of motion, reduce pain, decrease swelling, increase flexibility, or improve muscle performance.

Instrument assisted soft-tissue mobilization –Therapeutic soft-tissue mobilization techniques that utilize specialized tools or instruments for the purpose of treating common soft-tissue disorders.

Non-instrumented soft-tissue mobilization –Therapeutic mobilization techniques applied with the skilled hands of a trained healthcare professional to treat pain, swelling, limited flexibility, or impaired muscle performance with the goal to improve functional abilities of a patient.

Muscle performance - The combination of muscle strength, power, and endurance necessary to execute a specific task or functional activity.

Muscular strength- A component of muscle performance that describes the maximal force generated by the volitional contraction of a muscle or group of muscles.

Pain - An unpleasant sensory or emotional experience associated with actual or potential tissue damage.

Neuromuscular Facilitation - An increase of muscle activation through stimulation of the sensorimotor system.

1.3 Limitations and Assumptions

1. Subjects consistently gave maximal effort during testing.
2. The delivery of Astym® treatment was consistent among subjects.
3. The time from the end of treatment intervention to the beginning of testing was the same for each subject.

4. The sample of subjects recruited for this study was representative of a population of patients attending outpatient physical therapy for a lower extremity musculoskeletal injury.

5. Any observed differences in muscle strength were a result of whether the patient had received Astym® treatment, a sham Astym® treatment, or no treatment at all.

6. The results only represented acute changes in muscular strength.

7. The sustainability of any observed effects on muscular strength is unknown.

8. The functional impact of any observed effects of Astym® treatment on muscular strength remains unknown.

1.4 Delimitations

1. Recruitment of 45 subjects from an outpatient sports medicine and orthopedic physical therapy clinic.

2. Randomization of subjects into a treatment group.

3. Primary investigator was blinded to the results of the isometric squat tests until all of the subjects had completed testing.

4. Secondary investigator and the subjects were blinded to the treatment intervention received.

5. Familiarization of the subjects to the operations of the computerized leg press machine to account for a learning effect.

6. Established a work:rest ratio to account for muscular fatigue during testing.

7. Astym® treatment was provided by the same provider, with 3 years of clinical experience administering the technique.

1.5 Problem Statement

The purpose of this study was to determine if Astym® treatment administered to the lower extremity resulted in an acute change of muscular performance as measured by maximal force output during an isometric squat test among subjects presenting with weakness associated with a musculoskeletal injury to the lower extremity.

1.6 Independent Variable

The Independent Variable in the present study was the treatment intervention administered to the subjects. The treatment intervention had three forms:

1. Control – received no treatment (12 minutes of rest)
2. Placebo – received 12 minutes of a sham Astym® treatment to the lower extremity
3. Astym® Treatment – received 12 minutes of Astym® treatment to the lower extremity

1.7 Dependent Variable

The present study investigated one dependent variable:

1. Percent change (%change) of pre-treatment to post-treatment maximal force output during an isometric squat test

1.8 Hypotheses

1. Astym® treatment will have a significant effect on maximal force output during a unilateral isometric squat test.

    1a. The group of subjects that receive Astym® treatment will produce a significantly greater percent change in pre-treatment to post-treatment maximal force output than the subjects that received no treatment (control) and the subjects that received a sham Astym® treatment (placebo).

    1b. The percent change in pre-treatment to post-treatment maximal force output produced during an isometric squat test for the control and placebo groups will not be statistically different.

CHAPTER 2

Review of Literature

2.1 Introduction

Astym® treatment is a manual therapy technique applied with specialized instruments by a physical therapist with advanced certification and training in the technique. There are specific Astym® treatment protocols used in the treatment of pathologies of the upper extremity, shoulder complex, cervical-thoracic spine, lumbar spine, hip complex, and lower extremity. Each of the Astym® treatment protocols addresses the entire kinetic chain that includes treatment to the body regions that are distal and proximal to the specific area of pathology. For example, Astym® treatment for patellar tendinopathy includes treatment of the foot, ankle, and leg, as well as the structures of the hip complex and thigh. Astym® treatment is used to stimulate tissue regeneration. Astym® treatment may also be indicated to treat pain, limited mobility, and muscle weakness related to common musculoskeletal conditions. Astym® treatment provides a mechanical stimulus to soft-tissue structures through the therapist's application of the Astym® instruments. There are three Astym® instruments of varying sizes that are used during each treatment session. The larger instruments are used to perform longitudinal strokes over the entire length of musculotendinous structures from the origin to insertion. This is followed by specific strokes using the smaller instruments over bony prominences where tendons and ligaments commonly attach. A total of 2 sets

of strokes in a superior to inferior direction, followed by 2 sets of strokes in an inferior to superior direction are performed until the entire body region has been treated. The strokes are applied at a rate of 6-8 inches per second. The amount of pressure applied through the instruments is enough to feel the unique texture of the ligaments, tendons, deep fascia, and muscular tissues that are deep to the skin and superficial fascia. Because each individual possesses a different amount of adipose tissue within the superficial fascia, the amount of pressure applied through the instruments varies according to each individual's body composition. However, contact of the instruments with the muscle, tendon, deep fascia, and ligamentous tissues as determined by the unique texture that these structures provide remains consistent regardless of body composition. Therefore, each Astym® treatment provides a consistent stimulation of the muscle, tendon, deep fascia, and ligamentous structures despite variability in body composition between individuals. Once the entire kinetic chain has been treated with all of the appropriate Astym® instruments in accordance to the regional Astym® protocol, the Astym® treatment is complete and the patient will perform additional therapeutic exercises and activities as determined by the physical therapist.

Despite limited evidence, Astym® treatment has shown promise as a therapeutic intervention to improve muscle performance.[5,9] However, the acute effects of Astym® treatment on muscle performance have yet to be explored in a clinically controlled trial. The purpose of this literature review is to define the current understanding of the relationship of Astym® treatment to muscle performance. Emphasis will be placed on reviewing peer-reviewed literature that explains the known and theorized physiological mechanisms of Astym® treatment as it pertains to muscle performance. The review will

further encompass analysis of forms of instrumented and non-instrumented soft-tissue mobilization techniques employed by physical therapists and the impact of those interventions on muscle performance. The review will conclude by comparing the theorized physiological mechanisms and outcomes related to muscle performance to other forms of instrument assisted and non-instrument assisted soft-tissue mobilization techniques.

2.2 Influence of Soft-Tissue Mobilization on Muscle Performance

Soft-tissue mobilization techniques facilitate several physiological changes that have the potential to affect muscle performance. Specifically, soft-tissue treatments are believed to enhance muscle performance through neuromuscular facilitation (2.2.1), modulation of pain (2.2.2), mechanosensitivity of the muscle tissue (2.2.3), and increased blood flow (2.2.4). The physiological mechanisms through which soft-tissue mobilization techniques, such as Astym® treatment, may act to enhance muscle performance are explored below.

2.2.1 Neuromuscular Facilitation

Riemann and Lephart [26,27], and Voss et al. [26,27] have theorized that soft tissue-mobilization techniques may influence muscle performance through activation of the sensorimotor system.[26,27] The sensorimotor system is responsible for resultant changes in motor or muscle activation that is directly or indirectly attributed to sensory stimulation.[26,27] An increase of muscle activation through stimulation of the sensorimotor system is referred to as neuromuscular facilitation.[27,28] The sensorimotor system receives

input from various types of somatosensory receptors found within the skin, fascia, ligaments, joint capsules, tendons, and muscle tissues. [27,28] The somatosensory receptors respond to stimuli such as pain, temperature, touch, vibration, and pressure.[27,28] When stimulated the somatosensory receptors send input to the motor processing centers of the central nervous system.[27,28] The pathway from the somatosensory receptors to the central motor processing centers is referred to as the afferent pathway. The spinal cord, brainstem, cerebellum, and cerebral cortex collectively integrate afferent signals from the somatosensory receptors and respond by sending signals via motor neurons to the appropriate muscle tissue.[27] The pathway from the central motor processing centers to the muscle tissue is known as the efferent pathway. An important role of the somatosensory receptors is to provide feedback to the central nervous system about joint position, body movement, and length-tension relationships of muscle. Improved awareness of joint position, body movement, and maintaining optimal length-tension relationship of muscles can positively influence muscle activation.[29] Therefore, the stimulation of the somatosensory system is capable of influencing muscle performance. This section will describe the different types of somatosensory receptors and how stimulation of these receptors through specific therapeutic interventions facilitates muscular activation and influences muscle performance.

2.2.1.1 Somatosensory Receptors

The soft tissues of the human body are richly innervated with several types of somatosensory receptors. Muscle spindles and golgi tendon organs are two specialized receptors found within musculotendinous tissue.[27] Muscle spindles are aligned in parallel to the extrafusal muscle fiber and are interspersed within a muscle belly. Muscle spindles

are sensitive to passive changes in muscle length. Rapid stretching of a muscle activates the muscle spindle, which in turn facilitates a contraction of the same muscle.[27] Golgi tendon organs are another type of somatosensory receptor commonly found at the musculotendinous junction of skeletal muscles. Golgi tendon organs are aligned in series to the extrafusal muscle fibers and are sensitive to muscle tension developed during a muscle contraction.[27] Stimulation of the Golgi tendon organs induce a spinal reflex that inhibits the stimulated muscle.[27] Although the mechanisms that activate the muscle spindle and golgi tendon organs are different, both receptors monitor and help maintain adequate length-tension characteristics of the muscle that may influence muscular strength.[27]

In addition to the muscle spindles and golgi tendon organs, specialized somatosensory receptors can be found in cutaneous, fascial, ligamentous, and capsular tissues. Table 1 summarizes the various types of somatosensory receptors based on location and sensitivity to sensory stimuli. Pacinian corpuscles are common receptors found in the hypodermis of the skin as well as in fascial, ligamentous, muscular, and tendinous tissue.[27,30,31] Pacinian corpuscles are poor at responding to sustained pressure but are very good at detecting rapid changes of mechanical stimuli, particularly vibration.[27,30,31] Ruffini endings are abundant throughout the dermis of the skin, subcutaneous tissue, capsular tissue, and ligaments of peripheral joints. Ruffini endings are slow adapting receptors, making them able to detect stimuli of sustained pressure. The Ruffini endings are particularly sensitive to tangential forces that create shearing-like stress of tissue.[27,30,31] Meissner Corpuscles are receptors found in the dermis layer of skin and are responsive to fine touch and tactile discrimination.[28,32] The most abundant

receptors found in the skin, muscular, fascial, and ligamentous structures are interstitial receptors. A majority of interstitial receptors serve as mechanoreceptors that respond to mechanical tension and pressure.[33] Interstitial receptors are often stimulated as a result of stretching of skin, muscle, and fascial tissue. [34]

Table 1. Peripheral Cutaneous Somatosensory Receptors

Receptor	Location	Stimuli
Pacinian Corpuscles	• Muscle • Myotendinous junctions • Joint Capsule • Spinal Ligaments	• Touch • Rapid change of pressure • Vibration
Ruffini Endings	• Dermis of the skin • Subcutaneous tissue capsular • Ligaments	• Sustained pressure • Shearing stress
Meissner Corpuscles	• Dermis layer of skin	• Fine touch • Tactile discrimination
Interstitial	• Skin • Muscle • Fascia • Ligaments	• Pain • Mechanical tension • Pressure

2.2.1.2 Influence of Somatosensory Receptors on Muscle Performance

The influence of somatosensory receptors on muscle performance is complex. [27] The integration of sensory input to muscular output may best be explained by the *final common input hypothesis*.[35] Based on the *final common input hypothesis*, sensory receptors from cutaneous, muscular, and articular sources, in addition to the motor centers of the central nervous system converge upon the gamma motor neurons. [35] The gamma motor neurons innervate muscle spindles, maintaining the sensitivity of the spindle to changes in length as the muscle shortens during contraction.[27] Once activated, the muscle spindle acts upon muscle fibers via the alpha motor neuron. According to the

final common input hypothesis, motor function can either be facilitated or inhibited by the input received from the somatosensory system.[35] Whether the muscle is facilitated or inhibited may depend on the type of stimulation and ultimately the type of somatosensory receptor that is transmitting the input to the central nervous system.[30]

Stimulation of somatosensory receptors can also influence muscle performance through stimulation of the autonomic nervous system. The autonomic nervous system controls hormonal responses, perfusion, and blood glucose levels that may influence force generation of voluntary muscle contraction.[36] Stimulation of somatosensory receptors has been suggested to trigger sympathetic nervous system responses,[37] while other sources report an increase of parasympathetic responses.[33] The type of stimulation received by the somatosensory receptors may ultimately determine whether the sympathetic or parasympathetic nervous systems are stimulated. Static pressure has been shown to lower arterial blood pressure suggestive of parasympathetic nervous system stimulation.[33] Slow rhythmic stroking of soft-tissue activates the parasympathetic nervous system, reducing muscle tone,[38] skin temperature, and activation of the muscle spindle.[30] Conversely, tactile pressures applied with strong and rapid manipulation of soft-tissue activates a sympathetic nervous system response capable of inducing muscle contraction.[30,39] The stimulus imparted by an Astym® treatment resembles the stimuli described for triggering sympathetic nervous system activation, but the effect of Astym® treatment on activation of the sympathetic nervous system has not been investigated.

2.2.1.3 Therapeutic Applications of Neuromuscular Facilitation

The facilitation of muscle performance through somatosensory stimulation has been the proposed physiologic mechanism behind many therapeutic interventions dating

back to the middle of the twentieth century.[40,41] Dr. Margaret Rood developed methods to either facilitate or inhibit muscle activation with the purpose of normalizing motor function.[40,41] The therapeutic interventions introduced by Dr. Rood became known as neurodevelopmental therapy.[40,41] Neurodevelopmental therapy is based on the principle that therapeutic interventions provide a sensory stimulus that targets a specific sensory receptor to elicit a desired response.[40,41] Rood proposed that therapeutic interventions that include rapid tissue stroking, fast brushing of the skin, and vibration facilitate muscle contraction.[40,41] Although these therapeutic interventions have been commonly employed in clinical settings, there is limited evidence to support the idea that the techniques are capable of facilitating neuromuscular function and enhancing muscle performance.

2.2.1.3.1 *Tactile Stimulation*

According to the original theories described by Rood[41], fast brushing of the skin causes a stimulation of the same somatosensory receptors that are sensitive to pain. Rood believed the sensory stimulation from fast brushing would influence the muscle spindle to have a facilitatory effect on muscle activation.[41,42] The facilitation of the muscle was believed to last up to 40 minutes after cessation of fast brushing.[41,42] However, a study performed by Mason[42] revealed no clear conclusion of the effect of tactile stimulation through fast brushing on muscle activation measured by electromyographic activity and muscular strength as measured by peak force production of the stimulated muscle. Mason[42] tested the effect of 5 seconds and 30 seconds of brushing of the skin overlying the gastrocnemius muscle at speeds of 5, 180, and 360 revolutions per second in healthy subjects. The peak force and electromyographic activity of the gastrocnemius muscle in response to an Achilles reflex was recorded sequentially at 30 seconds following the

cessation of brushing and every 5 minutes thereafter for 30 minutes. The results of the study indicated that electromyographic activity of the gastrocnemius muscle was not significantly different from a control condition that did not receive the fast brushing stimulus. The peak force production, however, was significantly different according to the analysis of variance, but was unable to show a significant effect for the different speeds, duration, and elapsed time from the fast brushing stimulus. In a similar study, Wood et al.[43] demonstrated an inhibitory effect of the gastrocnemius-soleus muscle reflex in response to fast brushing among a group of healthy subjects. Conversely, Matyas et al.[44] demonstrated a significant effect of fast brushing on maximal volitional contraction of the hamstrings and quadriceps muscles among subjects with hemiplegia. These findings were consistent with those described by Garland and Hayes [45] who reported improved voluntary contraction of the tibialis anterior muscle in response to fast brushing among a group of individuals suffering from foot drop. Based on the findings of these research studies it appears that the response to fast brushing in healthy subjects is equivocal or inhibitory to muscle activation. On the contrary, subjects with neurologic impairment experience a facilitatory muscle response.[42-45] The authors of these studies concur that the influence of sensory stimulation on muscle activation and strength is complex and may depend on several intrinsic factors of the individual that may explain the variable response to the stimulation.[40,42-45]

2.2.1.3.2 *Vibration*

Vibration is another sensory stimulus that has been proposed to have a facilitatory effect on muscle performance. Therapeutic applications of vibration can be applied locally to a single muscle-tendon complex, to an entire limb segment, or through the entire body.[46] The mechanical stimulation from a therapeutic application of vibration is

believed to stimulate the muscle spindle complex found within the muscle tissue. The stimulation of the muscle spindle increases excitability of motorneurons transmitting efferent signals to the muscles that received the mechanical stimulus from vibration.[46] The increase of motorneuron excitability has been substantiated with studies that demonstrate acute increases of electromyographic activity of muscles in response to vibration stimuli compared to control groups.[47-53] The effects of vibration on cutaneous mechanoreceptors may last for several minutes post vibration stimulation.[54] Reflex responses affecting motorneurons are also heightened following vibration stimulation when compared to non-vibration conditions. [51,55,56]

The acute effects of vibration on muscle performance, specifically muscle strength and power, have been well documented. Bosco et al.[57] studied the acute effects of vibration on single limb squat strength in elite volleyball players. The subjects experienced a 6-8% increase in squat strength when tested immediately following whole-body vibration. Similar findings were reported for the elbow flexor muscles as electromyographic activity and muscle force production tested 5 minutes after vibration treatment to the entire upper extremity showed a significant improvement compared to a control group that did not receive upper extremity vibration.[58] Issurin et al.[59] corroborated these findings with approximately 10% increases in muscular strength of the elbow flexor muscles with vibration stimulus to the entire upper extremity. Mileva et al.[60] demonstrated significantly greater muscular strength of the knee extensor muscles during trials superimposed with a form of vibratory stimulus to the quadriceps muscles when compared to performance without a vibratory stimulus. Conversely, de Ruiter et al.[61] demonstrated no significant effect of whole-body vibration on maximal voluntary

isometric knee extensor force. In fact, they found an approximate 5% decrease in isometric knee extensor force.[61] Cormie et al.[62] also demonstrated a decline in muscular strength as determined by peak force during an isometric squat test. However, in the studies by Cormie et al.[62] and de Ruiter et al.[61], the whole body vibration was applied while subjects assumed a squat position. This placed the knee angle of the subjects between 100-110° of flexion. The position would require activation of the knee extensor muscles that could have fatigued the muscles prior to the post-treatment force testing. Research has demonstrated that vibration applied during muscle contraction or active exercise results in accelerated muscle fatigue.[51] Therefore, differences in the application of the vibration may explain the contradictory results found for vibration and muscular strength. A recent meta-analysis of studies investigating the short-term effects of vibration on muscle performance concluded that vibration has an overall positive influence on muscular strength, specifically for the muscles involved in extension of the knee.[63] Astym® treatment is hypothesized to stimulate the same somatosensory pathways as vibration and thus may share similar treatment effects on muscle performance.

2.2.2 Pain Modulation

Pain is defined as an unpleasant sensory or emotional experience associated with actual or potential tissue damage.[64] Pain serves as a natural warning system to protect the body from impending damage through input from specialized receptors called nocioceptors.[65] Nocioceptors elicit pain in response to mechanical, thermal, and chemical stimuli.[65] Stimulation of nocioceptors has been shown to suppress muscle activation and decrease muscular strength.[66-68] Conversely, when stimuli from nocioceptors are abated, muscular strength and activation is restored to pre-painful levels.[69] Soft-tissue treatment

techniques are thought to influence muscular strength by altering the patient's perception of pain.[70] Astym® treatment has been shown to improve self-reported measures of pain over the course of several treatment sessions.[1,5-8,10,11,16,17] However, the acute effects of Astym® treatment on pain have not been studied.

2.2.2.1 Gate-Control Theory of Pain

One possible mechanism of action through which soft-tissue mobilization techniques might influence a person's perception of pain is the gate-control theory of pain. The gate-control theory of pain is based on the principle that stimulation of larger diameter relatively rapidly conducting peripheral nerve fibers blocks painful stimuli transmitted through smaller, slow conducting neurons that enter the spinal cord at the same spinal level.[71] Based on the gate-control theory of pain, a patient's perception of pain is reduced as stimuli from small fiber nocioceptors are blocked from transmitting signals to central command centers in the brain by mechanical or electrical stimulation of larger diameter neurons from cutaneous mechanoreceptors.[71]

Physical therapists commonly employ therapeutic interventions to electrically and/or mechanically engage the mechanisms of the gate-control theory of pain in an effort to reduce pain.[71] A transcutaneous electrical stimulation device uses electric current to stimulate large fiber, cutaneous mechanoreceptors thereby blocking signals originated by small fiber, nocioceptors from reaching the brain and thus modulating or changing the perception of pain.[72] Hopkins et al.[73] showed that experimentally-induced pain and effusion to otherwise healthy knee joints resulted in decreased activation and strength of the quadriceps muscle group was reversed for up to 30 minutes following application of

transcutaneous electrical stimulation to the knee joint.[73] Similarly, Pietrosimone et al.[74] demonstrated significant increases of quadriceps activation among subjects with knee osteoarthritis treated with transcutaneous electrical stimulation. Cetin et al.[75] demonstrated increases of isokinetic strength of the quadriceps between 50-70% from baseline measures following 20 minutes of transcutaneous electrical stimulation combined with application of a moist hot pack to the knee joint. With the exception of the study performed by Pietrosimone et al.,[74] the improvements in muscle performance coincided with a reduction of patient perceived pain that suggests therapeutic interventions that mediate pain have the capability to acutely change muscle activation and influence strength.

2.2.2.2 Descending Pain Suppression Mechanism

Pain suppression can also occur as unpleasant cutaneous sensations received by the central command centers of the brain trigger responses to inhibit the painful stimuli. When a painful stimulus is transmitted to the central nervous system, it stimulates nuclei in the midbrain. The nuclei of the midbrain initiate activity through the descending spinal tracts that are returning to the spinal level in which the painful stimuli was received. This stimulus causes a release of endogenous opiates at the spinal level receiving the painful input.[70] Endogenous opiates, collectively referred to as endorphins, are inhibitory neurotransmitters that work to blunt the transmission of painful stimuli to the brain. Endorphins are produced by the pituitary gland and hypothalamus and are released to the brain and spinal cord in response to pain as well as during exercise and elevated emotional states. Soft-tissue mobilization techniques, specifically massage techniques, have been shown to cause an increase of serum endorphins for up to one hour

following treatment.[76] Based on this information, it is possible that Astym® treatment produces similar increases of serum endorphins that could decrease pain and result in improved muscle activation and performance.

2.2.2.3 Theorized Effect of Astym Treatment on Pain Modulation

Astym® treatment has been shown to improve musculoskeletal sources of pain[5,8,10,11], however, the mechanisms through which pain reduction is achieved are unknown. Soft-tissue mobilization techniques are theorized to mediate pain through the gate-control and/or descending pain suppression mechanisms.[70] Research suggests that reduction of pain results in a reversal of muscle inhibition that results in improved muscular activation and strength.[69] To date, research that has investigated soft-tissue treatment on acute changes in muscle activity and strength has been equivocal,[77-83] however, these studies were not performed on subjects with musculoskeletal pain. There is no existing study that has examined if a reduction of pain following Astym® treatment affects muscular activation or strength.

2.2.3 Mechanosensitivity of Muscle Tissue

Soft-tissue mobilization techniques are thought to induce changes in cellular functions in response to mechanical stimulation.[13,14] Davidson et al.[13] and Gehlsen et al.[14] studied the effect of Astym® treatment on the cellular functions of fibroblast cells. Fibroblast cells are found in ligaments, tendons, and fascia and are responsible for producing collagen, a structural protein that gives various soft-tissues its inherent strength.[13] The results of the research by Davidson et al.[13] and Gehlsen et al.[14] demonstrated that mechanical stimulation applied through Astym® treatment resulted in a

significant increase of collagen production by the fibroblast cells in a rat model.[13,14] These findings were consistent with related research that has shown that mechanical stimulation of fibroblast cells facilitates cellular growth, increases protein synthesis, promotes the release of growth factors, and attracts additional fibroblast cells.[84-86]

Other types of cells are sensitive to mechanical stimulation and may be influenced by Astym® treatment as well. The membranes of skeletal muscle tissue contain mechanosensitive ion channels that facilitate exchange of potassium and calcium ions necessary to propagate muscle contraction.[87] Researchers have shown that increases of intracellular calcium within the muscle results in greater force of contraction by muscle fibers.[88-90] Conversely, a reduction of the magnitude or rate of calcium release to working muscle cells results in decreased force of contraction.[91] This intimate relationship of calcium to muscle force production is known as the force-calcium relationship.[88-90] Mechanical stimulation of various cells has been shown to increase the exchange of calcium ions across cellular membranes.[92] Mechanical stimulation of muscle cells is believed to alter the concentration of calcium ions [87] that may increase force of muscle contraction. Whether mechanical stimulation applied through Astym® treatment affects the force-calcium relationship to increase muscle force production, however, has yet to be studied.

2.2.4 Increase of blood flow

Astym® treatment causes a hyperemic response that can be seen on the surface of the skin of the body regions that have been treated. This suggests that Astym® treatment results in a local increase of blood flow to the treated areas. Studies have substantiated

changes in blood flow as a result of other forms of soft-tissue mobilization.[93-95] An increase of blood flow is related to physiologic changes in soft-tissue temperature that may enhance force output during a maximal contraction.[96,97] Longworth [98] reported increases of tissue temperature following 6 minutes of massage that was maintained for 10 minutes following treatment. Drust et al.[99] demonstrated increased intramuscular temperature of the quadriceps muscles as a response to massage. Increased soft-tissue temperature can directly influence muscle strength. Gray et al.[100] found that muscle fiber conduction velocity is increased in muscles with an elevated temperature. An increase of muscle fiber conduction velocity is strongly correlated with maximal force and rate of force development of a muscle.[101] Based on this evidence, it is hypothesized that Astym® treatment may induce similar changes of blood flow resulting in increased temperature and potential for increased force development of the treated muscles.

2.2.5 Summary of the Proposed Mechanisms for Improving Muscle Performance through Soft-tissue Mobilization.

Evidence suggests that pain modulation, neuromuscular facilitation, increased blood flow, and increases of intracellular calcium within muscle tissue are possible mechanisms by which Astym® treatment may acutely increase muscle performance. Astym® treatment may change the perception of pain experienced by the patient. A reduction of pain can result in an improved ability of the muscle to produce force. Astym® treatment may also stimulate neuromotor mechanisms that facilitate muscle contraction and force production through somatosensory stimulation. Tactile stimulation

and vibration are examples of facilitatory therapeutic techniques that have been shown to enhance muscular strength. Perhaps Astym® treatment could provide a similar effect to treated muscles through stimulation of the somatosensory system. Astym® treatment may also cause changes in blood flow that increases intramuscular temperature and resultant muscle force production. Finally, Astym® treatment may provide a stimulus to mechanically sensitive ion channels found within muscle tissues that facilitate muscle contraction. These physiologic mechanisms provide a theoretical framework through which Astym® treatment may influence the motor system to improve muscular strength. A randomized, clinically controlled trial is needed to determine if Astym® treatment has an acute effect on muscle performance.

2.3 The Effects of Therapeutic Soft-Tissue Mobilization Techniques on Muscle Performance

Therapeutic soft-tissue mobilization techniques are manual therapy interventions directed at soft-tissue structures to increase joint range of motion, reduce pain, decrease swelling, increase flexibility, or improve muscle performance. Traditionally, soft-tissue mobilization techniques are performed with the hands of a skilled professional, however, new soft-tissue mobilization techniques have evolved that utilize specialized instruments to assist the therapist in administering treatment. These are collectively known as instrument assisted soft-tissue mobilization techniques. Research suggests that non-instrumented and instrumented soft-tissue mobilization techniques may facilitate or inhibit muscle performance, depending upon the specific technique

employed.[5,9,70,77,82,102-105]

2.3.1 Instrument Assisted Soft-Tissue Mobilization

Many different types of instruments and methods have evolved for the purpose of mobilizing soft-tissue. These techniques are known generally as instrument assisted soft-tissue mobilization techniques. There is limited information regarding the effects of instrument assisted soft-tissue techniques, specifically as it relates to muscular strength. The purpose of this section will be to examine patient outcomes in muscle performance as a result of treatment with instrument assisted soft-tissue mobilization techniques. Emphasis will be placed on how instrument assisted soft-tissue techniques, including Astym® treatment, Graston® technique, "the Stick" ®, and Foam rollers effect measures of muscular performance, specifically muscular strength.

2.3.1.1 Astym® Treatment

Improvements in muscular strength at the conclusion of care have been documented in studies reporting the outcomes of Astym® treatment. In a clinically controlled trial, Wilson et al.[17] explored the effect of Astym® treatment on patients diagnosed with patellar tendinopathy. The patients were randomized into an Astym® treatment group or a control group. The Astym® treatment group (6 males, 4 females) received Astym® treatment in addition to stretching and strengthening exercises for the lower extremity at a frequency of 2 times per week for 4 weeks. The control group (5 males, 5 females) received identical stretching and strengthening exercises 3 times per week for 4 weeks but did not receive Astym® treatment. Muscle performance tests were utilized to determine the success of treatment. The muscle performance tests included an

ability to perform: 1) 6 consecutive single limb hops, 2) a bilateral squat with thighs parallel to the floor, and 3) an eccentric step down test (lowering from a 10 inch step with the involved lower extremity) with less than a 3/10 pain by self-reported numeric pain scale. The results demonstrated that 100% of subjects in the Astym® treatment group successfully performed the muscle performance tests; while only 60% of subjects in the control group were able to successfully perform the muscle performance tests.[17] The results showed that the treatment program supplemented with Astym® treatment resulted in superior muscle performance tests compared to a control group that performed stretching and strengthening exercises for the lower extremity.[17]

Two case studies have also shown that Astym® treatment can influence muscle performance. Haller et al.[5] documented a case of a cyclist with a 2.5 year history of lateral epicondylalgia. Following 8 sessions of Astym® treatment in conjunction with stretching exercises, the individual's pain score changed from a 6/10 to a 0/10 by numeric pain scale and her grip strength improved from 19.35 kg to 36 kg at the time of discharge from physical therapy. Another case study reported by McCormack[9] documented the use of Astym® treatment and eccentric exercise on tendinopathy of the proximal attachment of the hamstring muscle group. Sixteen treatments resulted in an improvement of muscular strength of the hamstring muscles from a 4-/5 to a 4+/5 by manual muscle testing.[9] Each of these case studies demonstrated evidence of improved muscular performance, specifically related to measures of muscle strength, in a treatment program that included Astym® treatment. However, the results from these case studies should be interpreted with caution. A case study research design limits the ability to draw conclusions of a cause and effect relationship of the treatment intervention to the

outcome measures and limits the generalizability of the findings to a broader population.[106] The addition of other components of care, specifically the inclusion of progressive resisted exercise in the case studies described above, limits the ability to attribute improvements in muscular strength to the intervention of Astym® treatment. Therefore, it cannot be determined with certainty that Astym® treatment was the cause of improved muscular strength of the patients documented in the case studies. It also remains unknown if other patients with similar characteristics and complaints of symptoms would have the same outcome that was documented in the case studies. To date, no study has specifically examined the acute effects of Astym® treatment on muscle strength.

2.3.1.2 Graston® Technique

The Graston® technique is an instrument assisted soft-tissue mobilization technique that also utilizes specialized instruments to treat soft-tissue dysfunction (Figure 2).[107] The purpose of the Graston® technique differs from that described for Astym® treatment. Astym® treatment is proposed to induce biological changes at a cellular level to promote the absorption of scar tissue and to stimulate the regeneration of soft tissues. The purpose of the Graston® technique is to mechanically mobilize scar tissue and breakdown adhesions that cause pain and limit function.[107] In general the Graston® technique is applied more aggressively to the specific areas of soft-tissue dysfunction, while Astym® treatment is performed globally to the soft-tissue structures of the entire affected limb or body segment.

Figure 2. Instruments used for application of the Graston® technique

Despite the inherent differences in the treatment approaches of Astym® treatment and the Graston® technique, both techniques have similar evidence of improving patient outcomes. Isolated case reports have shown that the Gratson® technique was part of a successful rehabilitation program in resolving symptoms of DeQuervain's tenosynovitis,[108] compression fracture of the lumbar spine,[109] plantar fasciitis,[107,110,111] lateral epicondylagia,[112] Achilles tendinopathy,[113,114] and arthrofibrosis of the knee.[102] Although these case reports demonstrate improvements in pain and self-reported functional scores, few of these cases have reported changes in muscular strength. In a case describing the outcome of a patient with arthrofibrosis following surgical repair of the quadriceps tendon, Black [102] showed that quadriceps muscle performance as measured by an extension lag during a straight leg raise maneuver, improved following a treatment program consisting of the Graston® technique as well as joint mobilization and strengthening exercises. Use of the Graston® technique with stretching and strengthening exercises in the management of a 35 year-old female with a 2-year history of chronic calf pain also resulted in modest changes in muscle performance.[115] Improvements of

plantarflexion strength from 4/5 by manual muscle test to 5/5 were documented over the course of 9 treatment sessions. She also improved her ability to perform single-limb heel-raises from 22 repetitions to 25 repetitions. A cause and effect relationship, however, cannot be concluded from a case study research design and thus it remains uncertain how much the Graston® technique can influence muscular strength.

2.3.1.3 "The Stick" ®

"The Stick" ® is described as a non-motorized massage device composed of a 24-inch rod around which several individual 1-inch cylinders rotate (Figure 3). The instrument is intended for patients to self-administer treatment by rolling the device over the affected areas of perceived pain or dysfunction.[103] Mikesky et al.[103] studied the use of "the Stick" ® on muscle strength, power, and flexibility. In this randomized, double blind study, 30 collegiate athletes were recruited to participate and were exposed to three different treatment protocols: a control group that received no treatment, a placebo group that received mock electrical stimulation (electrodes placed on the leg, but never turned on), and a treatment group using "the Stick" ® on the muscles of the lower extremity for a total of 2 minutes. Four tests were performed immediately following the designated treatment to represent different components of muscle performance: 1) peak torque generated during isokinetic knee extension set at 90°/second, 2) a vertical jump test, 3) timed speed during a 20-yard sprint, and 4) angle of flexion of the hip joint while performing an active straight leg raise (maximum flexion angle of the hip joint with the knee extended and ankle in neutral dorsiflexion). The order in which the tests were administered was standardized for each testing session: 1) flexibility, 2) vertical jump, 3) 20-yard sprint, and 4) isokinetic strength. The subjects were asked to attend 3 separate

treatment sessions spaced a week apart. A different treatment protocol was performed each week so that by the end of the 3 weeks, each subject was exposed to each of the three treatment protocols (control, placebo, and "the Stick"®). At the conclusion of every weekly treatment session, the measures of muscle performance were performed. The researchers compared the results of the measures of muscle performance for each of the treatment protocols using a one-way analysis of variance. The statistical analysis showed that none of the treatment conditions, including use of "the Stick"®, resulted in a significant difference in the measures of muscle performance.[103] The researchers concluded that use of "the Stick"® had no impact on facilitating improvements in muscle performance.

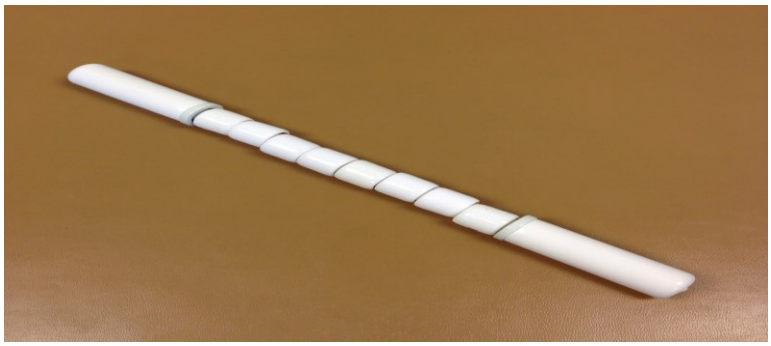


Figure 3. "the Stick"®

2.3.1.4 Foam roller

The foam roller has become an increasingly more common tool for patients to self-administer soft-tissue treatment (Figure 4). Abels et al.[116] studied the effects of self-administered soft-tissue treatment using a foam roller on muscle performance. A 2.5-minute foam roller protocol to the muscles of the lower limb was followed by the drop-jump test. The researchers compared maximal vertical height displacement and magnitude of the soleus reflex in the limb that received treatment to the limb that did not

receive treatment. The results showed that the foam roller intervention did not have a statistically significant effect on vertical height displacement (p=0.525) and latency of the soleus reflex of the limb (p=0.693) when compared to the limb that did not receive the foam roller treatment.[116] Sullivan et al.[117] noted improved performance of flexibility measures with use of a foam roller protocol that did not influence maximal muscular force production or electromyography of the treated muscles. Healey et al.[118] showed that a foam roller protocol affected self-perceived post-exercise fatigue but did not have an impact on muscular performance as noted on a vertical jump test, isometric squat force production, and speed on the Pro agility test. Collectively, much of the literature on soft-tissue mobilization using self-administered techniques with a foam roller has demonstrated the capability to improve flexibility while having no significant effect on acute muscle performance, specifically in regards to muscular strength.

Figure 4. Self-administered treatment of the lower extremity using a Foam Roller

2.3.1.5 Summary of the effects of Instrument Assisted Soft Tissue Mobilization on Muscle Performance

There is limited evidence to make definitive conclusions regarding the effect of instrument assisted soft-tissue mobilization on muscle performance. Improved measures of lower extremity muscle performance was found in one randomized clinical trial that investigated the effect of a series of Astym® treatments compared to a control group that received treatments of stretching and strengthening exercises.[17] Case studies documenting the effect of Astym® treatment and Graston® technique have shown modest improvements in muscle performance.[102,115] However, clinical trials that examined self-administered techniques including those utilizing "the Stick" ® or foam rollers have shown inhibitory or equivocal effects in measures of muscle performance.[103,117,118] The conflicting results from the existing literature make it unclear as to how instrument assisted soft-tissue mobilization techniques affect muscle performance.

2.3.2 Non-Instrumented Soft-tissue Mobilization

Non-instrumented soft-tissue mobilization techniques can be defined as therapeutic mobilization techniques applied with the skilled hands of a trained professional for the purpose of treating pain, swelling, limited flexibility, or impaired muscle performance that limits the functional abilities of an individual. There are many types of non-instrumented mobilization techniques used to treat soft-tissue dysfunction, the most common being therapeutic massage techniques. The purpose of this section will be to explore the scientific literature that exists regarding the influence of the different types of massage and other non-instrumented soft-tissue techniques on muscle

performance, specifically muscular strength.

2.3.2.1 Types of Massage Techniques

There are many types of massage techniques used to treat soft-tissue dysfunction.[119] The most common techniques reported in the literature include effleurage, petrissage, deep transverse friction massage, and tapotement.[119,120] Effleurage consists of light or gentle stroking techniques performed longitudinally along the length of a muscle or body segment.[119,121] This technique is usually performed in a distal to proximal direction and is commonly used to sooth, relax, or comfort a patient in between more aggressive or vigorous types of massage.[119,121] Petrissage is an example of a more aggressive type of massage technique that incorporates kneading, wringing or scooping strokes to the soft-tissue.[119,121] Petrissage techniques are generally performed more vigorously and more rapidly than effleurage techniques with deeper pressure administered to the underlying muscular tissues. [119,121] Deep transverse friction massage is described as a penetrating massage technique that targets tissues deep to the hypodermis including muscle, ligaments, and tendons. Deep transverse friction massage is generally performed with small vigorous strokes applied through the fingertips, perpendicular to the fiber alignment of the target tissue. This technique is designed to induce mild tissue destruction characterized by hyperaemia and an inflammatory reaction with the intent to reduce adherent or contracted tissue and induce tissue remodeling.[119,121,122] Tapotement refers to percussive massage techniques that may include tapping, striking, or clapping on the recipient's body. The purpose of tapotement techniques is to cause vasodilation and trigger cutaneous reflexes that are believed to increase muscular tone.[121]

2.3.2.2 Effect of Massage on Muscle Performance

Several studies have investigated the effect of massage on muscle performance. The majority of evidence suggests equivocal and potential negative influence of massage on muscle performance. Arroyo-Morales et al. [77] studied the effects of a combination of a 20-minute massage session consisting of effleurage, petrissage, and tapotement administered to the gastrocnemius-soleus muscle complex, hamstrings, and quadriceps muscles on the isokinetic peak torque of knee flexor and extensor muscles. The study found that isokinetic peak torque output of the knee extensor muscles was significantly reduced immediately following massage treatment compared to a placebo treatment when tested at isokinetic speeds of 240°/second and 180°/second. There were no statistical differences noted between the placebo and massage treatment groups for isokinetic peak torque output of the knee extensor muscles at 60°/second, 120°/second nor were there statistical difference in isokinetic peak torque of the knee flexor muscles at any of the tested speeds (60°/second, 120°/second, 180°/second, 240°/second).[77] Wiktorsson-Moller et al. [82] reported similar effects of massage on isokinetic and isometric peak torque of the knee extensor and flexor muscles. A significant decrease in isokinetic peak force of the knee flexor muscles at isokinetic speeds of 30°/second and 180°/second and decreased isometric peak force for the knee extensor muscle group were observed following an average of 12 minutes of petrissage to the lower limb. McKechnie et al. [80] compared the peak torque of the plantarflexor muscle group between three different massage treatment groups. The first group received 3 minutes of petrissage treatment to the gastrocnemius-soleus muscle complex. The second group received 6 minutes of tapotement treatment to the gastrocnemius-soleus muscle complex. The third group

received a placebo treatment to the gastrocnemius-soleus muscle complex. The results showed that peak torque did not demonstrate a significant difference for either of the massage treatment groups compared to the placebo.[80] Similar results have been reported in studies using massage protocols that included 8-30 minutes of petrissage and effleurage treatment. These studies failed to demonstrate improvements in variables of muscle performance including power and peak torque.[78,79,81,123,124] Arazi et al.[104] studied the effect of a 15-minute swiss massage protocol to both of the lower limbs that included components of effleurage, petrissage, tapotement, and vibration on vertical jump, agility, and sprint performance. Using a pre-test/post-test design, the results showed that vertical jump, agility, and sprint performance significantly decreased immediately following massage treatment. Mancinelli et al. [125] also demonstrated decreased performance in agility testing with a 17-minute massage protocol consisting of effleurage, petrissage, and vibration techniques. However, vertical jump performance demonstrated a statistically significant improvement.[125]

There are only a few clinical trials that have shown an improvement of muscular performance following massage treatment. According to Micklewright et al.,[126] a 30-minute massage treatment that included effleurage and petrissage techniques significantly improved anaerobic power as determined by the Wingate Anaerobic Cycling Test when compared to a control group that did not receive massage treatment. In a similar study, Ogai et al. [127] demonstrated increased total power of cycling following a 10-minute petrissage treatment to the lower extremity compared to a control group that did not receive treatment. A 3.1% improvement of performance was noted in the massage group compared to a 0.8% decrease of performance in the control group. In a similar study,

Brooks et al.[16] investigated the effect of massage on grip strength after fatiguing exercise Subjects were randomized into a massage group, a passive range of motion group, and a control group that received no treatment. The subjects in the massage group received 5-minutes of effleurage and cross-friction massage to the hand and forearm. A comparison of the groups showed that the massage group yielded a significantly greater increase of grip strength when compared to subjects that received passive range of motion or no treatment at all. The authors concluded that stimulation of available motor units, an analgesic effect, and a perceived recovery effect experienced by the subjects resulted in improved muscular strength.[128]

The majority of evidence on massage and muscle performance suggests that massage has a negative influence on muscle strength and power. With the exception of the study performed by Brooks et al.,[128] massage has shown little value in recovery of strength following muscle fatigue.[78,79,81,123,124,129,130] Analysis of the literature should consider the methods of massage employed by these studies. The majority of the articles reviewed utilized protocols of massage of varying techniques and times. Most of the techniques incorporated effleurage and petrissage. These specific massage techniques are proposed to have inhibitory effects on the excitability of motorneurons.[105] Tapotement techniques, however, are believed to have an excitatory effect on motor neurons. McKechnie et al.[80] provided a study that compared a group that was treated with a massage protocol consisting of only tapotement techniques compared to a group that received petrissage techniques. If tapotement techniques do provide an excitatory effect on motor neurons, then it was not enough to elicit significantly greater production of peak torque in the plantarflexor muscles of the ankle when compared to a group that received

petrissage treatment.[80] The collective findings from studies on the effect of massage on muscular strength suggest that massage does not result in an increase of muscular strength.

2.3.2.3 Active Release Therapy®

Active Release Therapy® is a non-instrumented soft-tissue mobilization technique that uses sustained longitudinal manipulation of soft tissue in cooperation with active and passive motion of the individual's body.[131] Active Release Therapy® is indicated in the treatment of various soft-tissue disorders, including shin splints, sciatica, carpal tunnel syndrome, plantar fasciitis, and tendinopathy.[83] Because Active Release Therapy® involves conscious activation of muscle tissue by the patient, it is believed to directly affect muscle performance.[131]. Drover et al.[83] studied the effect of Active Release Therapy® on the maximal force production of the quadriceps muscle group. The results demonstrated that Active Release Therapy® did not have a significant effect to either increase or decrease force production of the quadriceps muscle group. Although Active Release Therapy® requires conscious muscle activation by the individual, the techniques also place the muscle tissues in a lengthened position that stretches the muscles.[131] Stretching of muscle tissue has been shown to cause a decrease in muscle performance, specifically measures of muscular strength.[132-136] Based on the results described by Drover et al.,[83] it may be concluded that any facilitory effect elicited by stimulation of the somatosensory system during Active Release Therapy® is negated by an inhibitory effect caused by lengthening and stretching of the muscle tissue.

2.3.2.4 Summary of Non-Instrumented Soft-Tissue Mobilization Techniques

The majority of evidence presented on non-instrumented soft-tissue mobilization techniques suggests a negative or equivocal effect on muscle performance. The evidence from clinically controlled trials studying various types of massage techniques indicates a negative impact on multiple measures of muscle performance.[78,79,81,123,124] Active Release Therapy® combines soft-tissue mobilization with active and passive lengthening of the treated tissues. A clinically controlled trial demonstrated no significant change in muscle performance as a result of Active Release Therapy®.[83] The summary of the literature suggests that, depending on the technique used, non-instrumented soft-tissue mobilization has a negative or equivocal influence on muscle performance.

2.3.3 Comparing Astym® Treatment to Other Therapeutic Soft-Tissue Mobilization Techniques

Based on the review of therapeutic soft-tissue mobilization techniques, it remains unclear how Astym® treatment will influence muscular strength. There are conflicting results presented in the existing literature on the effect of soft-tissue mobilization techniques on muscle strength. The contradictory findings may be explained by the differences between the specific techniques.

The use of Astym® instruments may enable greater pressure to be applied to the tissues during treatment. Gehlsen et al.[14] found that measures of fibroblast cell function were greatest for the treatment condition in which the greatest amount of pressure was applied through the Astym® instruments during treatment. Although the effect of

pressure applied with the Astym® instruments has yet to be studied on muscle tissue, research presented by Kukulka et al.[137] reported a 10-15% increase of motorneuron excitability in response to deep pressure applied to the muscle belly. Astym® treatment and the Graston® technique both use hand-held instruments to administer deep pressure to the targeted treatment areas. Although the strength of the evidence is weak, the existing evidence suggests that the Graston® technique [102,115] and Astym® treatment [5,9,17] have a positive influence on muscle strength, whereas soft-tissue mobilization techniques that require less treatment pressure, such as effleurage and petrissage, have an equivocal or inhibitory effect on muscle performance.[77,78,81,82,123,124]. Differences in the pressures used for these techniques may explain the contradictory findings.

The speed of which the soft-tissue mobilization is administered may also have an influence on muscular strength. The strokes applied with the Astym® instruments are administered at an approximate rate of 6-8 inches per second. [12] This provides a faster pace of soft-tissue mobilization compared to the techniques described for effleurage, petrissage, foam roller, "the Stick", and active release therapy that are performed with slower strokes and were found to have an equivocal or inhibitory effect on muscle strength.[77,78,80,82,83,103,116,123,124] Goats[121] suggests that the speed in which massage strokes are administered can influence whether an excitatory or inhibitory effect on muscle contraction is produced. Quicker, more vigorous strokes are believed to be excitatory while slower strokes are thought to be inhibitory to muscle contraction.[121] Slower massage strokes and techniques are also thought to stimulate the parasympathetic nervous system. Stimulation of the parasympathetic nervous system will lower heart rate and blood pressure and promote muscle relaxation.[30] Fast and vigorous cutaneous stimulation,

conversely, stimulates the sympathetic nervous system and promotes muscle excitation.[30] In contrast to effleurage, petrissage, foam roller, "the Stick" ®, and Active Release Therapy® techniques, Astym® treatment may act to stimulate the sympathetic nervous system, resulting in a short-term improvement of muscle performance.

Astym® treatment also differs from other soft-tissue mobilization techniques in that the treatment is administered to the entire limb or body segment.[12] As a result, Astym® treatment may stimulate a broader range of muscles, including agonist muscle groups found within the kinetic chain. With the exception of massage, none of the other soft-tissue mobilization techniques described are used to treat regions other than the specific area of pain or injury. It is possible that a more global approach in treatment may result in enhanced recruitment of muscle groups that ultimately increase measures of muscular strength.

The acute effects of Astym® treatment on muscle strength remain unclear. There are unique aspects of Astym® treatment that are different from other soft-tissue mobilization techniques that may initiate physiological mechanisms to enhance muscular strength. Astym® treatment is performed with generally greater pressure, speed, and a globally wider area of treatment compared to other soft-tissue mobilization techniques. These factors are believed to have a positive influence on muscular strength, but must be further explored in a clinically controlled trial that investigates the effects of Astym® treatment on muscular strength.

Chapter 3

Methods

3.1 Experimental Design

A double-blinded, repeated measures design was used to investigate the effect of Astym® treatment on acute muscular strength of the lower extremity. The dependent variable of interest was the maximal force generated during a unilateral isometric squat test. The independent variable of interest was the treatment received by the subjects: 1) Astym Treatment - received a lower extremity Astym® treatment 2) Control-received no treatment; 3) Placebo-received a sham Astym® treatment. Subjects were randomly assigned to receive the control, placebo, or Astym® treatment intervention and were blinded to the treatment of their assigned group. The primary investigator (brk) performed the control, placebo, or Astym® treatment interventions. A second investigator (lb), blinded to the treatment, administered the pre- and post-treatment isometric squat tests. Both investigators remained blinded to the results of the isometric squat tests until the post-treatment tests were completed for all subjects.

3.2 Subjects

A total of 45 subjects between the ages of 18 to 65 years that met the inclusion/exclusion criteria were recruited from the outpatient facilities of Tri-State Physical Therapy, Seven Fields, Pennsylvania. Sample size estimates were projected

based on data from a pilot study (see section 3.6). Potential subjects were informed of the study by front office staff of Tri-State Physical Therapy during the subject's first appointment and presented the individual with an informational flyer highlighting the purpose and procedures of the study. Recruitment of subjects continued until each group had 15 subjects.

Selection criteria for subjects included: 1) males or females aged between 18-65 years, 2) a referral from a medical doctor for physical therapy services for a musculoskeletal injury/condition to the lower extremity, and 3) no complaints of bilateral symptoms to the lower extremities. Exclusion criteria included: 1) medical history of hemophelia or other clotting disorders of the blood; 2) medical history of cardiovascular disease including those with previous cardiovascular surgery and uncontrolled hypertension; 3) current use of prescription blood thinners (e.g. Lovenox, Coumadin); 4) a history of metastatic disease; 5) neuropathy of the lower extremity; 6) current complaints of lumbar or shoulder symptoms; and 7) an active infection (or taking medication for an infection). All subjects were asked to read and sign an informed consent form approved by the Duquesne University Institutional Review Board and to complete the Lower Extremity Functional Scale to objectify functional limitations caused by their condition. Subjects that scored below a score of 40 or above a score of 70 points out of a possible 80 points on the Lower Extremity Functional Scale were excluded from the study. Once subjects consented to the study and completed study-related paper work they performed strength testing as described under procedures (section 3.4). Subjects with less than a 10% deficit in maximum force output during an isometric squat test when compared to the uninvolved side were excluded from further testing. Testing during a

pilot study determined that less than 10% of subjects with a musculoskeletal pathology of the lower extremity do not have a strength deficit as determined by an isometric squat test. Subjects that did not tolerate the Astym® treatment as described in the procedures were also excluded from the study. Data from a pilot study determined that less than 1% of subjects do not tolerate Astym® treatment.

3.3 Instrumentation

Maximum force output during an isometric squat test was measured using a computerized leg press machine (Figure 5) equipped with a load cell (CDM Sport; Fort Worth, TX). The load cell was tested by the manufacturer and demonstrated less than 0.02% error for repeatability, zero balance, creep, non-linearity and hysteresis.[138] Data from a pilot study demonstrated excellent criterion validity for the computerized leg press machine to a digital force dynamometer with a Pearson correlation coefficient of 0.99. The analysis revealed the Typical Error of the Estimate to be 10.69 Newtons (95% CI: 8.13-15.62 Newtons). A detailed description of the testing performed during a pilot study to establish validity of the measurement is found in Appendix A. Measurement of force production during an isometric squat test has demonstrated test-retest reliably of 0.97.[139] However, there is no published literature documenting the reliability of the specific computerized leg machine used in this study. An investigation during a pilot study to establish the test-retest reliability of the computerized leg press machine is presented in Appendix B. An intra-class correlation coefficient of 0.99 indicated excellent test-retest reliability of the computerized leg press machine used in this study. The standard error of the measurement was determined to be 2.7% change with a minimal detectable change of 7.5% change.

Figure 5. Patient performing a maximal isometric squat test on the Monitored Rehab Systems Computerized Leg Press Machine.

3.4 Procedures

All procedures were identical for each subject. Demographic information was collected including age, height, weight, gender, lower extremity-dominance, and musculoskeletal diagnosis as determined by assimilation of a physician prescription and office notes, current subjective complaints/symptoms, and objective findings from physical therapy examination. Subjects filled out a medical history form that included items specific to the exclusion criteria. The subjects also filled out a self-reported functional questionnaire containing the numeric pain scale (0-10) and the Lower Extremity Functional Scale. The numeric pain scale and Lower Extremity Functional Scale are commonly used in research and clinical settings to assess a patient's severity of pain and the functional impact of their injury to the lower extremity.[140,141] The numeric

pain scale has demonstrated adequate test-retest reliability (r=0.63) [142] and established a minimal detectable change of 3 points.[143] The Lower Extremity Functional Scale has demonstrated test-retest reliability of r=0.94, construct validity to the Short Form-36 physical function score (r=0.80), and a minimal detectable change of 9 points.[140] Once the subject completed the forms, they were asked to 'warm-up' by cycling at a self-selected pace on a lower body ergometer (Sports Art c530 Lower Body Ergometer, Woodinville, WA) for five minutes.

Next, maximum isometric force during a squat test was measured for each lower extremity using a computerized leg press machine (CDM Sport; Fort Worth, TX). The lower extremity that was tested first was randomly selected for each subject by a coin flip. The leg press was adjusted for the designated lower extremity such that the subject's knee joint was placed and maintained at 70° of knee flexion as determined by a standard 8-inch goniometer (AliMed 5055 - Med. International Standard 8-in. Goniometer, Dedham, MA). The test-retest reliability for goniometry of the knee joint has been reported at r=0.80.[144] Foot position was standardized on the footplate of the leg press so that the bisection of the foot, ankle, and hip joints are in alignment in the sagittal plane and the crest of the tibia is parallel to the floor. A testing protocol as described by Carcia et al.[138] was utilized to collect maximum force output during the isometric squat test. The subjects were asked to push through their heel against the footplate of the leg press a total of five times. The first repetition was performed at approximately 50% effort, the second at 75% effort, and the remaining three repetitions at 100% effort. The average of the maximum force output (Newtons) produced during the final three trials was used to represent the subject's maximal force output during an isometric squat test. An

investigation during a pilot study performed prior to the initiation of this research study demonstrated no evidence of a learning or fatigue effect utilizing a 1:10 work/rest ratio over ten consecutive trials on the same lower extremity (Appendix C). Pain was monitored before and after isometric testing using the numeric pain scale. Once the testing had been completed on the designated lower extremity, the opposite lower extremity was tested using the same testing procedures. Subjects that did not demonstrate greater than a 10% deficit of the involved side compared to the uninvolved side were not considered to have a significant strength deficit caused by their injury and were dismissed from the study.

Next the subjects were randomly assigned to the control, placebo, or treatment group. Random assignment to the groups was determined using a random numbers generator (http://www.graphpad.com/quickcalcs/index.cfm) to create three equal groups of 15 subjects. The treatment group received Astym® treatment to the muscles of the anterior and lateral compartments of the leg, the gastrocnemius/soleus muscle complex, the quadriceps muscle group, the hamstrings muscle group, the gluteus maximus, and the gluteus medius muscles on the involved side as described by the Astym® Clinical Manual.[12] This technique includes two sets of strokes that were performed with the Astym® instruments in both proximal to distal and distal to proximal directions. A set of strokes covered the entire width and length of the muscle groups mentioned above from origin to insertion. The Astym® treatment was performed as the edge of the instruments indirectly contacted the fascial and musculotendinous tissues deep to the skin and subcutaneous tissue. The indirect contact of the instruments with the underlying fascial and musculotendinous tissues present with a discernable texture that is different from the

texture appreciated from contacting only the skin and superficial fascia.[12] The difference in the texture that can be appreciated by the therapist determines the appropriate amount of pressure applied through the instruments to mechanically stimulate the targeted underlying soft-tissue structures.[12] Individuals that are lean require less pressure through the instruments to indirectly contact the ligamentous, deep fascial, muscular, and tendinous tissues that are deep to the superficial fascia.[12] Because each individual possess a different amount of adipose tissue within the superficial fascia, the exact amount of pressure applied through the instruments varies according to each individual's body composition. However, indirect contact of the instruments with the muscle, tendon, deep fascia, and ligamentous tissues as determined by the unique texture that these structures provide remains consistent regardless of body composition of an individual. Therefore, each Astym® treatment provides a consistent stimulation of the muscle, tendon, deep fascia, and ligamentous structures despite variability in body composition between individuals. The speed of the strokes over the musculotendinous structures was consistent at 6 inches/per second. [12] The investigator performing the Astym® treatment (brk) has been certified in the technique and has over 3 years experience administering the technique for lower extremity musculoskeletal dysfunction. Although the treatment is not intended to be painful, the investigator monitored the subject's comfort level during treatment with a post-treatment numeric pain scale rating. Pain that exceeded a 7/10 on the numeric pain scale or any verbal or non-verbal indication by the subject that suggested they were not comfortable with the treatment resulted in an immediate termination of the treatment and the subject was withdrawn from the study.

The control group did not receive any treatment and was asked to sit on a treatment table for 12 minutes. Twelve minutes represented the average time it took to perform an Astym® treatment to the lower extremity as determined during a pilot study. The placebo group received a sham Astym® treatment. The sham treatment was analogous to an effleurage massage with the Astym® instruments. The sham treatment differed from the actual Astym® treatment only in the pressure administered by the investigator and the treatment-edge of the instrument used to administer the treatment (Figure 6). The primary investigator (brk) glided the non-treatment edge of the Astym® instruments over the skin of each of the treatment areas previously described for the Astym® treatment group. Pressure through the instruments was light enough to avoid the texture felt through indirect contact of the fascial and musculotendinous structures deep to the subcutaneous layer with the Astym® instruments. The direction, number of strokes, and speed of the strokes remained consistent with that previously described for the Astym® treatment group and continued for approximately 12 minutes.

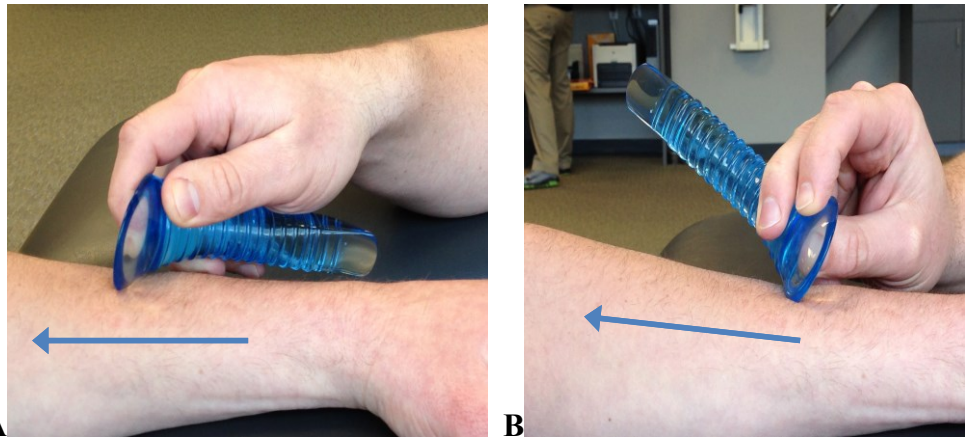


Figure 6. Treatment edge used for the A) Astym® treatment versus the B) Sham treatment.

Once the designated treatment intervention was completed, the subject was retested on the computerized leg press machine using the identical testing procedures as described above. A second investigator (lb) blinded to the type of treatment the subject received administered the isometric squat tests. The investigator performing the Astym® treatment did not have access to test results until testing was completed for each subject. Once the post-test was complete the subject satisfied the obligations of the research study and resumed the normal course of his/her care as determined by the physical therapist.

3.5 Statistical Analysis

All data was entered into SPSS Version 20 (SPSS Inc.; Chicago, IL) for statistical analysis. Descriptive statistics (means /standard deviations/range) of age, height, weight, self-reported functional score, pre-treatment pain rating, and post-treatment pain rating of the subjects was reported and compared between groups with an analysis of variance. The frequency of gender and the medical diagnoses by type (musculotendinous versus non-contractile) and region (proximal portion of the lower limb versus distal portion of the lower limb) for each respective treatment group was compared using a chi-square analysis. The percent change of maximum force output from pre-test to post-test was calculated by the following formula:

$$\frac{\text{Post-Test} - \text{Pre-Test}}{\text{Pre-test}} \times 100 = \text{Percent Change}$$

The mean of the percent change for each group (Control, Placebo, Astym® treatment) was compared using a one-way analysis of variance with a predetermined alpha set at 0.05. A Tukey's post-hoc analysis was then used to determine which groups were statistically different from each other.

3.6 Power Analysis

Data from a pilot study were collected to determine an appropriate sample size for this research project. Using the data collection procedures described above, the percent change of maximum force output was collected for 12 volunteers that received the control treatment, 12 volunteers that received the placebo treatment, and 12 volunteers that received the Astym® treatment. The mean and standard deviation of the percent change of maximum force output from each group is presented in Table 2. The data were used to determine the mean difference and the effect size of the control and placebo groups to the treatment group. The mean differences and effect sizes are presented in Table 3. A commercially available power analysis software program (JMP Pro 10; Cary, North Carolina) was used to calculate the sample size needed to obtain 80% power with alpha set at 0.05 based on the smallest effect size (Astym®-Control) determined from the pilot study data. The results of the power analysis concluded that a sample size of 15 subjects per group was needed to detect a minimal difference of 14% between the groups. The results of the pilot study testing also demonstrated that 20% of prospective subjects did not meet the exclusion criteria and less than 1% of subjects did not to tolerate the Astym® treatment. Based on this estimate, we anticipated that a total of 54 subjects would be needed to meet the required minimum of 15 subjects per group.

Table 2. Pilot Study Data: Mean and standard deviation of the percent change of maximum force output according to treatment group.

Group	Number of Subjects	Mean % Change	Standard Deviation
Astym®	12	19	17
Placebo	12	1	10
Control	12	5	9

Table 3. Pilot Study Data: Mean differences and effect size of group comparisons.

Group	Mean Difference	Effect Size
Astym® - Placebo	18%	0.54
Astym® - Control	14%	0.46

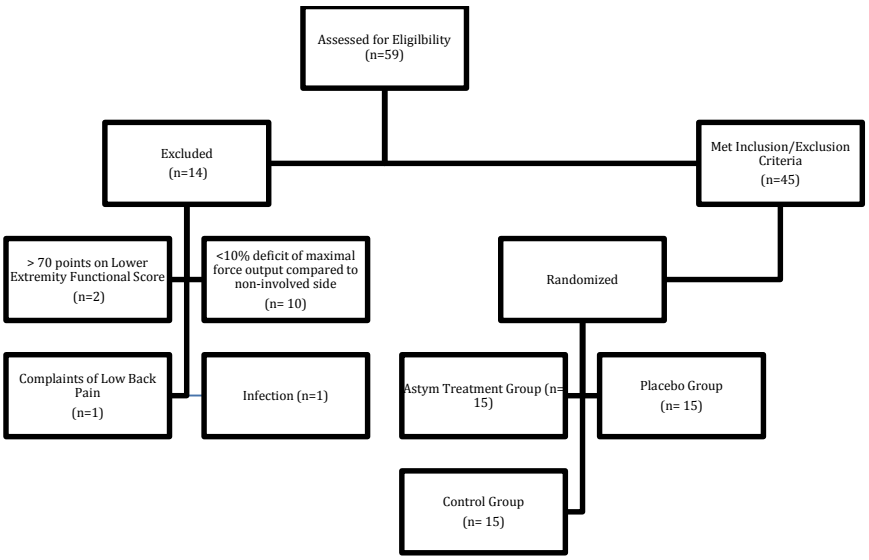
Chapter 4

Results

4.1 Subjects

A total of 59 subjects enrolled in the study. There were 14 subjects that did not meet the exclusion criteria. A flow diagram of the subjects enrolled in the study is represented in Figure 7. Ten subjects were excluded from the study because they did not exhibit a 10% strength deficit of the involved side compared to the uninvolved side, 2 subjects scored greater than 70 points on the Lower Extremity Functional Score, 1 subject had a medical history of low back pain within the past 6 months, and 1 subject was taking medication for an infection that excluded them from participating in the study.

Figure 7. Flow diagram of the subjects enrolled in the study.



Data were collected on a total of 45 subjects. The average age, height, weight, self-reported functional score, pre-treatment pain rating, post-treatment pain rating, and involved side to uninvolved side strength deficit is reported according to each respective treatment group in Table 4. The analyses of variance demonstrated no statistical difference between the treatment groups for age ($p=0.19$), height ($p=0.60$), weight($p=0.72$), self-reported functional score($p=0.99$), pre-treatment pain rating($p=0.85$), post-treatment pain rating($p=0.08$), and involved side versus uninvolved side strength deficit ($p=0.56$). Gender, lower extremity dominance, and involved side ratios of the subjects are also organized according to treatment group in Table 4. A chi-square analysis demonstrated no significant difference in the female to male ratio($p=0.48$), lower extremity dominance ratio($p=0.76$), or involved side ratio($p=0.77$) for the subjects between the three treatment groups. Diagnoses were also not statistically different between treatment groups according to the region (distal or proximal; $p=0.71$) and type(musculotendinous or non-contractile; $p=0.69$) (Table 5). The frequency of gender, lower extremity dominance, and diagnosis of the subjects according to treatment group is reported in Appendix D.

Table 4. Mean and standard deviation of age, height, weight, self-reported functional score, pre-treatment pain rating, post-treatment pain, and involved side to uninvolved side strength deficit according to treatment group.

	Astym® (mean±SD)	**Placebo** (mean±SD)	**Control** (mean±SD)	**TOTAL** (mean±SD)
Age (years)	42±12	43±13	35±12	40±13
Height (cm)	166±13	168±12	170±9	168±11
Weight (kg)	68±11	70±14	75±20	71±15
Functional score (0-80 points)	60±10	60±9	60±8	60±9
Pre-treatment Pain Rating (0-10)	2±2	2±2	3±2	2±2
Post-treatment Pain Rating (0-10)	2±2	3±2	3±2	3±2
Gender (Females:Males)	4:1	3:2	2:1	31:14
Lower Extremity Dominance (Right:Left)	14:1	13:2	14:1	41:4
Involved Side (Right:Left)	3:2	7:8	8:7	24:21

SD = standard deviation.

Table 5. Frequency of Diagnoses by Region and Type According to Treatment Group.

	Astym®	**Placebo**	**Control**	**TOTAL**
Diagnosis by Region				
Hip	2	0	2	4
Thigh	2	6	3	11
Knee	6	6	6	24
PROXIMAL TOTAL	**10**	**12**	**11**	**33**
Leg	0	1	0	1
Ankle	3	0	2	5
Foot	2	2	2	6
DISTAL TOTAL	**5**	**3**	**4**	**12**
Diagnosis by Type				
Musculotendinous	5	5	7	17
Non-Contractile	10	10	8	28

4.2 Statistical Results

A one-way analysis of variance was conducted to explore the effect of Astym® treatment on maximal force output by comparing a percent change in the maximal force output among subjects that received an Astym® treatment, control treatment, or a placebo treatment. There was a significant effect of the percent change of maximal force output at the $p<0.05$ level for the Astym®, placebo, and control treatment groups [$F(2,42) = 7.91$, $p = 0.001$]. The partial eta-squared calculated to determine effect size was $\eta^2 = 0.27$. Tukey's post hoc analysis showed that the percent change of maximal force output was significantly greater in the Astym® group that improved from 994 Newtons to 1150 Newtons (15$\pm$18%change) compared to the placebo group that decreased from 965 Newtons to 918 Newtons (-6$\pm$11%change) and the control group that decreased from 1043 Newtons to 972 Newtons (-1$\pm$17%change). No significant difference was noted between the control and placebo groups ($p=0.68$). Table 6 summarizes the analysis of variance. Table 7 presents the mean and standard deviation of the percent change of maximum force output according to treatment group and Table 8 compares the mean differences and the level of significance (p-value) between each of the group comparisons. The raw data describing age, height, weight, Lower Extremity Functional Score, involved versus uninvolved strength deficit, pre and post-treatment pain levels, pre-treatment force output, post-treatment force output, and percent change in force output is reported in Appendix E.

Table 6. Summary table for analysis of variance for percent change in maximal force output (Newtons).

Source	*df*	*Sum of Squares*	*Mean Square*	*F*	*p*	η^2
Between Groups	2	3902.53	1951.27	7.91	0.001	0.27
Within Groups	42	10366.28	246.82			
TOTAL	44	14268.80				

Table 7. Mean, standard deviation, and range of the pre-treatment force output, post-treatment force output, and percent change of maximum force output according to treatment group.

Group	**Pre-treatment Force Output (Newtons)**			**Post-Treatment Force Output (Newtons)**			**Percent Change in Force Output (%)**		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
Astym	994	527	354-2465	1150	630	475-2909	15	18	-30 - 35
Placebo	965	533	371-1936N	918	515	350-1861N	-6	11	-38 - 10
Control	1043	646	212-2672	972	503	234-2128	-1	17	-31 - 29

SD=Standard Deviation

Table 8. Mean differences of group comparisons.

Group	Mean Difference	Significance (p-value)
Astym® - Placebo	21%	0.001
Astym® - Control	16%	0.014
Control - Placebo	5%	0.675

Chapter 5

Discussion

5.1 Introduction

The purpose of this study was to determine if Astym® treatment administered to the lower extremity would result in an acute change of maximal force output during a unilateral isometric squat test among subjects presenting with weakness associated with a musculoskeletal injury to the lower extremity. The group of subjects that received Astym® treatment was hypothesized to produce a significantly greater percent change in pre-treatment to post-treatment maximal force output than the subjects that received no treatment (control) and the subjects that received a sham Astym® treatment (placebo). The control and placebo treatment groups were hypothesized not to be statistically different in the percent change of maximal force output produced during a unilateral isometric squat test. The results of the current study supported both hypotheses. Subjects that received Astym® treatment increased maximal force output of the lower extremity immediately following treatment by an average of 15% from pre-treatment values. The percent change in maximal force output (Newtons) was significantly greater for the subjects that received Astym® treatment compared to the placebo ($p=0.001$) and control ($p=0.01$) treatment groups. The placebo treatment and a control treatment were found not to be statistically different ($p=0.68$) and averaged a negative change of maximal force output by 6% and 1%, respectively.

This discussion will provide additional analysis on the results of the current study. Specifically, the discussion will explore the potential mechanisms that may explain the observed increase of maximal force output following Astym® treatment and compare the effect of Astym® treatment on muscular strength to other interventions including joint mobilization, vibration, massage, and other forms of instrumented soft-tissue mobilization that may share similar mechanisms to affect muscle performance. The clinical significance of the results of the study will be discussed as well as consideration for the limitations of the study that may affect the interpretation of the results of the current study. The discussion will conclude with suggestions for possible future investigations stemming from the results of the current study.

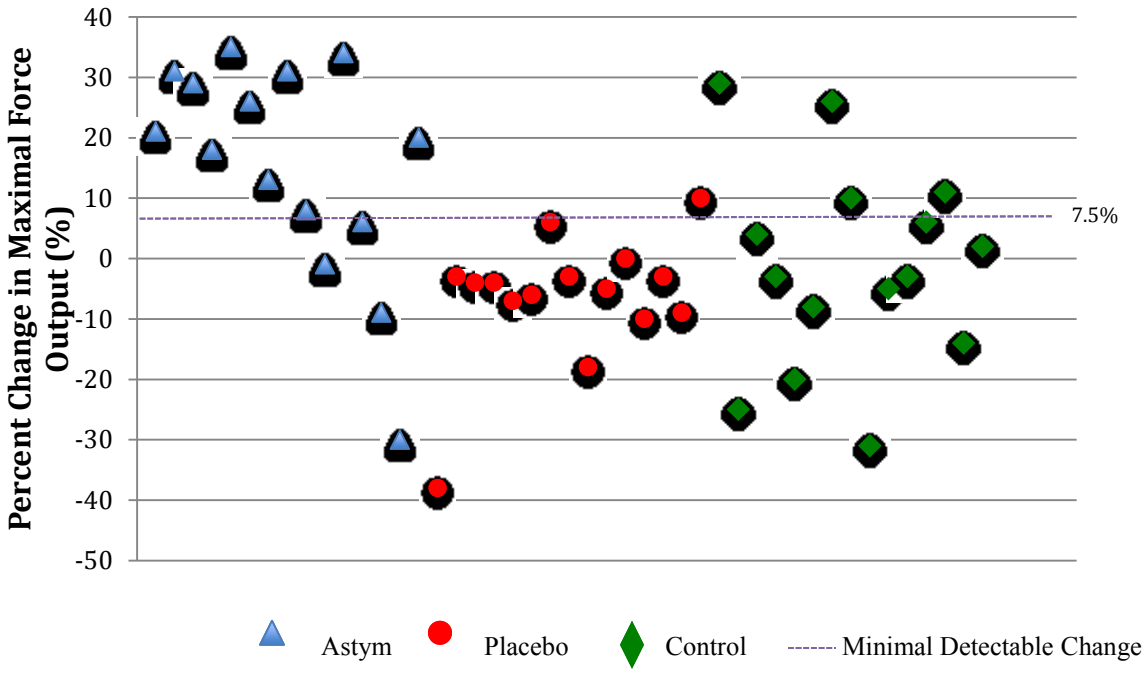
5.2 Percent Change in Maximal Force Output

The main finding from the current study was that subjects that received Astym® treatment improved maximal force output (Newtons) of the lower extremity by an average of 15% immediately following treatment. This was significantly greater ($p<0.01$) than the average 1% and 6% decrease in maximal force output (Newtons) demonstrated in the control and placebo treatment groups, respectively. The effect size calculated for the analysis of variance that compared the treatment groups was $\eta^2 = 0.27$. The effect size describes the magnitude of the differences between the groups.[145] According to Cohen,[145] a partial eta-squared calculated for an analysis of variance that is greater than 0.14 is considered to be a "large" effect size. A partial eta-squared also describes the proportion of variance in the dependent variable explained by the independent variable. The calculated eta-squared ($\eta^2 = 0.27$) suggests that the type of treatment received by the

subjects in the current study explains 27% of the variance in the percent change in maximal force output. Although this is considered a large effect size,[145] greater than 70% of the variance in the maximal force output is explained by factors other than the type of treatment received by the subjects.

An analysis of the individual performances of the subjects may help to identify other potential factors that may explain the variance in the percent change of maximal force output. Figure 8 is a plot graph showing the percent change in maximal force output of each of the subjects according to the respective treatment groups. Eleven out of the 15 subjects that received Astym® treatment had an improvement of maximal force production greater than the minimal detectable change of 7.5% established for the isometric squat test during pilot testing (Appendix B).The minimal detectable change represents an estimate of the smallest amount of change that is not due to measurement error and may be used to determine if the individual performances were likely due to measurement error or a true change in maximal force output.[146] Conversely, only 4 subjects that received the control treatment and 1 subject that received the placebo treatment exhibited a positive percent change in maximal force output greater than the minimal detectable change.

Figure 8. Plot Graph of Percent Change of Maximal Force Output by Treatment Group



The plot graph of individual performances shows a wide dispersion of values within the Astym® treatment group. This explains the rather large standard deviation of the percent change in maximal force output that was computed for subjects in the Astym® treatment group. The type and location of diagnosis may help to explain variance in the percent change of maximal force output found in the group of subjects that received Astym® treatment.

5.2.1 The Influence of the Location of the Diagnosis

Of the four subjects in the Astym® treatment group that did not improve beyond the minimal detectable change, two subjects had diagnoses involving the foot and ankle

region. A closer look at the results of the Astym® treatment group revealed that subjects that were diagnosed with a condition affecting the proximal aspect of the lower extremity (hip, thigh, and knee regions) tended to have a greater percent change in maximal force output compared to the subjects with diagnoses affecting the distal portion of the lower extremity (leg, ankle, and foot). Table 9 presents the average percent change in maximal force output according to the location of the subject's musculoskeletal diagnosis. This observation could be related to the specific demands of the isometric squat test. Muscles of the hip, thigh, and knee regions have shown greater muscle activation during a squat compared to muscles of the leg, ankle and foot regions.[147] Thus the isometric squat test may be more likely to have a positive change in maximal force production for individuals with a diagnosis affecting the proximal portion of the lower extremity. The current study was not powered to perform a statistical comparison that would reveal whether the percent change of maximal force output was indeed influenced by the location of the individual's diagnosis, but may provide the groundwork for a future study that investigates the influence on the location of diagnosis on changes in muscle performance following Astym® treatment.

5.2.2 The Influence of the Type of Diagnosis

The type of diagnoses may have also contributed to the variance in the percent change of maximal force output within the Astym® treatment group. The subjects that participated in the study all had diagnoses affecting the musculoskeletal system. These diagnoses were further categorized by involvement of contractile (musculotendinous) and non-contractile structures. Table 9 shows the mean percent change of maximal force

output according to diagnoses involving musculotendinous versus non-contractile structures. The subjects in the Astym® treatment group that were diagnosed with a musculotendinous condition had an average percent change in maximal force output of 21% versus 13% for those with a diagnosis involving non-contractile structures. Again, an accurate statistical comparison cannot be made with the small sample size from the current study. The findings do, however, illustrate the need to perform a future investigation to determine the effects of diagnosis type on muscle performance following Astym® treatments.

Table 9. Percent Change in Maximum Force Output following Astym® Treatment by Diagnosis Region and Type.

Diagnosis Categories					
Region				**Type**	
Hip-Thigh-Knee Regions		Leg-Ankle-Foot Regions		Musculotendinous	Non-Contractile
Hip	15%(n=2)	Leg	NA(n=0)		
Thigh	28%(n=2)	Ankle	17%(n=3)		
Knee	20%(n=6)	Foot	-11%(n=2)		
TOTAL	**20%(n=10)**	**TOTAL**	**5%(n=5)**	**21%(n=5)**	**13% (n=10)**

5.3 Proposed Mechanisms Contributing to Increased Muscular Performance Following Astym® Treatment

The mechanisms through which Astym® treatment enhances muscular performance are unknown, but previous reports in the literature regarding other methods of soft-tissue mobilization would suggest that Astym treatment may influence muscle performance through modulation of pain, an increase of blood flow, neuromuscular

facilitation, or mechanical sensitivity of calcium channels within the muscle tissue.[35,70,87,148] This section will explore possible physiological explanations as to why subjects that received Astym® treatment demonstrated an acute improvement of muscular strength.

5.3.1 Modulation of Pain

Pain can be a powerful inhibitor of muscle strength. [66-68] In individuals experiencing weakness accompanied by pain, a reduction of pain will often lead to a subsequent improvement of muscle performance.[69] Therefore Astym® treatment may be capable of influencing muscular strength by modulating the perceived pain of the subject. Soft-tissue mobilization techniques such as Astym® treatment are theorized to mediate pain through the gate-control and/or descending pain suppression mechanisms. [70] Under the principle of the gait-control theory of pain, Astym® treatment provides a mechanical stimulation of the larger peripheral nerve fibers found in the soft-tissue that block the painful stimuli transmitted by smaller nerve endings called nocioceptors.[70] Astym® treatment may also trigger descending pain suppression mechanisms that cause the release of endogenous opiates at the spinal level receiving the painful input.[70] These endogenous opiates, known as endorphins, work to blunt the transmission of painful stimuli to the brain. Soft-tissue mobilization techniques have been previously shown to cause an increase of serum endorphins for up to one hour following treatment.[76] It is possible that Astym® treatment could cause a release of endorphins to reduce pain that would result in improved muscle performance.[56]

In the current study, pain was assessed using the numeric pain score during pre-

treatment and post-treatment isometric squat tests. The Astym® treatment group did not show an improvement of pre-treatment (2/10) to post-treatment (2/10) pain scores. The placebo group averaged a 2/10 pre-treatment pain score and a 3/10 post-treatment pain score while the control group averaged a pre-treatment pain score of 3/10 and a post-treatment pain score of 3/10. Thus, the average pain scores show that the improvement of maximal force output in the Astym® treatment group was not accompanied by a reduction of pain reported during the unilateral isometric squat tests. Further, a majority of the subjects in the Astym® treatment group (7/11) that demonstrated an improvement in maximal force output did not show an improvement in their post-treatment pain scores. The improvements of muscular strength for these subjects cannot be explained simply by a reduction of pain reported during the unilateral isometric squat tests. The average pain scores of the subjects in the Astym® treatment group do not suggest that pain modulation played a significant role in an improvement of maximal force output.

5.3.2 Increase of Blood Flow

Another possible explanation for the observed effect of Astym® treatment on acute muscle strength may be explained by an increase of blood flow to the treated musculature. The subjects that received the Astym® treatment were noted to have a hyperemic response to the treated areas. This was evident by a red/flushed appearance of the color of the skin and an increase of the tissue temperature to the touch. The subjects that received the placebo and control treatments did not exhibit a hyperemic response. Perhaps these observations suggest that an increase of blood flow to the soft-tissues occurred in response to the Astym® treatment. Researchers have shown that soft-tissue mobilization techniques can cause an increase of local blood flow blood to the treated

tissues.[148] Bell [149] demonstrated that the amount of local blood flow nearly doubled from baseline measures up to 40 minutes following soft-tissue mobilization. More recently, Franklin et al.[150] showed similar increases of blood flow in response to a massage protocol that lasted approximately 90 minutes following treatment. Similarly, Dubrosky[93] reported increases of muscular blood flow that lasted for greater than 3 hours after soft-tissue mobilization. An increase of local blood flow to muscular tissue causes an increase of intra-muscular temperature that may be capable of enhancing force output during a maximal contraction.[35,39, 100, 98] Although soft-tissue mobilization techniques have been shown to improve blood flow and muscle tissue temperature, the collective research on the immediate effect of soft-tissue mobilization on muscle strength has been equivocal.[78,79,81,123,124] This decreases the likelihood that an increase of blood flow to the treated muscle tissue was the primary cause of the improved maximal force output that was observed following Astym® treatment. However, the effect of Astym® treatment on local blood flow could be an interesting topic of further research.

5.3.3 Neuromuscular Facilitation

The observed increase in muscular strength following Astym® treatment could also be explained by neuromuscular facilitation. Neuromuscular facilitation refers to an increase of muscle activation through stimulation of the sensorimotor system.[27,28] Astym® treatment may provide a mechanical stimulus that is processed in the motor centers of the central nervous system similar to what researchers have previously described for other forms of soft-tissue mobilization.[35] In response to the heightened sensory input, central motor centers send signals to surrounding muscle tissue that result in greater muscle activation.[130] The effect of soft tissue mobilization techniques, such as Astym®

treatment, on muscular performance may depend on several different factors including the speed and pressure through which the soft-tissue mobilization technique is administered.[40,42-45] Based on reports in the literature that describe how rapid vigorous stroking facilitates muscle contraction,[30,40,41] the strokes applied with the Astym® instruments could likewise have a facilitating influence on muscle contraction. However, the influence of sensorimotor stimulation on muscular performance is complex [40,42-45] and would require additional study to determine the exact mechanisms through which Astym® treatment affects the sensorimotor system to improve muscle performance.

5.3.4 Mechanical Sensitivity of Calcium Channels in Muscle Tissue

The mechanical stimulation produced during an Astym® treatment may also work directly on the muscle tissue. Muscle tissue contains mechanically sensitive calcium channels. [87] These calcium channels regulate the amount of calcium entering the muscle tissue and are sensitive to mechanical stimulation. The amount of calcium available to a working muscle can determine the amount of force it is capable of producing.[88-90] This phenomenon is known as the Force-Calcium relationship.[88-90] Because the amount of calcium available to working muscles can be manipulated by mechanically sensitive calcium channels, [87] improvements in muscular strength following Astym® treatment may be the result of an increase of calcium to the working muscle tissue.

5.4 Comparison to Other Therapeutic Interventions

At this point in time there are no reports in the literature that address the mechanisms through which Astym® treatment affects muscle performance. However,

research has been performed on therapeutic interventions such as joint mobilization, vibration, massage, and other forms of instrument assisted soft-tissue mobilization techniques that may share similar proposed mechanisms to influence muscle performance. This section will compare and contrast the findings of the current study to previously published literature that has investigated the effects of joint mobilization, vibration, massage, and other forms of instrument assisted soft-tissue mobilization techniques on acute muscular strength.

5.4.1 Joint Mobilization

The subjects from the current study that were randomized into the Astym® treatment group demonstrated an average increase in maximal force output of 15%. This increase of muscular strength is comparable to the increases in muscular strength that have been reported immediately following joint mobilization of the lower extremity. Yerys et al.[151] studied the effects of hip joint mobilization on muscular strength of the gluteus maximus muscle. Subjects that received grade IV mobilization of the hip joint in a posterior-to-anterior direction experienced a 14% increase of maximal force output. Makofsky et al.[152] reported that in subjects that received grade IV hip joint mobilization in an inferior direction had an immediate increase of hip abduction force output of 17.35%. Ghanbari et al.[153] demonstrated an acute increase of maximal voluntary isometric contraction of the knee extensors by 18.7% following grade IV posterior-to-anterior mobilization of the knee joint. The improvement of strength increased to 23.6% at 30 minutes after the treatment.[153]

Researchers have proposed that the changes observed in muscle performance following joint mobilization occur in response to stimulation of mechanoreceptors found

within the joint capsule and surrounding soft tissue structures.[151] We may speculate that Astym® treatment could also influence muscle performance through stimulation of mechanoreceptors found in soft-tissue structures that are directly or indirectly contacted by the Astym® instruments. Both joint mobilization[151-153] and Astym® treatment have shown to have a positive influence on maximal force output and may work through similar physiologic mechanisms to facilitate muscle performance. Additional study is needed to determine how manual therapy interventions including joint mobilization and Astym® treatment affect the sensorimotor system to influence muscle performance.

5.4.2 Vibration

Vibration is another therapeutic intervention believed to stimulate mechanoreceptors in an effort to improve muscle performance.[47-53] The acute effects of vibration on muscle performance of the lower extremity have been well documented. Rhea et al.[154] studied the acute effects of whole-body vibration on peak power output during a squat test. Subjects that received a 2 minute whole-body vibration treatment prior to squat testing significantly ($p<0.05$) increased their peak power by 5.20% compared to a control group that rested for 3 minutes.[154] Jacobs et al.[155] demonstrated average isokinetic torque generated by the knee extensors improved by 9.6% following a 6-minute treatment of whole-body vibration immediately prior to isokinetic testing. A similar improvement of 7.8% was noted for the average isokinetic torque of the knee flexor muslces.[145] McBride et al.[156] demonstrated that the inclusion of whole-body vibration immediately prior to isometric testing of the gastrocnemius muscle resulted in a 9.4% increase in maximal isometric force compared to a control group ($p<0.05$).[156]

Researchers have suggested that vibration stimulates mechanoreceptors found in the muscle, tendon, deep fascia, and joint capsule structures,[46,157] in a manner similar to that described for joint mobilization. The mechanoreceptors respond to the vibration stimulus and send signals to the central nervous system that may reflexively increase the firing of alpha motor neurons that are traveling back to the working muscle.[46,157] This may explain the observed increases of muscle activation and performance [46,53,157]

Some researchers, however, have suggested that the improvements in muscle performance in response to vibration are not caused by neuromuscular facilitation, but are more likely explained by an increase of intra-cellular concentrations of calcium within the muscle tissue.[158,159] Cochrane et al.[160] proposed that whole body vibration causes post-activation potentiation, a phenomenon in which the contractile elements of muscle tissue increase their sensitivity to intracellular calcium, thus enhancing the force production of the contracting muscle. Cochrane et al.[160] attempted to determine whether the increases of muscular strength following whole body vibration were the result of neural mediated effects or post-activation potentiation. The peak force generated by a muscle-tendon reflex was used to assess the neural-mediated effects. The peak force generated from a consistent electrical stimulus to the muscle assessed the effects of post-activation potentiation. The results showed that peak force from the electrical stimulus increased the force production by 12.4%, while force generated from the reflex-induced contraction changed only 0.1% and was not statistically significant. Based on these results, the authors concluded that the changes noted following whole body vibration were likely related to post-activation potentiation that increased the availability of calcium to the contractile elements of muscle tissue.[160] As previously described,

calcium channels that potentiate muscle contraction have shown to be sensitive to mechanical stimulation.[87] The work of Cochrane et al.[160] supports the theory that the improvements in muscular strength following Astym® treatment could be caused by an influx of calcium through mechanically sensitive calcium channels within muscle tissue.

5.4.3 Massage

The results of the current research project conflict with previous research documenting the effects of massage on muscle performance. Arroyo-Morales et al.[77] used a cross-over design to compare the peak isokinetic torque produced by the quadriceps and hamstring muscles following massage versus a sham ultrasound treatment. The peak isokinetic torque of the quadriceps and hamstring following a massage protocol of effleurage, petrissage, and tapotement to the gastrocnemius, quadriceps, and hamstrings muscles were not greater than the peak torque recorded following a sham ultrasound treatment.[77] In fact, isokinetic torque of the knee extensors was 9-11% less at speeds of 240°/second and 180°/second peak following massage compared to a sham ultrasound treatment.[77] Wiktorsson-Moller et al.[82] reported similar findings. Isokinetic testing at speeds of 30°/second and 180°/second for the quadriceps and hamstring muscle groups resulted in statistically significant decreases (equivalent to 3-10% deficits) in peak isokinetic torque following massage treatment. Wiktorsson-Moller et al.[82] also tested the quadriceps and hamstring muscle groups isometrically and found similar decreases in muscular strength. McKechnie et al.[80] studied the effects of massage on isokinetic testing of the plantarflexor muscle group following massage treatment. The results showed that the peak torque of the plantarflexor muscle group did

not significantly change and was equivocal to that of a placebo treatment that received 3 minutes of static light touch to the skin overlying the gastrocnemius muscle.[80]

The difference between the effects of Astym® treatment and massage on muscle strength may best be explained by the differences between the techniques. Astym® treatment is performed with the intent to stimulate muscle tissue.[12] This requires sufficient pressure to allow the instrument to contact the underlying muscle tissue indirectly through the skin and superficial layer of fascia.[12] Strokes applied with the Astym® instruments are performed rapidly and with enough pressure to appreciate the distinct texture that occurs as the instruments indirectly contact muscle tissue.[12] The massage techniques used in the research studies that investigated the acute effects of massage on muscle strength used combinations of effleurage and petrissage techniques that were described as slow and rhythmic.[77,80,82] Effleurage is a light or gentle massage applied over the skin.[119,121] With effleurage there is no intent to indirectly contact the deep soft-tissue structures, including the muscle tissue.[119,121] This is similar to the intent described for the placebo treatment of the current research project. Instead of the caregiver's hands, the placebo treatment was applied with the rounded, non-treatment edge of the Astym® instrument. The Astym® instruments were glided lightly over the skin without indirectly contacting the deeper soft-tissue structures including muscle tissue. The subjects in the placebo treatment group did not demonstrate a significant difference from the control group($p=.30$), and averaged a 6% decrease of maximal force output. The 6% decrease of muscular strength is consistent with subjects that received massage treatment in the previously described studies.[77,80,82]

However, the massage techniques described in the studies above also included petrissage techniques.[77,80,82] Petrissage is a more aggressive type of massage that may indirectly contact muscular tissue with kneading, wringing, or scooping type strokes that are believed to facilitate muscle function.[119,121] Because effleurage and petrissage were often combined in the massage protocols used to investigate the effects of massage on muscular strength,[77,80,82] it is unknown if the effects of petrissage facilitated or inhibited muscular strength. McKechnie et al [80] suggested that petrissage techniques are a means to stretch muscle fibers. Stretching of muscle fibers is well documented to cause an acute decline in muscular performance,[132-136,147] and may explain why massage can negatively influence muscle performance. Because the instruments are moved rapidly across the length of the muscles, there is likely no sustained lengthening of the muscle fibers during an Astym® treatment. As a result, a decline in muscular strength similar to that found following stretching or massage may not be expected after an Astym® treatment.

5.4.4 Instrument Assisted Soft-Tissue Mobilization

The results of the current study are also different from what has been previously reported for forms of instrument assisted soft-tissue mobilization techniques. Mikesky et al.[103] studied the effect of the use of a device known as "the Stick" on isokinetic peak torque of the knee extensors. Subjects were tested immediately following each of the three treatment conditions: 1) a 2 minute self-massage of the quadriceps using the "Stick" instrument, 2) a control intervention that received no treatment, and 3) a placebo treatment that was described as a sham electrical stimulation treatment. The peak torque generated by the quadriceps muscles following the "Stick" protocol (689.8 N) was not

statistically different than the peak torque following the control intervention (687.5 N) or following the placebo treatment (681.7 N).[103] Sullivan et al.[117] studied the use of a foam roller-massager device that was administered to the hamstring muscles for 5-10 seconds at a constant rate and pressure. The maximal force produced by the hamstring muscles decreased up to 6% following the massage-roller treatment.[117] Healey et al.[118] used a cross-over study design to investigate the effects of self-administered soft-tissue mobilization using a foam roller compared to a control treatment that consisted of isometric trunk exercises on measures of athletic performance. The subjects completed two separate days of testing that included maximal force output during a squat immediately following the designated treatment. The maximal force output produced following the foam roller treatment to muscles of the trunk and lower extremity was not different from the control treatment of isometric trunk exercises. The authors concluded that the foam roller intervention to the trunk and lower extremity had no effect on maximal force output immediately following the self-administered foam roller treatment.[118]

The findings reported by Mikesky et al.[103], Sullivan et al.[117], and Healey et al.[118] are in contrast to the results of the current study that demonstrated a 15% increase in maximal force output following Astym® treatment. The differences in how Astym® treatment is administered versus the other forms of instrument assisted soft-tissue mobilization may help to explain the differences in the results. One of the major differences was the length of time in which the treatment was administered. Mikesky et al.[103] described a 2 minute treatment time and Sullivan et al.[117] described the treatment intervention as a 5-10 second treatment over the muscle tissue. These two studies also

isolated the treatment to include only the muscle group that was being tested for muscular strength. Healey et al.[118] described the treatment administered with the foam roller to be 30 seconds for each muscle group treated. The protocol included treatment to the quadriceps muscle group, latissimus dorsi, hamstring muscle group, gastrocnemius, and rhomboid muscles. Based on the description of the methods, one may conclude that the total treatment time was approximately 2.5 minutes to complete a unilateral treatment. Comparatively, the Astym® treatment protocol used in this study averaged 12 minutes to complete the subject's anterior and posterior aspects of the involved extremity. The difference in the total time of treatment and the number of structures treated during the session may help to explain the discrepant findings.

5.4.5 Summary of the Comparison of Astym® Treatment to other Therapeutic Techniques

In the preceding discussion evidence was presented that supports the possibility that Astym® treatment enhances muscle performance through neuromuscular facilitation, an increase of calcium concentration within the muscle tissue, an increase of blood flow, or modulation of pain. Therapeutic interventions including joint mobilization[151-153] and vibration[154-156] are believed to facilitate the neuromuscular system and have shown similar increases of maximal force output to the subjects that received Astym® treatment. Vibration has also been shown to open mechanically sensitive calcium channels within the muscle tissue, allowing an influx of calcium to enter the muscle tissue and improve the ability of the muscle to produce force.[88-90] Astym® treatment could have increased calcium concentrations within muscle tissue through stimulation of these mechanically

sensitive calcium channels to enhance muscle performance. The subjects that received Astym® treatment experienced a hyperemic response to the Astym® treatment. An increase of blood flow and tissue temperature associated with a hyperemic response could have contributed to an improvement of muscle performance,[97,98,100] but no study to date has been performed to determine if Astym® treatment results in an increase of blood flow and tissue temperature. Pain modulation was another proposed mechanism believed to influence maximal force output following Astym® treatment. However, a majority (7/12) of the subjects that improved muscular strength following Astym® treatment did not show improvement of self-rated pain scores. Therefore, pain modulation cannot be considered a likely explanation for the results of the current study.

The results of the current study are in contrast to the findings that have been previously reported on the acute effects of soft-tissue mobilization on muscle performance.[77,80,82] There are inherent differences in the way that Astym® treatment is administered that include the speed, the pressure, and the length of treatment when compared to other instrument [103,117,118] and non-instrument assisted soft-tissue mobilization techniques [77,80,82] that have shown to have a negative impact on muscle performance. Instrument assisted techniques that more closely resemble the Astym® treatment protocol for the lower extremity have not been studied to determine the effect on muscular performance. Additional research is needed to determine how instrument-assisted soft-tissue techniques like Astym® treatment can be used to enhance muscle performance.

5.5 Clinical Significance

The results of the current study may have a clinical significance to physical therapists treating patients with deficits in muscular strength due to a musculoskeletal condition. To put a clinical perspective on the magnitude of the change that Astym® treatment may have on muscular strength we can use the following clinical example. A patient with a musculoskeletal injury to the lower extremity may produce 1000 Newtons of force during a maximal isometric squat test compared to 1200 Newtons on their non-involved side. The maximal force produced during the squat test on the involved side equates to squatting a maximum of 225 pounds. Following an Astym® treatment to the lower extremity, we would expect the average maximal force output to increase by 15%. For our clinical example, we would expect the patient to have an immediate improvement of their maximal squat from 225 pounds to nearly 260 pounds or for an improvement of 35 pounds. This change in force output could temporarily enhance their ability to perform their strengthening program, however, it remains unknown how long the effect will last.

Multi-joint, lower extremity muscular strength has been shown to be directly related to the functional abilities of an individual.[21] Muscular strength measured with a unilateral squat test has been associated with ambulatory and stair climbing function.[22] Lower extremity muscular weakness is also a risk factor for falls in an elderly population.[23] In a younger, athletic population, lower extremity strength has been related to sprinting speed as well as measures of agility and jumping ability.[24,25,161] The consensus of current scientific literature would suggest that multi-joint lower extremity

strength has implications to a wide range of functional activities, from basic ambulatory function to advanced athletic performance.

An area of future research would be to assess if the acute change in muscular strength following Astym® treatment in fact enables patients to perform functional tasks with less difficulty. This could include activities of daily living such as transitioning from a seated to a standing position or climbing stairs. Astym® treatment may also be used to help athletes with musculoskeletal injuries quickly improve their abilities to run, change direction, or jump. Maximizing the effectiveness and efficiency of treatment sessions in a physical therapy practice may be of elevated importance in today's health care environment where a physical therapist may be challenged to manage a patient's deficits in a limited number of visits. The results of the current study support the use of Astym® treatment in the management of patients with a documented weakness from a musculoskeletal injury/condition. The improvement in muscular strength produced by an Astym® treatment may be seen best in individuals who have a diagnosis in which the musculotendinous structures of the knee thigh region are injured. Based on the results of the current study, conditions affecting non-contractile tissues or those involving the structures of the foot, ankle, or leg may be less likely to experience an immediate increase in muscle strength measured with a unilateral squat test. Therapists may choose to use Astym® treatment as an efficient means to improve muscular strength, especially among patients with lower extremity weakness caused by a musculotendinous injury to the knee or thigh region.

5.6 Limitations

There are limitations to the current study that deserve consideration when interpreting the results. Limitations that challenge the cause and effect relationship established between the independent variable (Astym® treatment) and the dependent variable (percent change of maximal force output) are referred to as threats to the internal validity of the study. This section will explore the limitations of the study that pose potential threats to internal validity and how the threats were controlled. It will also explore the potential threats to external validity. External validity refers to how the results of the study can be generalized in other populations. The characteristics of the subjects enrolled in the current study will be analyzed to determine the generalizability of the reported effects of Astym® treatment on muscular strength.

5.6.1 Threats to Internal Validity

There are several potential threats to the internal validity of this study: selection bias, testing effects, statistical regression, experimental mortality, instrumentation, and design contamination. Each of these threats can affect the ability to establish a cause and effect relationship between Astym® treatment and maximal force output.

5.6.1.1 Selection Bias

The most substantial threat to internal validity in a multi-group study design that was employed in the current study is selection bias.[162] A selection bias occurs when the characteristics of the subjects in the groups that are being compared are inherently different from each other.[162] Thus the causality of the observed outcome cannot be delineated from the inherent differences between the groups or the effect of the

independent variable on the dependent variable. Random assignment of subjects to the treatment groups was performed to minimize the likelihood of a selection bias. Statistical comparisons of the treatment groups showed that none of the groups were statistically different with regard to age, height, weight, lower extremity functional score, lower-extremity dominance, involved versus uninvolved strength deficit, or diagnosis. Therefore, it was concluded that these subject characteristics likely did not contribute to the main outcome of the study. The distribution of gender was not statistically different. However, the Astym® treatment group had a greater female to male ratio (5:1), in comparison to the control (3:1) and the placebo group (3:2). Although the males in the Astym® treatment group proved to have a greater percent change in maximal force output (20%) compared to the females (13%), the unequal distribution of males to females does not allow an accurate statistical comparison to rule out the possibility of a gender bias that could have influenced the results of the study.

5.6.1.2 Testing Effects

Testing effects are another consideration in a pre-test/post-test type of study design that was used for this research project. Testing effects occur when the pre-test influences the results of the post-test.[162] Cumulative fatigue and learning effects due to the familiarity of the testing procedures using the computerized leg press are two possible testing effects to consider when interpreting the results of the current study. Pilot testing that investigated the learning/fatigue effect during repeated testing on the computerized leg press machine (Appendix C) was done prior to the initiation of the current study. Based on this pilot data a familiarization protocol[138] was adopted to control for learning/fatigue effects for the computerized leg press machine.

The data from the control group as well as the data collected on the non-involved side of the subjects enrolled in the study can be analyzed to assess the influence of testing effects. The subjects that received the control condition had a -1 percent change of maximal force output. Analysis of pre-test to post-test measures of the non-involved side averaged a 4-6% decrease in percent change of maximal force output for each of the designated treatment groups. The results of the pilot study as well as the analysis of data collected for the control group and the non-involved sides of all the subjects demonstrates strong evidence that testing effects did not impact the results of the current study. Thus testing effects were not likely explanations for the improvement noted in maximal force output of the subjects that received Astym® treatment.

5.6.1.3 Instrumentation Effects

Poor consistency and reliability of the instruments used to collect data is another possible threat to internal validity.[162] The computerized leg press machine used for this study was calibrated to within 0.1 Newtons. Pilot data was collected prior to the initiation of the current study to establish test-retest reliability and criterion validity of the computerized leg press machine. (Appendix A and B). The computerized leg press machine demonstrated excellent criterion validity (r=0.99) to a digital force dynamometer. The test-retest reliability of the leg press machine was also excellent with an ICC(2,1) of 0.99. Based on the pilot data, it is unlikely that an instrument effect occurred to influence the results of the study.

An instrument effect may have also occurred as the investigator performed treatment with the Astym® instruments. While the Astym® treatment protocol was

standardized with regard to the order and the areas treated, the amount of pressure applied during the treatment differed according to the thickness of the superficial fascia overlying the muscular tissue. A lack of standardized treatment pressure may be perceived as a weakness or confounding variable in the study. Using a predetermined pressure, however, would presumably create a bias where leaner subjects would likely receive greater mechanical stimulation of the soft-tissue compared to subjects with greater mass or thicker adipose tissue over the muscle tissue. To account for the variability of body composition among the subjects, the amount of pressure applied during treatment was dependent on the appreciable change of tissue texture noted by the investigator during the Astym® treatment. This allowed a consistent Astym® treatment experience for each individual subject and is consistent with how Astym® treatment is performed in clinical settings.

5.6.1.4 Regression to the Mean

A regression to the mean may occur when the subjects score extremely high or extremely low on the measurement of interest. To be included in the current study, subjects had to demonstrate a minimal deficit of 10% of maximal force output of their involved side compared to the uninvolved side. Since subjects demonstrated a strength deficit to qualify for the study, there could be concern that their scores would improve regardless of treatment intervention with repeated testing. The average percent deficits of the involved side to the non-involved side were 22%, 19%, and 20% for the Astym®, placebo, and control treatment groups, respectively. The groups were not statistically different for the average percent strength deficits, yet only the Astym® treatment group

showed a positive improvement of maximal force output following treatment. Given that the control and placebo groups did not improve maximal force output lessens the likelihood that a regression towards the mean would explain the improvement observed in the Astym® treatment group.

5.6.1.5 Design Contamination

Design contamination occurs when the subjects become aware of his/her treatment group. This may motivate the subjects to apply more effort to meet the expectations of the researchers. In the current study, subjects were blinded to their assigned group. Only the primary investigator knew the treatment that was administered to each subject. A second investigator performed all the testing and was blinded to the treatment received by each subject. Blinding of the subject and the investigator performing the testing can help to reduce the effects of design contamination. The blinding methods used in the current study therefore minimize the threat of design contamination.

5.6.1.6 History and Maturation Effects

An effect of history can occur when an event in the subject's past influences their outcome during the study. Similarly, maturation effects occur as the natural process of growth and aging. History and maturation are potential threats that are more commonly associated with longitudinal studies. The purpose of the current study was to examine the acute effects of Astym® treatment on muscle strength, and thus the contracted time between pre-test and post-test measures limits the effects of history or maturation on the

results of the current study. However, if a subject had previously been exposed to Astym® treatment, this could alter his/her perceptions of the treatment and lead to a different result. For this reason, subjects with previous exposure to Astym® treatment were excluded from participation in the study.

5.6.2 Threats to External Validity

External validity refers to the extent to which the results of the study are generalizable to other populations. There are threats to the external validity of this study, with regard to the type of the diagnoses as well as pre-existing weakness that may limit the generalizability of the results of the current study. This section will explore the how the type of diagnosis and pre-existing weakness may affect the generalizability of the results to other populations of subjects.

The conclusions from this study should only be applied to adult patients with muscular weakness caused by a musculoskeletal injury or condition affecting the lower extremity. The sample of subjects from the current research study was recruited from an outpatient physical therapy facility believed to be representative of a population commonly seen in other outpatient physical therapy facilities. The diagnoses of the subjects that participated in this research study were all musculoskeletal in nature. There are other conditions that may cause muscular weakness including neuromuscular disease or conditions that impair the central or peripheral nervous systems. None of the patients in the study presented with weakness caused by a neuromuscular condition or disease affecting the nervous system. Individuals with the aforementioned conditions may have debilitating weakness that would benefit from therapeutic interventions to improve

muscular performance. Although the results of the current study suggest a positive influence of Astym® treatment on muscle strength among subjects with musculoskeletal conditions, it remains unknown if weakness caused by neuromuscular disease or impairments to the nervous system would experience a similar improvement of muscular performance.

All of the subjects enrolled in the current study presented with a measurable strength deficit of at least 10% when compared to the non-involved side. Those subjects that did not have a minimum strength deficit of 10% were excluded. Therefore it remains unknown how Astym® treatment may influence strength in those without a deficit. Athletes are a population that may not present with weakness, but may benefit from an increase in muscle performance. Anecdotal reports from athletes note enhanced athletic performance immediately following Astym® treatment. However, no study has been performed to test the influence of Astym® treatment on athletic performance. The results of the current study are encouraging that Astym® treatment may facilitate athletic performance by improving muscular strength, but the sample from this study included only subjects that had muscular weakness and a known injury. Therefore, the results cannot be generalized to an athletic population that is healthy or does not have an existing strength deficit.

5.7 Future Research Considerations

The use of Astym® treatment in the management of musculoskeletal pathology is relatively new and there remains limited evidence describing its effects on individuals with various musculoskeletal conditions. The results of the current research project have demonstrated how Astym® treatment acutely affects maximal force output during an

isometric squat test. This discovery has generated interest in additional inquiries examining the effects of Astym® treatment.

While Astym® treatment was shown to cause an acute change in muscle strength, the longevity of this change remains unknown. Researchers have reported mechanical stimulation in the form of brushing of the skin can cause excitatory changes in muscle activity for up to 40 minutes after treatment.[40,41] More current research has shown that the mechanical stimulation produced with joint mobilization can influence muscular strength for 15-30 minutes after treatment. Ghanbari et al.[153] demonstrated that while muscular strength of the knee extensors occurred immediately following a grade IV mobilization of the knee joint, the maximal increase of muscular strength occurred 30 minutes after the joint mobilization. Makofsky et al.[152] noted significant improvements in hip abductor strength measures 15 minutes following grade IV inferior mobilization of the hip joint. Grindstaff et al.[163] studied the temporal effect of joint mobilization on muscular strength. The results of the study by Grindstaff et al.[163] showed a statistically significant improvement in muscular strength and activation of the quadriceps muscle group immediately following lumbopelvic manipulation, but the change was not sustained upon repeated testing at 20, 40, and 60-minutes after the manipulation. Based on these studies, one may speculate that the effect of Astym® treatment on muscular strength would last 20-40 minutes, similar to the sustainability that has been previously reported for joint mobilization and manipulation. A study that investigates the effect of Astym® treatment on muscle strength over time is needed to determine the sustainability of the effects of Astym® treatment on muscular strength.

In addition to muscular strength, other aspects of muscle performance such as muscular power may also be influenced by Astym® treatment. Power is defined as the amount of energy output per unit of time and is often expressed as the amount of muscular force multiplied by the velocity of movement.[164] Muscular power is a strong predictor of self-reported functional status [165] and predictive for falls in an elderly population.[166] Muscle power has also been associated with athletic performance in cycling, [167] swimming, [168] jumping, [169] and sprinting [170] Current research indicates that soft-tissue mobilization techniques such as massage and self-administered instrument-assisted techniques do not improve muscle power. McKechnie et al.[80] demonstrated no significant change in measures of muscle power following petrissage and tapotement massage. Mikesky et al. [103] demonstrated no improvement of measures of muscle performance after treatment using "the Stick". Similarly, no change in muscle power during a vertical jump was observed by Healey et al.[118] after self-administered soft-tissue mobilization with a foam roller. These studies, however, also demonstrated no effect on muscular strength, which is contradictory to the findings from this current research project. Whether Astym® treatment would cause an increase of muscular power that is similar to the increase that was demonstrated for muscular strength is unknown. There is a need for studies that examine the effects of Astym® treatment on muscular power and the implications to functional activities, athletic performance, and injury prevention.

Another potential research inquiry may be to investigate how Astym® treatment can directly influence function. The ability to perform activities of daily living such as walking and negotiating stairs have been related to measures of muscular strength.[118] Muscular strength has also been related to athletic performance in measures such as

timed sprinting speed and vertical jump height.[24,25,161] Since the results of the current research project demonstrated improvements in strength, it may be hypothesized that functional performance measures may also demonstrate acute improvements. Previous research has shown that Astym® treatment can help to improve measures of self-reported function.[1,4,7,11,17] However, these studies were primarily case series or studies and examined the impact of Astym® treatment over the course of several treatments. As a result, there remains little quality and quantity of evidence to establish a cause and effect relationship between Astym® treatment and measures of functional performance. Future research may investigate the effect of Astym® treatment on functional performance tests through clinically controlled trials. Examples of functional performance tests may include the stair climb test, that measures the time it takes a patient to ascend and descend a flight of stairs, or the timed-up-and-go test that measures the ability to transition from sit-to-stand and walk.[171] Functional performance in an athletic population may be measured by agility and balance tests, timed run tests, and hop/jump tests.[172] Future research that examines the impact of Astym® treatment on measures of functional performance, specifically on the abilities of individuals to perform common daily or athletic activities may help to determine the clinical significance of the acute changes in muscular strength observed in the current research project.

Future research may also investigate the mechanisms such as pain modulation, neuromuscular facilitation, mechanosensitivity of muscle tissue, and increased blood flow, through which Astym® treatment is hypothesized to influence muscular strength. Previous studies have investigated the effects of therapeutic interventions on acute muscle pain and weakness caused by an aggressive eccentric exercise protocol.[173-175]

Eccentric exercise protocols can create delayed onset muscle soreness and cause temporary damage to muscle tissue that coincides with a loss of muscular strength.[173-175] A research project that induces delayed onset muscle soreness and then evaluates the effect of Astym® treatment to reduce the associated pain and restore muscular strength deficits may help to determine the association of pain reduction and muscle performance. Such a study may also determine if Astym® treatment is indicated to manage delayed onset muscle soreness. Pain can also be produced in laboratory settings with a hypotonic injection into a joint.[66,71,73,175-177] Muscle strength measures have been shown to significantly decrease following an injection of hypotonic solution into an otherwise healthy joint.[66,71,73,175-177] A research project that examines the effect of Astym® treatment on muscle strength after laboratory induced joint pain may help to explain if improved muscle performance is related to reduction of pain and may further determine the role of Astym® treatment for patients with impaired muscular strength caused by joint pain.

To determine the effect of Astym® treatment on the sensorimotor system, a clinical trial may be constructed that uses an anesthetic nerve block that impedes sensory input to the brain, but does not affect motor signals to working muscles. The current study used a placebo intervention that consisted of tactile stimulation using lighter pressure to avoid contact with the deeper, musculoskeletal tissue. The placebo group received sensory stimulation from the mechanoreceptors found in the skin but differed from the Astym® treatment group in that there was careful attention not to stimulate the musculotendinous and fascial structures deep to the skin. The results showed a statistically significant increase of muscular strength for the Astym® treatment group, but not the placebo group. This could suggest that tactile stimulation of the skin does not

play a major role in the acute changes in muscular strength that were observed in this study, but perhaps stimulation of the mechanoreceptors in the musculotendinous and fascial structures are important to inducing a change in muscular strength. There is conflicting evidence regarding the influence of tactile stimulation and muscle performance. Tactile stimulation of the skin while wearing a neoprene sleeve was a proposed mechanism explaining improved measures of muscle performance according to research performed by Call.[178] Similarly, studies have shown that use of elastic [179,180] and non-elastic taping techniques [181-183] increases muscle activation and performance. Other studies, however, have shown no influence of taping techniques on muscle performance.[184-189] A recent meta-analysis of the evidence of elastic taping on muscle performance showed inconsistent findings and reached no definitive consensus on the effect of various taping techniques on muscle performance.[190] Therefore, it remains uncertain what effect tactile stimulation to the skin may have on measures of muscle performance. A research project that compares the impact of Astym® treatment on muscle strength in conditions with sensory input blocked versus conditions with the sensory system in tact may help to further determine if stimulation of the sensorimotor system from Astym® treatment could explain the acute changes in muscular strength observed in the current research study.

Determining how mechanical stimulation influences calcium concentrations in muscle tissue may further help to explain the mechanisms through which Astym® treatment influences muscular strength. However, measures of intra-cellular calcium are difficult to attain in vivo and require advanced laboratory techniques to measure.[191] Laboratory studies using animal models may compare intra-muscular calcium

concentrations of muscle tissue treated with Astym® to muscle tissue not treated with Astym®. Ziman et al.[191] described novel methods to measure concentrations of calcium released by the sarcoplasmic reticulum, however, these methods have not been used on human tissue. To determine the effect of Astym® treatment on calcium exchange in muscle tissue, animal studies using advanced methodology would be necessary until novel measures can be developed that can quantify calcium exchange occurring in human muscle in vivo.

The effect of Astym® treatment on blood flow may be another potential research question. Previous research has demonstrated that soft-tissue mobilization in the form of massage increases local blood flow to treated areas. [93,95,149] Massage has also shown to increase muscle temperature.[99] While it would be reasonable to suggest that Astym® treatment may induce similar increases in blood flow and tissue temperature, no study to date has been performed to investigate the effect of Astym® treatment on local blood flow and tissue temperature. Such studies would provide evidence that would help determine if increases of blood flow and tissue temperature accompany improvements in muscular strength.

5.8 Conclusions

1. Astym® treatment caused an acute improvement on maximal force output during a unilateral isometric squat test. Subjects that received Astym® treatment had a significantly greater percent change in pre-treatment to post-treatment maximal force output than the subjects that received no treatment (control) and the subjects that received a sham Astym® treatment (placebo).
2. Subjects that received the control and placebo treatment did not yield an acute improvement in maximal force output during a unilateral isometric squat test.
3. Future research is needed to understand the physiologic mechanisms that explain how Astym® treatment increases muscular strength, the longevity of the observed increases in muscular strength, and to determine if Astym® treatment will also result in acute changes in muscle power, functional abilities, and athletic performance.

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APPENDIX A. VALIDITY OF COMPUTERIZED LEG PRESS MACHINE

To establish evidence of validity, a pilot study was performed to determine the agreement of the maximum force output recorded with a digital force dynamometer (criterion) versus the computerized leg press machine (practical test) during a maximal isometric squat test. A digital force dynamometer (Microfet 2 Manual Muscle Testing Handheld Dynamometer; Salt Lake City; Utah) that was calibrated to within one hundredth of a Newton was secured to the surface of the foot plate of the computerized leg press machine. The subject then placed their foot on the center of the dynamometer and was asked to push through their foot as hard as possible. The agreement of the force computed on the computerized leg press machine to the dynamometer was determined for 21 consecutive trials using a Pearson correlation coefficient. The computerized leg press machine demonstrated evidence of excellent criterion validity to the digital force dynamometer with a Pearson correlation coefficient of 0.99. The Typical Error of the Estimate was also computed through linear regression.[192] The Typical Error of the Estimate represents the typical amount by which the estimate is wrong for any given subject. The analysis revealed the Typical Error of the Estimate to be 10.69 Newtons (95% CI: 8.13-15.62 Newtons).

APPENDIX B. RELIABILITY OF THE COMPUTERIZED LEG PRESS MACHINE

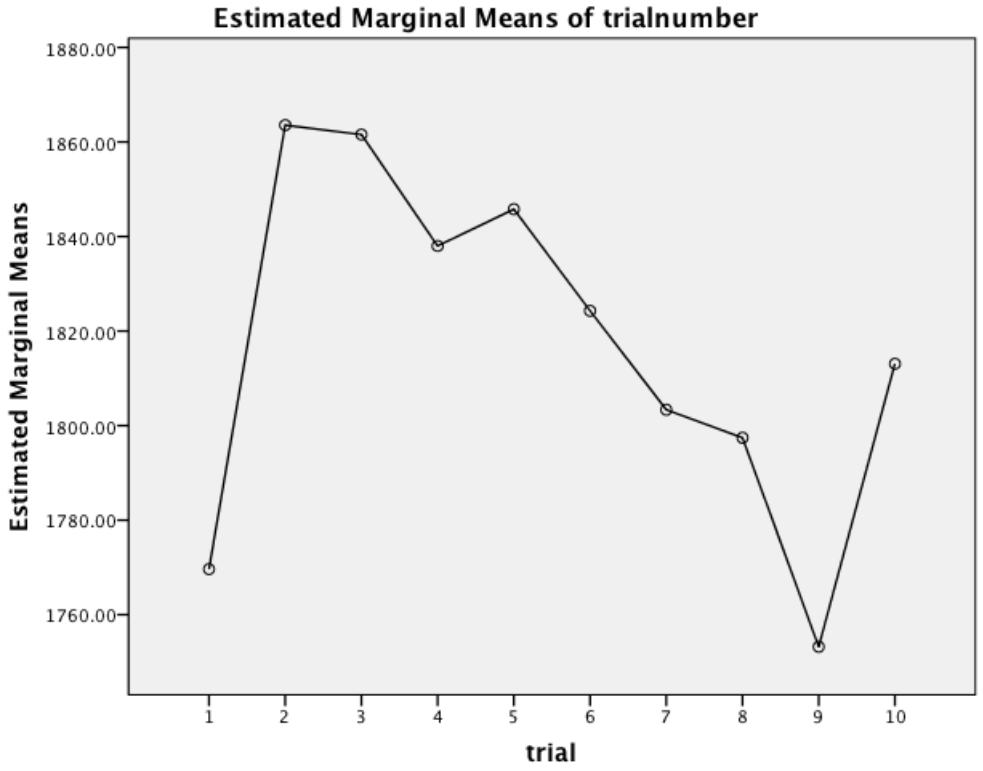
A pilot study was performed to establish test-retest reliability of the Computerized Leg Press Machine. Twelve subjects healthy performed 3 repetitions of maximal isometric testing on the computerized leg press machine. After a 12 minute rest, maximal isometric testing on the computerized leg press machine was repeated with an additional 3 repetitions. An intra-class correlation coefficient (ICC) was computed from the average of the first 3 repetitions and the average of the final 3 repetitions of maximal isometric testing. Test-retest reliability of maximal isometric testing using the computerized leg press machine was determined with an ICC(2,1) of 0.99. The standard error of the measurement is a reliability measure that estimates the given error in a set of measures. The standard error of the measurement was determined to be a 2.7 %change in maximal force output. The minimal detectable change represents the smallest amount of change in a given measure that is not attributable to measurement error. The minimal detectable change is computed as a confidence interval of the standard error of the measurement. Using a 95% confidence interval, the minimal detectable change was determined to be 7.5 %change in maximal force output.

APPENDIX C. ANALYSIS OF LEARNING AND FATIGUE EFFECT

A repeated measures analysis of variance was performed to determine if trial number influenced the subject's test performance on an isometric squat test. Determining a learning effect or fatigue effect is important in establishing a testing protocol that best represents the subject's true performance. A learning effect would be represented by an improvement of test performance with repeated trials. A fatigue effect would be represented by a decline in test performance with repeated trials. Fourteen healthy subjects performed 10 repeated trials of isometric testing on a computerized leg press machine. The results indicated a significant effect of trial number to isometric force output ($F(9,5) = 5.27$, $p<0.05$). Analysis of a plot of the estimated marginal means (Figure 9) shows a learning effect that occurs between trial 1 and 2. On average this accounted for approximately a 5% increase between trial 1 and 2. After trial 2, there appears to be a gradual linear decline in performance indicating the possibility of fatigue until trial 9. The average decline in performance between trial 2 and trial 9 is approximately 6%. The pairwise comparisons between trials, however, did not demonstrate a significant difference between any of the 10 trials. Although pairwise comparisons of trial 1 and trial 2, and trial 2 and trial 9 did not reach statistical significance, the testing protocol should account for the tendency of an initial learning effect and the possibility of a gradual fatigue effect with repeated testing. Carcia et al. [138] described a familiarization protocol for unilateral isometric testing on a computerized leg press machine. Based on data from our pilot study, the familiarization protocol described by Carcia et al. [138] would account for an initial learning effect and limit fatigue by

averaging only three trials performed at maximal effort. For this reason, the familiarization protocol described by Carcia et al.[138] was adopted for the proposed research study.

Figure 9. Estimated Marginal Means of the Trial Number



Appendix D. The frequency of gender, lower extremity dominance, and diagnosis of the subjects according to treatment group.

	Subject Number	Gender	Lower Extremity Dominance	Diagnosis
Astym				
	1	F	R	HAMSTRING STRAIN
	2	F	R	TROCHANTERIC BURSITIS
	4	F	L	ACHILLES TENDINOPATHY
	8	M	R	DISTAL ITB FRICTION SYNDROME
	9	M	R	HAMSTRING STRAIN
	15	F	R	PATELLOFEMORAL PAIN
	17	F	R	DISTAL ITB FRICTION SYNDROME
	21	F	R	FEMOROACETABULAR IMPINGEMENT
	24	M	R	PLANTAR FASCIITIS
	25	F	R	LABRAL TEAR
	27	F	R	TIBIALIS POSTERIOR TENDINOPATHY
	33	F	R	DISTAL ITB FRICTION SYNDROME
	40	F	R	PATELLOFEMORAL PAIN
	44	F	R	PLANTAR FASCIITIS
	45	F	R	MENISCAL TEAR
Control				
	3	F	R	POSTERIOR TIBIALIS TENDINOPATHY
	5	F	R	MCL SPRAIN
	7	M	R	ADDUCTOR STRAIN
	13	F	L	ANKLE SPRAIN
	14	F	R	PATELLOFEMORAL PAIN
	20	M	R	PATELLOFEMORAL PAIN
	22	M	R	PLANTAR FASCIITIS
	26	M	R	PATELLOFEMORAL PAIN
	29	F	R	ANKLE SPRAIN
	30	F	R	KNEE OSTEOARTHRITIS
	34	M	R	PLICA
	38	F	R	HAMSTRING
	41	F	R	PATELLOFEMORAL

			PAIN/QUAD STRAIN
42	F	R	FEMOROACETABULAR IMPINGEMENT
43	F	R	POSTERIOR TIBIALIS TENDINOPATHY
Placebo			
6	F	R	MCL SPRAIN
10	M	R	PATELLAR DISLOCATION
11	F	R	PATELLOFEMORAL PAIN
12	F	R	SHIN SPLINTS
16	M	R	PLANTAR FASCIITIS
18	F	R	PES ANSERINE BURSITIS
19	F	R	PATELLOFEMORAL PAIN
23	F	R	QUAD STRAIN
28	M	R	HAMSTRING
31	M	L	HAMSTRING
32	F	R	QUAD STRAIN
35	M	L	HAMSTRING
36	F	R	PATELLOFEMORAL PAIN
37	F	R	MENISCAL TEAR
39	M	R	PLANTAR FASCIITIS
6	F	R	MCL SPRAIN

Appendix E. Raw Data

Sub#	Group	Age	Ht	Wt	LEFS	% Deficit	Pre-Pain	Post-Pain	Pre-test (N)	Post-Test (N)	%Diff
1	A	53	165	60	50	23	5	1	1082	1308	21
2	A	45	172	68	68	19	3	0	658	864	31
3	C	49	155	51	65	30	2	2	607	753	29
4	A	28	170	70	70	11	0	0	1191	1543	29
5	C	58	165	73	66	11	2	2	1165	1185	2
6	B	62	162	73	52	30	2	0	595	431	-38
7	C	24	175	68	46	26	0	0	1794	1341	-25
8	A	21	175	79	69	11	0	1	2465	2909	18
9	A	33	185	86	69	29	5	3	1068	1442	35
10	B	39	183	84	62	12	2	6	1732	1681	-3
11	B	32	152	41	67	19	2	2	950	937	-4
12	B	26	165	64	57	10	6	8	1391	1338	-4
13	C	41	163	55	70	23	2	2	659	686	4
14	C	20	160	52	69	13	2	6	1732	1681	-3
15	A	47	165	52	70	12	0	0	832	1045	26
16	B	41	183	75	70	33	0	0	538	503	-7
17	A	54	165	67	70	32	5	5	653	733	13
18	B	56	152	72	65	14	5	5	371	350	-6
19	B	35	160	51	70	23	2	2	737	778	6
20	C	24	170	79	70	13	0	5	2672	2128	-20
21	A	48	157	64	40	19	5	3	731	957	31
22	C	28	173	107	62	33	2	2	1333	1261	-5
23	B	62	163	70	60	26	3	3	868	845	-3
24	A	40	165	70	67	20	3	3	1670	1805	8

25	A	43	167	57	57	18	1	2	726	719	-1
26	C	36	191	102	63	11	0	4	1111	1022	-8
27	A	32	168	88	46	20	0	0	836	764	-9
28	B	36	180	75	60	19	3	5	809	660	-18
29	C	54	175	97	50	50	3	3	461	581	26
30	C	28	170	67	54	25	7	5	212	234	10
31	B	49	167	64	42	10	1	1	659	625	-5
32	B	42	160	54	43	26	1	1	491	491	0
33	A	53	125	55	51	46	0	0	354	475	34
34	C	38	180	100	63	20	6	7	1122	855	-31
35	B	27	193	95	69	10	2	2	1936	1736	-10
36	B	28	163	68	65	10	0	4	1923	1861	-3
37	B	65	165	79	55	17	3	5	447	408	-9
38	C	32	157	63	59	10	5	5	564	546	-3
39	B	46	170	78	60	12	0	0	1024	1127	10
40	A	20	178	77	56	17	0	4	1364	1445	6
41	C	23	170	60	63	10	0	0	676	715	6
42	C	24	178	93	45	21	4	5	1053	1172	11
43	C	47	170	54	59	13	3	3	487	420	-14
44	A	49	168	75	62	28	2	2	660	506	-30
45	A	61	162	59	59	21	4	1	619	742	20

A= Astym treatment group; B= Placebo treatment group; C= Control group:

LEFS= Lower Extremity Functional Score.