THE EFFECTS OF SOFT TISSUE OSCILLATION ON

DELAYED ONSET MUSCLE SORENESS

by

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ABSTRACT

Numerous interventions have been used in attempt to treat delay onset muscle soreness (DOMS). Soft tissue oscillation therapy (STO) has the potential to alleviate the signs and symptoms of DOMS. However, there is a lack of scientific evidence supporting the effects of STO. The purpose of this study was to investigate the effects of STO as a treatment for DOMS after an eccentric exercise protocol. A total of 31 healthy, physically active volunteers (7 males, 24 females, age = 20.2±1.6 years, height = 168.1±10.3 cm, mass = 75.9±19.1 kg) were randomly assigned to either the STO (n = 16) or control (n = 15) group. Participants performed eccentric biceps curls with the non-dominant arm until fatigue at 80% of their estimated one-repetition maximum followed by either STO treatment or no treatment at 24, 48, 72, and 96 hours post-exercise. The main outcome measures included perceived soreness, self-reported functional ability, elbow range of motion, and upper arm circumference and were recorded at baseline, immediately after, 24, 48, 72, and 96 hours, and 7 days post-exercise. No significant effects of STO were evident on the recovery of perceived soreness ($F(6, 162) = 0.25$, $p = .854$, partial eta2 = .009), self-reported functional ability ($F(6, 162) = 0.24$, $p = .815$, partial eta2 = .008), elbow range of motion extension ($F(6, 162) = 0.96$, $p = .381$, partial eta2 = .034) and flexion ($F(6, 162) = 0.65$, $p = .597$, partial eta2 = .024), and upper arm circumference ($F(6, 162) = 0.31$, $p = .787$, partial eta2 = .011) when compared to the control group. It was concluded that STO is not an effective treatment for DOMS.

Key Words: eccentric exercise, massage therapy, therapeutic modality, manual therapy

CHAPTER I

INTRODUCTION

Soft tissue oscillation therapy (STO) is a relatively new therapeutic technique designed to treat soft-tissue injuries and disabilities. This technology was derived from percussion vibrator treatment designed to treat somatic dysfunctions in the 1950's.[1] Many years later, STO was marketed as a modality aiming to create changes in the myofascial system by combining electrotherapy with a manual therapy or massage.[1,2]

Application of STO generates an electrostatic field between the hands of the clinician and the tissues of the patient. This low-intensity electrostatic current occurs at various frequencies and polarities causing the cells in the tissue to be attracted and repelled which results in a vibratory action.[2] The vibration combined with light massage is believed to stimulate nerve endings to relieve pain and open the lymphatic pathways to transport swelling out of the tissue.[3-5]

Soft tissue oscillation therapy is intended to relieve pain and swelling of soft-tissue injuries.[2] The use of STO is recommended for acute sports injuries included a condition known as delayed onset muscle soreness (DOMS).[2] This condition is commonly experienced after individuals perform unaccustomed exercise or increase the load during resistance training. The likelihood of experiencing the functional deficits frequently observed with DOMS is increased with eccentric exercise as compared to isometric or concentric actions.[6-8] Eccentric exercise is believed to result in greater muscle soreness because the motion stimulates more neural activations to generate the force required to complete the exercise.[6,7]

Delayed onset muscle soreness typically occurs 24 to 48 hours after unaccustomed exercise, especially eccentric exercise, is performed. Its characteristics are similar to muscle soreness. However, muscle soreness tends to subside after a few hours while DOMS is prolonged for 5 to 7 days.[9,10] Clinical signs and symptoms associated with DOMS include increased pain, increased edema, decreased self-reported functional ability, decreased range of motion, and decreased muscle strength.[10-12]

The exact cause of DOMS remains unknown though there are various theories believed to be linked together.[9,13,14] There is a decrease in physical performance that can be attributed to functional impairment as perceived by the individual and decreases in joint kinematics, strength, and neural recruitment patterns which increases risk factors of further injury.[14] Although DOMS is not considered a major injury, all of these impairments can lead to an increased risk of injury; therefore, interventions to relieve the signs and symptoms of DOMS have been investigated.[15-17]

Numerous interventions have been researched in order to determine their effectiveness in preventing or alleviating the clinical presentations related to DOMS.[15-17] The effectiveness of these treatments remains inconclusive because of inconsistencies between studies and the limited amount of evidence of the interventions. Soft tissue oscillation therapy is a novel intervention that could be used as a treatment for DOMS.

The physiological outcomes of STO are pain control, circulatory benefit, and mechanical.[2] The wide range of frequencies output a vibration which depolarizes the sensory nerves to inhibit pain.[5] Theoretically, the altered polarity of the electrostatic current assists with circulation by stimulating blood vessels to relax and increase in diameter. This mechanism may stimulate lymphatic absorption of interstitial fluid by breaking up tissue adhesions through the mechanical pressure of massage in the direction of venous return.[4] The manufacture suggest that soft tissue injuries fall into the indicated outcomes of STO, which has minimal empirical evidence to support.[2]

Interventions comparable to the STO have been studied through deep oscillation with primary outcomes of reducing pain and edema following sports injuries.[18-20] In individuals with either post-injury edema, low back pain/sciatalgic pain, and cervicobrachial pain, STO showed to be effective at increasing pain threshold and functional abilities.[18] Among a variety of sports injuries, pain according to the Visual Analog Scale (VAS) was reduced and edema reabsorption was improved post-treatment.[19] Hamstring extensibility was improved unilaterally after deep oscillation compared to the contralateral leg and when compared to ultrasound.[5] Pain and swelling was improved in patients with acute lateral ankle sprains when combined with a conservative treatment and Aircast brace.[20] However, the effects of STO have not been examined on the signs and symptoms of perceived muscle soreness, edema, perceived functional disability, and elbow range of motion associated with DOMS.

Purpose of the Study

The purpose of this study was to determine the effectiveness of STO in reducing the signs and symptoms of DOMS.

Hypothesis

It was hypothesized that the experimental group receiving STO will experience larger decreases in the signs and symptoms of DOMS as compared to the control group.

Independent Variables

The independent variables in this study were the treatment conditions, time, and gender.

Dependent Variables

The dependent variables consisted of perceived muscle soreness, upper arm circumference, perceived functional disability, and elbow range of motion.

Delimitations

This study had set delimitations or controlled characteristics that could affect the findings and results. These delimitations included:

1. Subjects were healthy, physically active males and females between the ages of 18 and 30 years old.
2. To be considered physically active, subjects must perform a minimum of 150 minutes of moderately intense aerobic activity per week.
3. An intervention consisting solely of STO and not combined with other therapeutic treatments such as ultrasound, massage and cryotherapy.
4. The only condition being treated was delayed onset muscle soreness.

Limitations

This study had set limitations that could affect the findings and results. Generalizations of the results of this study were compromised by the following limitations as results cannot be applied to:

1. Pediatric or geriatric individuals who were not included in the study due to the readily available 18 to 30 year olds.
2. Individuals who are inactive due to the risk of injury during participation and the representation of an active lifestyle in 18 to 30 year olds.
3. Interventions consisting of a combination of STO and another treatment because of the time restraints to complete the study and the lack of necessary equipment and trained personnel.
4. Other soft tissue injuries or conditions due to the potential differences in the responses to trauma.

Assumptions

There are certain assumptions which exist that the principle researcher assumed to be true. The assumptions for this study included:

1. All subjects were randomly selected and a representation of the general population.
2. The eccentric exercise protocol was consistent throughout the study to assist in ensuring the elbow flexor muscles were isolated.
3. All subjects performed the exercises and tests with maximal effort.
4. Subjects did not receive any other form of medicine or therapeutic treatment during this study.
5. Subjects completed the medical health history questionnaire and dependent measurement forms accurately and honestly.

Operational Definitions

Eccentric exercise: A muscle contraction in which the active muscle is elongated during a resistive motion

Fatigue: A point during resistive exercise when the individual can no longer perform the required movement in a slow, controlled manner

Frequency: the number of occurrences over one second as measured in hertz

Hertz: Hz; the number of cycles per second

Output: the percentage of time that the electric current is being delivered

Significance of the Study

Delayed onset muscle soreness is muscular soreness and pain experienced 24 to 48 hours after an unaccustomed bout of exercise. Though DOMS is not considered a major injury, it compromises performance by decreasing range of motion, strength, and function.[21] The severity of the symptoms leading to the decrease in performance has led to the investigation in treatment for DOMS. There have been a number of treatment options researched in order to determine their effectiveness at reducing pain and edema, and increasing range of motion, though none of these interventions have consistently been proven effective.[16,21-23] Lack of sufficient evidence supporting treatment options for DOMS is unequivocal.

Soft tissue oscillation therapy combines an electrotherapeutic aspect and massage in order to treat DOMS. The few studies conducted on a similar intervention, known as deep oscillation, have shown promise at treating soft tissue injuries. Pain, swelling, and functional abilities have been shown to improve following the application of deep oscillation in a variety of sports injuries.[5,18-20] As a result, STO has the potential to effectively treating DOMS by reducing pain and edema.

CHAPTER II

LITERATURE REVIEW

Delayed onset muscle soreness is a condition that occurs when individuals perform unaccustomed or eccentric exercise. It is characterized by increased pain and edema and a decrease in self-reported functional ability, range of motion, and muscular strength evident 24 to 48 hours after the exercise session.[10-12] This condition has led to the investigation of the mechanisms of the injury along with methods for effective treatment.

Soft tissue oscillation therapy produces an electrostatic current at a wide range of frequencies and alternations in polarities which creates a vibration effect.[2] This vibration effect along with a light massage may lead to the inhibition of pain and removal of swelling from the localized area. Thus, STO may be implemented as an effective treatment for DOMS through further investigations. This chapter will discuss the varying mechanisms, measurements, induction procedures, and common treatment options for DOMS along with STO.

Mechanisms of Delayed Onset Muscle Soreness

The exact cause of DOMS remains unknown though there are various theories. Six theories have been investigated in previous research to determine the etiology.[9,13,14] It appears as if the mechanism is a combination of the six plausible theories with one leading to another and ultimately resulting in DOMS.

Lactic Acid Accumulation

Lactic acid is a waste by product produced during anaerobic exercise. This causes the body's pH level to turn acidic which irritates nerve endings to stimulate a pain sensation. Lactic acid accumulation was once thought to be a mechanism of DOMS. However, most research is in agreement on rejecting this theory due to the disconnection between lactic acid and delayed pain.[14] Lactic acid is cleared from the body within one hour of finishing exercise and for that reason it is not present when DOMS arises 24-48 hours later.[21] Studies examining the relationship between DOMS and lactic acid reveal there is no association.[24,25] Lactic acid levels were tested before, during, and after a 45 minute run on the treadmill in seven subjects and displayed no relationship with the experienced muscle soreness.[24] Two days after DOMS was induced in ten healthy active subjects through a 40 minute bench step protocol, the concentration of lactate was found to be similar between the exercise and control groups.[25]

Muscle Spasm

Exercise at a moderate level or above is thought to create muscle spasm through a vicious cycle. Active muscles during exercise experience ischemia which may lead to pain. The pain may cause a muscle contraction, or spasm, which extends the ischemia and keeps the vicious cycle going.[26] The muscle spasm theory was introduced when an electromyogram (EMG) detected increased muscle activity after eccentric exercise.[27] Controversially, later research concludes that there is no change in muscle or EMG activity accompanied with muscle soreness after eccentric exercise.[28,29] In a study on the elbow flexors, voluntary muscle activation fell immediately after eccentric exercise yet was similar to the control when measured 2, 4, and 8 days later.[28] Electromyogram levels, detecting change in muscle activity of eleven subjects, were not elevated 24, 48, or 72 hours after DOMS was induced in the gastrocnemius. These results suggest that muscle spasm is not a mechanism of DOMS.[29]

Muscle Damage

The muscle damage theory after eccentric exercise emphasizes a disturbance to the sarcomeres, mainly at the Z-line.[21] Eccentric exercise has been shown to alter the muscle fiber architecture.[30] This change in architecture can be allotted to a stretch of the sarcomere and Z-lines.[21,30] The irregular sarcomere length leads to a decrease in the contraction generated by the muscle because the actin and myosin are stretched and are no longer properly alligned.[10] Creatine kinase (CK) has long been used as a way of measuring muscle damage.[21] However, a recent study determined CK levels can be affected by other factors such as genetics, age, and gender.[31] This leads to questioning of using CK levels as a valid marker for muscle damage when it can be altered by changes of normal metabolic activities.[31] As a result, muscle damage can only be credited as part of the mechanism behind DOMS.

Connective Tissue Damage

Along with damage to the muscle itself, there is evidence that the connective tissue surrounding the muscle is also damaged.[32] Following DOMS, there is an increase in tension and stretch placed upon the connective tissue. This unaccustomed stress stimulates the free nerve endings in the connective tissue and musculotendon junction which generates localized soreness in the area.[32] It is evident that connective tissue varies based on the muscle fiber type. Type I, or slow twitch, and type II, or slow twitch, muscle fibers appear to be affected through eccentric exercise.[32] Research on the structure of the vastus lateralis muscle in nine healthy males has shown type II fibers are affected more than type I fibers after eccentric.[33] Muscle biopsies of the biceps brachii from twelve subjects were examined to compared the amount of type II versus type I muscle fibers.[34] The study found approximately 60% of the muscle fibers were type II.[34] In this study, DOMS was induced in the elbow flexor muscles.

Inflammation

Muscle soreness is increased after eccentric exercise, when compared to concentric exercise, due to the inflammation process.[30,35] After DOMS is induced, leukocytes, pro-inflammation cytokines, and neutrophils are released from the body as an inflammatory response to muscle damage.[35-38] A study compared thirteen trained runners to twenty-two trained cyclist to examine the inflammatory response.[35] These researchers observed a greater increase in the duration of inflammation cytokines for two days after running when compared to those who cycled.[35] The inflammation response tends to be greater after eccentric exercise, such as downhill running or eccentric cycling, that recruits larger muscles than those exercises which involve smaller muscles.[36] Blood and urine analysis were conducted to monitor leucocytes, cytokines, and neutrophils after DOMS was induced in the gastrocnemius following one-legged calf raises.[37] This analysis revealed an increase in neutrophils four hours after the exercise session indicating that the inflammatory process may be involved in DOMS.[37] One study examined the effect of eccentric exercise of the elbow flexors on the inflammatory response in nine young and eight postmenopausal women.[38] Younger women have a higher inflammatory response, as shown by the increase in cytokines, for up to 72 hours after eccentric exercise when compared to postmenopausal women.[38]

Efflux of Enzymes and Electrolytes

Damage to musculature may allow calcium to leak out of the sarcomere into the injured muscle.[10, 39] Eccentric exercises may lead to an increase in intracellular calcium due to the muscle damage evident by the stretched sarcomeres.[39] This stretching of the sarcomere may damage the t-tubules which release calcium into the muscle.[39] Evidence of increased calcium levels were observed in the working muscles after a 20 kilometer run was completed by twelve healthy individuals when compared to those who ran 10 kilometers.[40] With an increase of intramuscular calcium, strength is decreased.[10] This weakness can be attributed to a leakage in calcium from the sarcomere resulting in less calcium available to create an action potential and generate a muscle contraction.[10]

Measuring Delayed Onset Muscle Soreness

DOMS presents itself with muscle soreness, edema, reduced subjective functional ability, diminished range of motion, and reduction of strength. The likelihood and intensity of these characteristics being present after eccentric exercise is increased when induced in the elbow flexors.[41,42] The difference in the amount of muscle damage between the elbow flexors and knee extensors was studied in twelve sedentary males.[41]

The results showed muscle damage is much greater after eccentric exercise of the elbow flexors when compared to the knee extensors.[41] A similar study recruited eleven inactive males to examine the intensity of muscle damage between the arms and legs following eccentric exercise.[42] The elbow flexors displayed a greater level of muscle damage as compared to the knee extensors.[42] Therefore, the elbow flexor muscles were chosen as the target muscle for the induction of DOMS. It is important to effectively measure these conditions in order to diagnose the condition as DOMS and track their recovery.

Perceived Soreness

Soreness is one of the most effective ways to subjectively document the muscular pain and soreness associated with DOMS. The Visual Analog Scale (VAS) is a unidimensional subjective measurement tool designed to detect the level of perceived soreness and has been a common instrument in assessing DOMS.[11] Twenty-one individuals participated in a study to compare the unidimensional VAS to the multidimensional McGill Pain Questionnaire.[11] The study demonstrated no difference between the two assessment instruments indicating the VAS is a good tool for assessing pain or muscle soreness.[11] The reliability has been evaluated as having a high intraclass correlation coefficient for acute pain.[43] A study consisting of ninety-six patients with pain at two emergency departments concluded the VAS is a valid instrument to detect change in acute pain.[44] The VAS consists of a 10 cm ranging from 0 to 100 with 0 representing no pain and 100 representing worst pain. The subjects in this study recorded their perceived muscle soreness on this line and the intensity was considered the distance from the no pain mark to the individual's mark.[11]

Edema

Swelling has been reported as a sign of DOMS.[10-12] Upper arm circumference measurements was taken 3, 5, 7, 9, and 11 cm above the elbow crease with a constant tension tape measure to determine the amount of edema in the elbow flexor muscles. The use of upper arm circumference measurements of the elbow flexor muscles at these exact sites has been used in previous studies.[45-48] It has been suggested that other forms of measuring edema, such as magnetic resonance imaging (MRI) or ultrasonography, would produce better results as both instruments have been proven valid and reliable for assessing edema in the elbow flexor muscles.[49] However, due to time and monetary concerns involving the use of MRI or ultrasonography, the use of upper arm circumference measurements was used in this study.

Self-reported Functional Ability

Subjects completed the DASH questionnaire which consists of 30 items with 5 responses, ranging from no difficulty to unable, per question.[50] The DASH was developed as an outcome measure reflecting the patient's quality of life by assessing symptoms and functional limitations specific to the upper extremity after injury.[51] The reliability, validity, and test-retest reliability was assessed in two hundred patients with a shoulder or wrist/hand injury.[50] The results obtained from the study revealed the validity, test-retest reliability, and patient responsiveness was high and useful throughout the entire upper limb.[50] The DASH questionnaire was used to measure the overall upper extremity disability of the patient's health-related quality of life.

Range of Motion

A decrease in range of motion is evident with DOMS.[10-12] Subjects laid supine on a treatment table, rest the arm parallel to the body with the forearm in supination, and were instructed to perform elbow flexion and extension for measuring elbow joint range of motion. The use of a standard goniometer is a common method to record range of motion measurements with a relatively high inter-observer reliability and has been used in other studies.[41,52-54]

Muscle Strength

One of the most common characteristics prevalent in DOMS is a decrease in muscle strength[12] This study used a multiple repetition maximum test to estimate the subject's one repetition maximum (RM). The gold standard for measuring muscle strength is the 1 RM.[55] However, it is documented that the 1 RM may be unsafe to complete for some populations such as novice lifters.[55,56] An ideal method of measuring muscle strength is to use an isokinetic machine to test maximal voluntary contraction torque. Although the reliability is high, the outcome can be affected by fatigue, motivation, and pain.[57] Another method of determining muscle strength is by using an isometric measurement to determine maximal voluntary contraction torque however it does not allow movement throughout the entire range of motion.[57]

Seventy subjects completed a 1, 5, 10, and 20 RM chess press and leg press test to compare maximum muscle strength obtained from multiple repetition testing versus a 1 RM.[55] It was concluded that muscular strength can be effectively estimated from a multiple repetition testing as long as no more than ten repetitions are performed.[55] Multiple repetition maximum testing has been shown to create muscle soreness after a bench press, incline press, triceps extension, biceps curl, and leg extension in thirty-four novice individuals while lowering the risk of injury.[58] Submaximal strength test from a 7-10 repetition maximum has been indicated as a valid method to predict 1 RM.[58] The subject's muscular strength was estimated using the estimating one-repetition maximum table.

Protocols to Induce Delayed Onset Muscle Soreness

Eccentric exercise has been proven to effectively induce DOMS.[6-8] Several protocols have been implemented using various techniques. Therefore a combination of several techniques from previous studies were implemented to induce DOMS.[59-62] Delayed onset muscle soreness was induced eccentrically in the elbow flexor muscles of thirty subjects using a free weight, determined from a concentric 1 RM, as the subject fully extended the elbow and a researcher lifted the weight back to the start position while seated behind an inclined-biceps curl bench.[59] The process was completed until exhaustion was achieved.[59] A similar technique was utilized in sixty-five participants who lowered a dumbbell set at 10%, 20%, or 100% of the individuals maximal voluntary isometric contraction behind a preacher curl bench.[60] The participants eccentrically lowered the weight in a controlled manner from 130° of elbow flexion to 10° of elbow extension over the course of five seconds followed by a researcher lifting the weight up to the start position.[60] This movement was completed every 45 seconds for a total of 30 repetitions.[60] Once the participant was unable to control the lowering of the weight, the researcher minimally spotted the movement.[60] Another study recruited twenty-four participants who completed an eccentric biceps curl for three sets of 10 repetitions with a set weight of 140% of their 1 RM.[61] Sixty athletes completed an eccentric exercise protocol for the elbow flexors as a dumbbell, set at 80% of the participants maximum voluntary contraction, was lowered from the elbow flexed to elbow extended over five seconds as the examiner provided verbal encouragement.[61] DOMS was induced in the elbow flexor muscles through completion of an eccentric exercise protocol using 80% of the subject's estimated 1 RM. The elbow flexor muscles were the targeted muscle because studies have shown DOMS is greater in the elbow flexors when compared to the knee flexors and extensors because of the prevalence of type II muscle fibers and smaller amount of use of the biceps brachii during activities of daily living.[30,34,41,42] The severity of muscle damage is dependent upon the architecture and specific type of the muscle fibers recruited during the eccentric exercise.[30] Type II muscle fibers are affected to a greater degree than type I fibers following eccentric exercise.[30] Inspection of the biceps brachii revealed it consists predominately of type II fibers.[34] A comparison of muscle damage between elbow flexors and knee extensors following eccentric exercise showed that the elbow flexors are affected more than the knee extensors.[41] When comparing muscle damage between limbs, the elbow flexors experience greater muscle damage from eccentric exercise as compared to knee extensors.[42] The American College of Sports Medicine recommends novice and intermediate individuals lift a load set at 70-85% of the 1 RM for muscular strength.[63] Eighty percent of the 1 RM is commonly used in resistance training programs.[64] The relationship between repetitions performed at 80% of 1 RM was examined in seven trained and ten untrained subjects.[64] The results concluded there was no difference between the two groups during the bench press in respect to the number of repetitions with a load of 80%.[64] Therefore, this study used a set resistance intensity of 80% of the participants 1 RM.

Treatment of Delayed Onset Muscle Soreness

It is important to determine an effective treatment to alleviate the signs and symptoms of a soft tissue injury such as DOMS. Numerous interventions have been researched in order to determine their effectiveness on alleviating the clinical presentations related to DOMS.[15-17] This section will provide an overview of treatment options suggested for DOMS.

Cryotherapy

The standard conventional treatment for acute soft tissue injuries is rest, ice, compression, and elevation (RICE principle).[14] A common treatment for DOMS that is similar to RICE is cryotherapy. Cryotherapy has been considered a treatment option due to the possibility of potentially limiting the inflammatory response that occurs during soft tissue injuries by causing vasoconstriction.[14] However, evidence is inconclusive on cryotherapy as a recovery method for DOMS.[65] Some studies have concluded that cryotherapy and cold-water immersion has been shown to reduce the signs and symptoms of DOMS.[66-68] Results for a 10 minute cold-water immersion at 10°C after a soccer match indicated a reduction in muscle soreness and increase in muscle strength.[66] Likewise, muscle strength and muscle soreness were positively affected at 24 and 48 hours after exercise when ten males completed a 10 minute cold-water immersion at

10°C immediately after a shuttle run when compared to the control.[67] A 15 minute cold-water immersion at 15°C immediately, 4, 8 and 24 hours after a series of repetitive jumps showed a decrease in muscle soreness and muscle strength during a crossover study of twenty males.[68] On the other hand, studies display no effect in the measures of DOMS after cryotherapy or cold-water immersion.[69-72] In a study consisting drop jumps by eighteen subjects, a 12 minute cold-water immersion at 15°C immediately after and every 12 hours for the next 72 hours revealed no effect on muscle strength, soreness, or range of motion.[69] In another study where sixteen participants completed drop jumps, muscle strength , soreness, and range of motion was not affected by a 12 minute cold-water immersion at 15°C when compared to a control.[70] A 10 minute cold-water immersion at 10°C immediately after counter-movement jumps by nine athletes displayed no change in muscle strength or soreness versus the control.[71] After DOMS was induced via a dynamometer on the elbow flexors in twelve subjects, there were no differences in muscle strength, soreness, or range of motion when a 15 minute ice massage was applied immediately, 24, and 48 hours after exercise when compared to a control.[72]

Massage

One of the most popular treatments after sport related injuries and has been investigated as a treatment for DOMS is massage.[46] Previous studies show a mild positive effect on reducing soreness associated with DOMS. In an arm-to-arm comparison of ten participants, massage was applied for 10 minutes 3 hours after DOMS was induced in the elbow flexors.[46] The study concluded massage was effective at decreasing muscle soreness and edema with no differences in muscle strength or range of motion.[46] Muscle soreness and pain pressure threshold was decreased after a 30 minute massage was applied to the quadriceps 2 hours after downhill running.[73] The intensity of muscle soreness has been decreased for up to 48 hours post exercise following a 20 minute massage to the knee flexors applied 2 hours after eccentric knee flexor contractions but there was no improvement in hamstring function.[74] A 17 minute massage was applied to the quadriceps following pre-season training and participants displayed a decrease in muscle soreness.[75] A decrease in muscle soreness in the quadriceps after downhill walking has been evident following a 25 minute massage immediately after the exercise.[76] However, one study concluded that a 6 minute massage is not effective in relieving muscle soreness when DOMS was induced in the elbow flexors.[77] Therefore, massage may have a small positive effect in diminishing muscle soreness but has not been proven effective in altering muscle strength, range of motion, or function.

Stretching

Stretching is widely performed before and after exercise in attempt to decrease the risk of injury and reduce muscle soreness. Therefore, it has been considered as a way to manage DOMS. One study investigated the effect of pre-exercise stretching on the prevention of DOMS in the knee flexors and concluded that 4 sets of 20 second static stretching is not preventative.[78] Static stretching of the quadriceps muscles for 3 sets of 30 seconds immediately after exercise did not prevent the occurrence of DOMS in a group of seven females.[79] This same result was concluded in a study where seventeen males completed 10 sets of 30 second static stretches for the knee extensors immediately after exercise.[80] Current systematic reviews state the overwhelming consensus that stretching after exercise does not reduce the occurrence of muscle soreness.[15,81]

Low-intensity Exercise

Another common treatment intervention is low-intensity exercise. Bouts of low-intensity exercise are performed on the days following the induction of DOMS. A study consisting of fifty participants examined the effect of low-intensity exercise after downhill running and concluded treadmill running each day afterwards did not have any benefits.[82] A similar study on the elbow flexors revealed no changes in the recovery from DOMS. [83] Sixty participants completed a workout on the cycle ergometer 48 hours after DOMS was induced in the elbow flexors and results indicated no changes in muscle soreness or pain pressure threshold.[83] However, one study showed low-intensity concentric exercise performed up to four days after eccentric exercise of the elbow flexors had a temporary analgesic effect.[45] The current evidence on low-intensity exercise does not support its use in alleviating DOMS.[15]

Soft Tissue Oscillation Therapy

Based upon the previous studies, none of the preceding interventions have consistently been proven effective. This lack of sufficient evidence supporting treatment options for DOMS has left a gap in research. Soft tissue oscillation therapy could be effective in the treatment of DOMS as it incorporates a combination of vibratory forces and massage to relieve muscle pain and decrease edema by improving localized circulation.[2] Soft tissue oscillation therapy is a relatively new device on the market with a limited amount of evidence to determine its effectiveness.

The majority of studies focusing on the effects of STO are on lymphoedema treatment. After breast cancer, many patients develop secondary breast lymphoedema in the breast, chest, and arm.[4] One study compared the effects of manual lymphatic draining through STO versus manual lymphatic drainage alone in twenty-one patients with secondary breast lymphoedema.[4] The patients in the treatment group displayed a reduction in pain and swelling when compared to manual lymphatic drainage alone.[4] In a comparable study, swelling and pain due to secondary breast lymphoedema was reduced following application of STO as opposed to the control group.[84] When STO was combined with complex decongestive therapy in patients with lymphoedema, edema was decreased while the patient's quality of life and motility/flexibility was improved.[85]

Another area STO has been researched is on patients with fibromyalgia syndrome (FMS). A common complaint from FMS patients is persistent pain that is debilitating. Seventy patients with FMS were recruited to receive STO treatment over a ten session period.[3] The outcome measurements from this study included symptom severity including pain, quality of life, and safety and tolerability of the treatment.[3] Results presented improvements in all of these measurements.[3] A similar study comprised of sixty-three FMS patients concluded improvements in FMS symptoms, pain, and patient quality of life after STO treatments.[86]

One study has been conducted on post-surgical patients.[87] Sixty-four patients with a hip prosthesis were enrolled directly after the surgical operation. Soft tissue oscillation therapy was added to the traditional treatment of increasing strength, endurance coordination, and flexibility. The results conclude the additive treatment reduces pain while increasing mobility and flexibility.[87] This study revealed STO is an effective treatment for post-surgical patients.[87]

Soft tissue oscillation therapy on an athletic population has focused on ninety-four cases of either surgical wounds, sports traumatic edema, low back pain/sciatic pain, or cervicobrachial pain implemented an STO treatment and concluded that the treatment increased the patient's pain threshold and restored function.[18] In forty-nine sports injuries among fourteen individuals, STO treatment displayed an improvement in VAS scores and a positive effect on the anti-inflammatory process.[19] Symptoms present during lateral ankle sprains have been shown to improve after STO treatment was implemented alongside a conservative treatment with an Aircast brace.[20] Extensibility of the hamstring muscles was improved greater following STO than when ultrasound was applied to the area.[5] Though the evidence is limited, the available studies indicate that STO can be an effect treatment for DOMS.

Frequency

The frequency is an important aspect of STO as it is one of the treatment parameters that can be set at a low, mid, high, or consecutive range. However, many of the studies on STO do not report the frequency utilized in the study. Those that report the frequency use a wide range. The frequency used for hamstring extensibility was set at 150 Hz for 10 minutes and 60 Hz for 5 minutes.[5] In breast tissue, the frequency was 100 Hz for 30 minutes and 30 Hz for 15 minutes.[4] In another study on breast lymphoedema, the frequency was set at a range of 25-80 Hz and 80-200 Hz.[84] The manufacture recommends a frequency of 200 Hz for 10-15 minutes for acute pain control followed by 15 Hz for 2-5 minutes for edema reduction.[2] Therefore, this study used a set frequency of 200 Hz for 10 minutes and 15 Hz for 5 minutes.

Duration

The duration of the treatment time varies depending on the targeted area and the goals of the treatment. Similar to frequency settings, there are limited studies which document the duration length and the results vary. A study on FMS and another on breast lymphoedema reported the duration lasted 45 minutes for each session over the course on 10 weeks and 4 weeks respectively.[3,4] The other study on breast lymphoedema applied treatment for 30 minutes each session for an unknown length of time.[84] For hamstring extensibility, STO was applied one time for 15 total minutes.[5] The manufacture states treatment durations should last 8-15 minutes at least three times a week with acute injuries benefiting from 10-15 minute applications.[2] Therefore, this study provided the treatment for 15 minutes total over the course of four days.

Conclusion

Delayed onset muscle soreness has various theories for its mechanism, however it appears the true mechanism is a combination of these theories.[9,13] The conventional treatments examined for their effectiveness in treating DOMS have been shown to be ineffective. Soft tissue oscillation therapy claims to reduce pain and edema from in soft tissue injuries and has been shown effective when applied to a variety of sports related injuries.[2,18-20] Therefore, the use of STO may provide an effective treatment for DOMS.

CHAPTER III

METHODOLOGY

The purpose of this study was to determine the effectiveness of STO in reducing DOMS. The known signs and symptoms of DOMS include an increase of perceived pain, increased edema, decreased self-reported functional ability, decreased range of motion, and decreased strength.[10-12] An eccentric exercise protocol was performed by each participant to initiate DOMS. Participants received one of two treatment protocols, either STO or control, and report for dependent measurements to be obtained. The outcomes being measured consisted of perceived muscle soreness, upper arm circumference, perceived functional disability, and elbow range of motion.

Participants

Thirty-one healthy, physically active individuals volunteered for this study. To be included in this study, participants must have been between the ages of 18 and 30 and considered physically active as defined by the U.S. Department of Health and Human Services.[88] It is recommended for adults to perform the equivalent of a minimum of 150 minutes of moderate-intense aerobic activity or 75 minutes of vigorous aerobic activity per week.[88] Individuals were excluded from the study if they have had an upper extremity musculoskeletal injury in the previous 6 months, performed upper extremity resistance training in the previous 6 months, acute infections, untreated vascular disorders, cardiac disorders, and pregnancy. Participants provided written informed consent (Appendix A) and the study was approved by the Texas State University

Institutional Review Board (Appendix B) and Texas Lutheran University (Appendix C). Each participant was required to complete a medical health history questionnaire (Appendix D) that was reviewed by the primary researcher before being accepted for the study. Demographic information including gender, age, height, weight, and arm dominance was recorded (Appendix E). Participants were randomly assigned to participate in one of two groups. Both groups completed the same eccentric protocol for inducing DOMS in the non-dominant elbow flexor muscles. Group 1 received the STO treatment and Group 2, the control group, received no form of treatment. Participants were asked to refrain from strenuous exercise, anti-inflammatory or analgesic medications, ice, compression, massage, and stretching for the duration of the study. During the duration of the study, participants were able to seek medical aid at any point in the study investigation. Participants were asked to wear loose fit clothing, including a short sleeve shirt, to all sessions.

Study Design

This study was a randomized control trial performed in the fitness center and athletic training room facilities at Texas Lutheran University located in Seguin, Texas. Randomization was done by a computerized random number generator. Upon entering the research facility, participants received their designated treatment group. The researcher, who was involved in randomly assigning participants to the treatment groups, was blinded to the data collection. During the initial exercise bout (Day 1), demographic measurements consisting of gender, age, height, weight, and arm dominance were recorded. Participants completed baseline measurements for perceived soreness, upper arm circumference, self-reported functional ability, and elbow range of motion for the non-dominant arm before the eccentric exercise protocol was performed (Appendix E). Participants completed the Visual Analog Scale (VAS) for perceived soreness and the Disabilities of the Arm, Shoulder, and Hand (DASH) for self-reported functional ability. A researcher, blind to assigned treatment group, measured elbow range of motion with a standard goniometer, and edema via upper arm circumference with a constant tension tape measurer. Following baseline measurements, participants performed the eccentric exercise protocol to induce DOMS in the elbow flexor muscles of the non-dominant arm. The treatment group received a 15 minute STO treatment on the exercised arm 24, 48, 72, and 96 hours after exercise. Participants assigned to the treatment group completed a familiarization session to familiarize themselves with the treatment. The independent variables were the type of treatment, STO and the control, time, and gender. The dependent variables were perceived muscle soreness, upper arm circumference, self-reported functional ability, and elbow range of motion. Measurements on all participants were taken before and immediately after the eccentric exercise protocol, and on days 1, 2, 3, 4, and 7 post-exercise.

Eccentric Exercise Protocol

The participant's 1 RM was determined concentrically using the estimated 1 RM (Appendix H) with a free weight biceps curl.[89] Participants were seated behind an inclined biceps curl bench to enable full flexion and extension of the elbow while remaining in full supination. The researcher, blind to measurements, observed the participants to ensure proper technique was maintained throughout the lift. Participants performed a warm up consisting of 5-10 repetitions using a light dumbbell followed by a two minute rest. The researcher and participant estimated a dumbbell weight load based on the participants perceived near-max load. The participant began the strength test with this initial weight. The participant was instructed to perform multiple repetitions until they can no longer concentrically lift the weight. If the subject was able to lift the initial weight for 10 or more repetitions, the weight load was increased by 10%. The subject repeated the strength test after a 5 minute rest period.

The eccentric exercise protocol consisted of fatiguing the elbow flexor muscles of the non-dominant arm using 80% of the participants 1 RM as recommended for novice individuals in resistance training programs.[63] Participants were seated behind an inclined biceps curl bench with the elbow in full flexion and supination. The researcher placed the designated weight in the subject's hand. Participants were instructed to lower the weight in a slow, controlled manner until the elbow was in full extension. Once the elbow was in full extension, the researcher returned the weight to the starting position of elbow flexion so there was no concentric action being performed by the participant. This process was performed until fatigue of the elbow flexor muscles was reached. Fatigue was defined as when the subject can no longer control the lowering of the weight in a slow, controlled manner. The researcher gave verbal cues on lowering the weight by counting from 0 at the beginning of movement to 5 at the end of the motion. Participants received verbal encouragement to maximally resist the action until fatigue was reached.

Treatment

Treatment was given 24 hours, 48 hours, 72 hours, and 96 hours post-eccentric exercise protocol. Prior to treatment on each day, measurements of perceived soreness, upper arm circumference, self-reported functional ability, and elbow range of motion were recorded.

Group 1 received the STO treatment manually via the Dynatron X5 device (Dynatronics Corporation, Salt Lake City, UT) using a light massage stroking technique applied by a researcher blind to dependent variable measurements. The STO creates an electrostatic field between the hands of the researcher and the tissue of the participant. This electrostatic field, which alters polarity, attracts and repels the tissue creating a vibratory action.[5] Nitrile rubber gloves (Dynarex, Orangeburg, NY) were worn by the researcher to serve as an insulator between the participant and researcher. The electrical frequency of the device was set at 200 Hz for 10 minutes and 15 Hz for 5 minutes with an output of 90% for a total treatment time of 15 minutes.[2] For the duration of the treatment, the subject laid supine on a treatment table with the involved arm elevated. During the treatment, the researcher performed an effleurage massage to the elbow flexor muscles in the direction of venous return, going distal to proximal. The massage began with light strokes, advance to moderate strokes during the middle of the treatment time, and return to light strokes near the end of the treatment session.

Group 2 was the control and did not receive any treatment. Participants assigned to this group returned to the athletic training room daily to perform the measurements as described above.

Outcome Measures

The dependent variables of perceived soreness, upper arm circumference, self-reported functional ability, and elbow range of motion for the non-dominant arm were recorded on the initial day prior to participation in the study for baseline measurements. Participants performed the eccentric exercise protocol and measurements were retaken. Both groups returned for measurements 1, 2, 3, 4, and 7 days post completing the eccentric exercise protocol. Group 1 received the treatment post measurements. To ensure repeatability and reliability of the elbow range of motion and upper arm circumference, the designated sites were marked with a black permanent marker. Participants were asked to leave these markings until the study was fully completed.

Perceived Soreness

Perceived muscle soreness was assessed using the VAS (Appendix F) designed to measure pain intensity. Subjects recorded their perceived muscle soreness on a horizontal 10 cm line ranging from 0 to 100 with 0 representing no pain and 100 representing worst pain possible. The muscle soreness intensity was considered the distance from the no pain mark to the participant's mark.[11] The VAS was performed upon arrival the first day, after the eccentric exercise protocol was performed to induce DOMS, and before their designated treatment each day afterwards.

Self-reported Functional Ability

Self-reported functional ability was measured using the DASH (Appendix G). The DASH consists of a 30 question questionnaire regarding physical function and symptoms in those with musculoskeletal injuries to the upper extremity. Subjects completed the DASH upon arrival the first day, after the eccentric exercise protocol was performed to induce DOMS, and before their designated treatment each day afterwards. Scores from the DASH were calculated for each day. The score were formulated to range from 0 to 100 with the higher score representing greater disability.[50]

Range of Motion

Range of motion for the elbow joint was measured using a twelve and a half inch standard plastic goniometer (MEDCO, Tonawanda, NY). Elbow extension was measured by having the subject lay supine on a treatment table with the arm parallel to the midline of the body and the forearm in supination. Subjects were instructed to keep the elbow as straight as possible. Three trials were performed and the mean of these scores were calculated for recording. Elbow flexion was measured by having the subject lay supine as described above. Subjects were instructed to flex their elbow by bringing the forearm towards the upper arm while maintaining supination. Three trials were performed and the mean of these scores were calculated for further analysis. Measurements for elbow range of motion were taken upon arrival the first day, after the eccentric exercise protocol was performed to induce DOMS, and before their designated treatment each day afterwards. For both measurements, important landmarks consisting of the humeral line, lateral epicondyle of the humerus, and styloid process of the radius were marked with a black permanent marker as this method has been utilized in previous studies.[52,53] The axis of the goniometer was placed over the lateral epicondyle of the humerus. The stationary arm was parallel to the humerus pointing towards the acromion process. The moving arm was parallel to the radius pointing to the styloid process of the radius. To ensure repeatability and reliability, the designated sites were marked using a black permanent marker and the subjects were instructed to leave the marks until the study was complete.

Upper Arm Circumference

Upper arm circumference was taken to determine changes in girth measurements due to potential edema within the elbow flexor muscles. A constant tension tape measurer (MEDCO, Tonawanda, NY) was used to measure the upper arm circumference at 3, 5, 7, 9, and 11 cm above the elbow crease. These measurements were recorded with the subject's arm relaxed, hanging by the side. Two measurements from each site were averaged. The mean value from the 5 sites were calculated for further analysis. The designated sites were marked with a black permanent marker to ensure reliability and repeatability on each day measurements are taken. This measurement was taken upon arrival the first day, after the eccentric exercise protocol was performed to induce DOMS, and before their designated treatment each day afterwards.

Data Analysis

The dependent variables in this study were: 1) upper arm circumference, 2) range of motion - extension, 3) range of motion - flexion, 4) perceived muscle soreness - VAS, and 5) self-reported functional ability - DASH. The three independent variables were: 1) the treatment (control versus STO treatment), 2) gender (males versus females), and 3) trials (baseline plus post-tests immediately after exercise, 24, 48, 72, and 96 hours after exercise, and 7 days after exercise). The treatment and gender variables are between-subjects variables, while the trial variable is a within-subjects (repeated) variable. A three-way ANOVA with repeated measures was used to determine differences among the treatment and gender combinations, differences among trials, and the interactions among treatments, gender, and trials for each dependent variable. Since all tests between treatments and gender were between two sample means (one degree of freedom), no between-subjects post-hoc tests were needed. Paired t-tests were used to determine individual differences between trials after ANOVA determined overall differences among trials. Greenhouse-Geisser epsilon was used to adjust probability values for any variation in sphericity among the trials. Partial eta2 was used to determine effect size for each statistical test. All statistical significance was defined as $p < .05$.

CHAPTER IV

MANUSCRIPT

Delayed onset muscle soreness (DOMS) is slight pain experienced following excessive exercise and peaks in approximately 48 hours. Though the exact mechanisms are inexplicit, previous research has documented that DOMS is increased after eccentric exercise as compared to isometric or concentric activities.[6-8] The signs and symptoms accompanying DOMS may include increased pain, increased edema, decreased self-reported functional ability, decreased range of motion, and decreased strength.[10-12] Delayed onset muscle soreness decreases physical performance which potentially increasing risk of injury thus supporting the need to determine the most appropriate interventions to alleviate the signs and symptoms of DOMS.[14-17] Numerous investigations have been utilized and studied in order to determine their effectiveness in relieving the wide array of signs and symptoms associated with DOMS.[15-17] These interventions include cryotherapy, massage, stretching, and low-intensity exercise, but none of these previously mentioned treatments have consistently been proven effective.[16,21-23] Soft tissue oscillation therapy (STO) is one therapeutic modality designed specifically to treat soft-tissue injuries and disabilities.

Few studies have investigated the effects of deep oscillation, a comparable intervention to STO, on reducing pain and edema following sport related injuries.[18-20] In previous studies, deep oscillation has been reported as an effective treatment for decreasing pain and swelling associated with various sports injuries.[18-20] One study reported functional performance was restored in patients with surgical wounds, sports traumatic edema, low back pain/sciatic pain, or cervicobrachial pain following deep oscillation treatments.[18] Hamstring extensibility improved unilaterally after deep oscillation when compared to the contralateral leg and again when compared to ultrasound.[5] However, the effects of STO have not been examined on the signs and symptoms of perceived muscle soreness, edema, perceived functional disability, and elbow range of motion associated with DOMS. Therefore, the purpose of this study was to determine the effectiveness of STO in reducing the signs and symptoms of DOMS.

Methods

Participants

Thirty-one healthy and physically active individuals (7 males, 24 females, age = 20.2±1.6 yrs, height = 168.1±10.3 cm, mass = 75.9±19.1 kg) with at least 150 minutes of moderate aerobic exercise per week volunteered to participate in this study. Individuals were excluded from the study if they had an upper extremity musculoskeletal injury in the previous 6 months, performed upper extremity resistance training in the previous 6 months, acute infections, untreated vascular disorders, cardiac disorders, and pregnancy. Participants were randomly assigned to either the treatment group (n = 16) or the control group (n = 15). Each participant provided written informed consent before testing and the study was approved by the University Institutional Review Board.

Experimental Design

A randomized control trial was performed to compare the effects of STO on DOMS after a bout of unaccustomed eccentric exercise, which targeted the elbow flexors.

The randomization was completed by a computerized random number generator and allocation was concealed by investigators in a central location. The investigators responsible for group allocation were blinded to the outcome measurements. The primary investigator, responsible for the outcome measurements, was blinded to group allocation and participants were advised not to reveal their assigned group to the investigator. During the initial day, demographic measurements consisting of gender, age, height, weight, and arm dominance was recorded. Participants performed an identical, maximal eccentric exercise protocol for the elbow flexors in the non-dominant arm. For the treatment group, participants received a 15 minute STO treatment on the exercised arm 24 hours, 48 hours, 72 hours, and 96 hours post-exercise. Therefore, the independent variables were the type of treatment, STO and the control, and time. The dependent variables were perceived muscle soreness, upper arm circumference, self-reported functional ability, and elbow range of motion. Participants reported to the research laboratory on six occasions. Measurements were taken before, immediately after, and on days 1, 2, 3, 4, and 7 post-exercise.

Exercise Protocol

Participants began with a warm up consisting of 5-10 repetitions of biceps curls with a free weight followed by a two minute rest. The exercise protocol consisted of participants performing eccentric biceps curls until fatigue at 80% of their estimated 1 RM.[63,89] Participants were seated behind an inclined biceps curl bench to enable full flexion and extension of the elbow while remaining in full supination. The researcher placed the designated weight in the participant's hand and instructed the participant to lower the weight in a slow, controlled manner until the elbow was in full extension. Once the elbow was in full extension, the researcher returned the weight to the starting position of elbow flexion so there was no concentric action being performed by the participant. This process was performed until fatigue of the elbow flexor muscles was reached. Fatigue was defined as when the subject could no longer control the lowering of the weight in a slow, controlled manner. The researcher gave verbal cues on lowering the weight by counting from 0 at the beginning of movement to 5 at the end of the motion. Each participant received verbal encouragement to maximally resist the action until fatigue was reached.

Soft Tissue Oscillation Treatment

Participants reported back to the research facility at their designated time approximately 24 hours, 48 hours, 72 hours, and 96 hours post-eccentric exercise protocol for treatment. Prior to treatment on each day, measurements for perceived soreness, upper arm circumference, self-reported functional ability, and elbow range of motion were recorded.

Group 1 received the STO treatment manually via the Dynatron X5 device (Dynatronics Corporation, Salt Lake City, UT) using a light massage stroking technique applied by one of two research assistants who were blind to dependent variable measurements. The STO creates an electrostatic field between the researcher and the participant, which alters polarity, attracts and repels the charged cells creating a vibratory action.[5] Nitrile rubber gloves (Dynarex, Orangeburg, NY) were worn by the research assistant to serve as an insulator between the participant and researcher. The electrical frequency of the device was set at 200 Hz for 10 minutes and 15 Hz for 5 minutes with an output of 90% for a total treatment time of 15 minutes.[2] For the duration of the treatment, the subject laid supine on a treatment table with the involved arm elevated. During the treatment, the research assistant performed an effleurage massage to the elbow flexor muscles in the direction of venous return, going distal to proximal. The massage began with light strokes, advance to moderate strokes during the middle of the treatment time, and return to light strokes near the end of the treatment session.

Group 2 was the control and did not receive any treatment. Participants assigned to this group returned to the treatment area daily to perform the measurements as described above.

Outcome Measures

The dependent variables of perceived soreness, upper arm circumference, self-reported functional ability, and elbow range of motion for the non-dominant arm were recorded on the initial day immediately after and 1, 2, 3, 4, and 7 days following the eccentric exercise protocol. To ensure repeatability and reliability of the elbow range of motion and upper arm circumference, the designated sites were marked with a black permanent marker.

Perceived Soreness

Perceived muscle soreness was assessed using the Visual Analog Scale (VAS) designed to measure pain intensity. Subjects recorded their perceived muscle soreness on a horizontal 10 cm line ranging from 0 to 100 with 0 representing no pain and 100 representing worst pain possible. The muscle soreness intensity was considered the distance from the no pain mark to the participant's mark.[11]

Self-reported Functional Ability

Self-reported functional ability was measured using the Disabilities of the Arm, Shoulder and Hand (DASH)[50] and completed upon arrival the first day, after the eccentric exercise protocol was performed to induce DOMS, and before their designated treatment each day afterwards. Scores from the DASH were calculated for each day. The score were formulated to range from 0 to 100 with the higher score representing greater disability.[50]

Range of Motion

Range of motion for the elbow joint was measured using a twelve and a half inch standard plastic goniometer (MEDCO, Tonawanda, NY). Elbow extension and flexion were measured by having the subject lay supine on a treatment table with the arm parallel to the midline of the body and the forearm in supination. Subjects were instructed to keep the elbow as straight as possible to measure extension. For flexion, subjects were instructed to flex their elbow by bringing the forearm towards the upper arm while maintaining supination. Three trials were performed and the mean of these scores were calculated for recording. For both measurements, important landmarks consisting of the humeral line, lateral epicondyle of the humerus, and styloid process of the radius were marked with a black permanent marker as this method has been utilized in previous studies.[52,53]

Upper Arm Circumference

Upper arm circumference was assessed with a constant tension tape measurer (MEDCO, Tonawanda, NY) at 3, 5, 7, 9, and 11 cm above the elbow crease. These measurements were recorded with the subject's arm relaxed, hanging by the side. Two measurements from each site were averaged and the mean value from the 5 sites was calculated for further analysis.

Data Analysis

The dependent variables in this study were: 1) upper arm circumference, 2) range of motion - extension, 3) range of motion - flexion, 4) perceived muscle soreness - VAS, and 5) self-reported functional ability - DASH. The three independent variables were: 1) the treatment (control versus STO treatment), 2) gender (males versus females), and 3) trials (baseline plus post-tests immediately after exercise, 24, 48, 72, and 96 hours after exercise, and 7 days after exercise). The treatment and gender variables are between-subjects variables, while the trial variable is a within-subjects (repeated) variable. A three-way ANOVA with repeated measures was used to determine differences among the treatment and gender combinations, differences among trials, and the interactions among treatments, gender, and trials for each dependent variable. Since all tests between treatments and gender were between two sample means (one degree of freedom), no between-subjects post-hoc tests were needed. Paired t-tests were used to determine individual differences between trials after ANOVA determined overall differences among trials. Greenhouse-Geisser epsilon was used to adjust probability values for any variation in sphericity among the trials. Partial eta2 was used to determine effect size for each statistical test. All statistical significance was defined as $p < .05$.

Results

All raw data (mean ± SD) collected throughout the experimental conditions are presented in the Table 1 (Appendix I). MANOVA indicated no significant pre-test differences between the treatment and control groups for the five dependent variables, Wilk's Lambda = 0.964, $F(5,23) = 0.17$, $p = .971$, indicating that the random assignment of subjects to treatment groups effectively prevented any pre-test performance bias.

Repeated measures ANOVA indicated no significant overall change in upper arm circumference among trials, Greenhouse-Geisser epsilon = 0.43, $F(6, 162) = 1.28$, $p = .287$, partial eta2 = .045, a moderately small effect. No significant difference in change in upper arm girth between treatment groups across trials was observed, $F(6, 162) = 0.31$, $p = .787$, partial eta2 = .011, a small effect. Also, there was no significant difference in change in upper arm girth between genders across trials, $F(6, 162) = 0.35$, $p = .757$, partial eta2 = .013, a small effect.

For range of motion – extension, a significant overall change was observed among trials, Greenhouse-Geisser epsilon = 0.30, $F(6, 162) = 3.74$, $p = .036$, partial eta2 = .122, a moderately large effect. Compared to baseline levels before exercise, paired t-tests indicated significant increases in range of motion – extension immediately post-exercise ($p= .003$), 24 hours after exercise ($p< .001$), 48 hours after exercise ($p< .001$), 72 hours after exercise ($p< .001$), and 96 hours after exercise ($p= .008$). Range of motion – extension did not return to baseline levels until 7 days after exercise ($p= .319$). Figure 1 demonstrates the changes in range of motion – extension across trials. However, no significant difference in change in range of motion - extension between treatment groups across trials was observed, F(6, 162) = 0.96, p = .381, partial eta2 = .034, a moderately small effect. Also, there was no significant difference in change in range of motion – extension between genders across trials, F(6, 162) = 0.57, p = .551, partial eta2 = .021, a small effect.

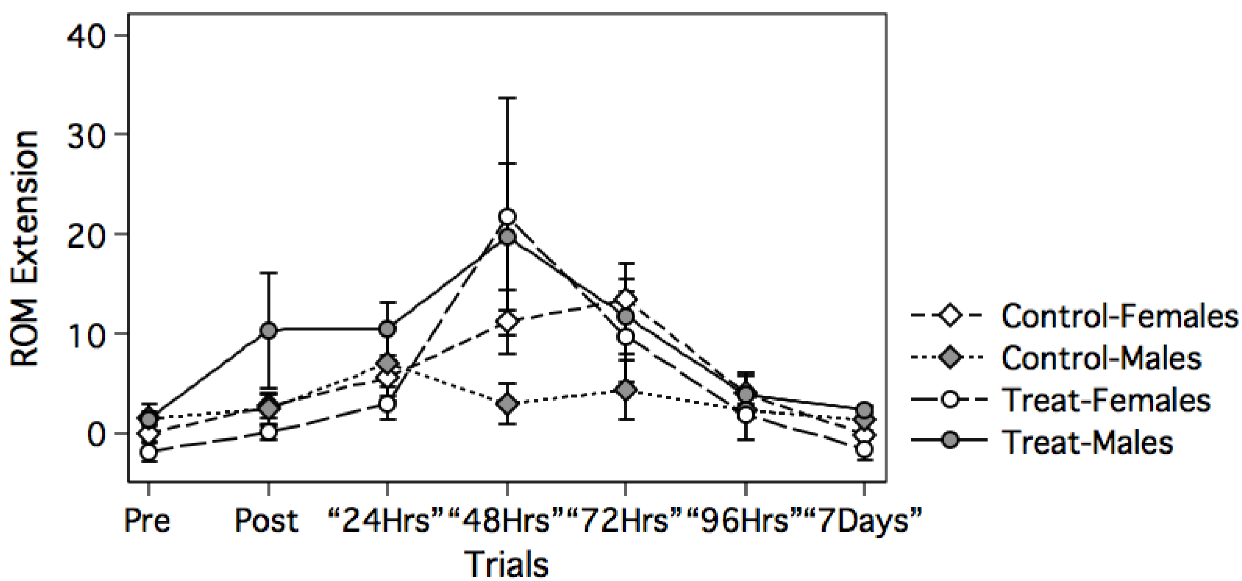

Figure 1: Range of Motion Extension

A significant overall change in range of motion - flexion was indicated among trials, Greenhouse-Geisser epsilon = 0.55, F(6, 162) = 11.39, p < .001, partial eta2 = .297, a very large effect. Compared to baseline levels before exercise, paired t-tests indicated significant decreases in range of motion – flexion immediately post-exercise (p< .001), 24 hours after exercise (p< .001), 48 hours after exercise (p< .001), 72 hours after exercise (p< .001), and 96 hours after exercise (p= .002). Range of motion – flexion did not return to baseline levels until 7 days after exercise (p= .358). No significant difference in change in range of motion - flexion between treatment groups across trials was observed, $F(6, 162) = 0.65$, $p = .597$, partial eta2 = .024, a moderately small effect. Also, there was no significant difference in change in range of motion - flexion between genders across trials, $F(6, 162) = 0.99$, $p = .408$, partial eta2 = .035, also a moderately small effect.

A significant overall change in VAS was observed among trials, Greenhouse-Geisser epsilon = 0.49, $F(6, 162) = 8.95$, $p < .001$, partial eta2 = .249, a very large effect. Compared to baseline levels before exercise, paired t-tests indicated significant increases in VAS immediately post-exercise ($p< .001$), 24 hours after exercise ($p< .001$), 48 hours after exercise ($p< .001$), 72 hours after exercise ($p< .001$), and 96 hours after exercise ($p= .001$). VAS values did not return to baseline levels until 7 days after exercise ($p= .335$). However, no significant difference in change in VAS between treatment groups across trials was observed, $F(6, 162) = 0.25$, $p = .854$, partial eta2 = .009, a small effect. Also, there was no significant difference in change in VAS between genders across trials, $F(6, 162) = 2.44$, $p = .071$, partial eta2 = .083, a moderate effect.

Significant overall change was indicated in DASH among trials, Greenhouse-Geisser epsilon = 0.38, $F(6, 162) = 7.11$, $p = .001$, partial eta2 = .208, a very large effect. Compared to baseline levels before exercise, paired t-tests indicated significant increases in DASH immediately post-exercise ($p< .001$), 24 hours after exercise ($p< .001$), 48 hours after exercise ($p< .001$), 72 hours after exercise ($p< .001$), and 96 hours after exercise ($p= .006$). DASH values did not return to baseline levels until 7 days after exercise ($p= .062$). Figure 2 demonstrates the changes in DASH across trials. However, no significant difference in change in DASH between treatment groups across trials was observed, F(6, 162) = 0.24, p = .815, partial eta2 = .008, a small effect. Also, there was no significant difference in change in DASH between genders across trials, F(6, 162) = 1.53, p = .222, partial eta2 = .054, a moderate effect.

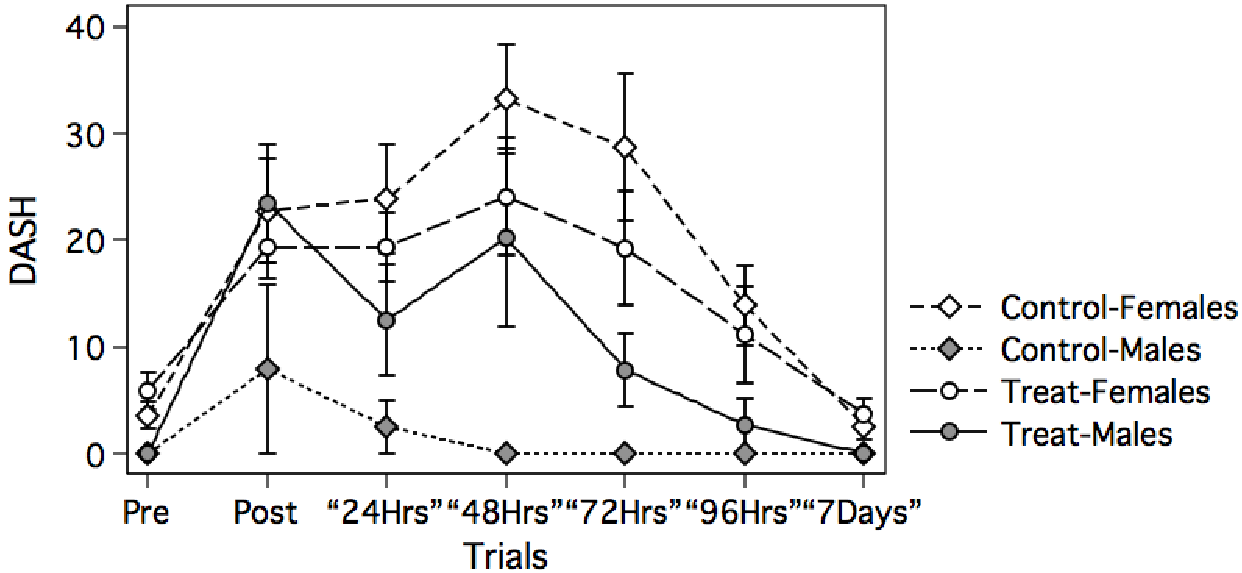

Figure 2: DASH

Discussion

Practitioners have proposed the effectiveness of STO in reducing symptoms of DOMS following intense bouts of exercise. This study examined that perceived soreness, self-reported functional ability, and elbow extension and flexion range of motion scores were increased after the eccentric exercise protocol with no significant differences between treatment groups, indicating that DOMS was effectively induced. All measurements, with the exception of upper arm circumference, were significantly increased for 96 hours and did not return to baseline until 7 days post-exercise, thus, illustrating the effectiveness of the exercise protocol in inducing muscle soreness. However, there were no significant differences between the treatment group and control group across trials, indicating that STO is not effective in alleviating DOMS.

The results of this study contradict previous investigations which administered STO as a treatment for acute musculoskeletal injuries with primary outcomes of pain and edema.[18,19,20] Although previous investigations have reported positive treatments effects from STO, there are several inconsistencies in the research designs that could affect the interpretations of the results. Investigators examining ankle sprains have reported significant improvements in a numerical rating scale for pain and edema after STO treatment, when accompanied by standard treatment and medication and immobilization with an ankle brace.[19,20] Individuals with either post-injury edema, low back, neck or shoulder pain reported STO as an effective method in raising patient's pain threshold.[18] One confounding variable in previous investigations is the time period when the measurements were recorded.[18,19,20] In this study, the dependent variables were measured at baseline, immediately after exercise, before the STO treatment at 24, 48, 72, and 96 hours post-exercise, and on day 7 post-exercise. Previous studies failed to report these timed intervals. Another confounding variable in previous research is the lack of a control group.[18,19,20] Without a control group, the treatment effects cannot be directly attributed to the STO treatment. This study included both a treatment and control group, therefore it was possible to determine if the differences could be credited to the STO treatment.

The differences in the perceived soreness measurement between this study and previous investigations could be contributed to the utilization of STO in addition to standard treatments. In this study, STO was the sole treatment to previous contamination from other forms of rehabilitation. Previous investigations administered additional treatment, such as including physiotherapy, cryotherapy, and immobilization, in addition to STO preventing direct assumption to the effectiveness of STO.[19,20] An increased pain threshold after STO treatment was observed in patients who received a nonsteroidal anti-inflammatory medication which could alter the patient's sensation of pain.[18] When other treatments are performed in combination with STO, it is difficult to determine whether STO truly decreased muscle soreness or pain.

In this investigation, the presence of edema was determined by upper arm circumference with a constant tension tape measure which is supported by previous studies in edema reabsorption.[19,45-48] To our knowledge, no other study investigating STO has objectively measured edema as well as self-reporting functional ability using the DASH in patients with DOMS. Although no significant treatment effect for self-reported functional ability was reported in this study, the DASH has been proven as a valid testing instrument and is a useful quality of life tool for the entire upper extremity.[50] Additionally, previous STO study did not investigate the effects of the treatment on range of motion. In this study, elbow extension and flexion range of motion were recorded with a goniometer to determine limitations in motion and has been validated in other studies.[41,52-54] Though STO did not have a significant effect on elbow range of motion, it remains an important variable to measure since it is a common characteristic of DOMS.

Previous authors have used STO protocols of various durations and frequencies.[18,19] In ninety-four cases of either surgical wounds, sports traumatic edema, low back pain/sciatic pain, or cervicobrachial pain, treatment was provided three times a week for 20 minutes.[18] In forty-nine sports injuries among fourteen individuals, STO treatment was administered once a day for 5-30 minutes at different frequencies.[19] In the current study, the treatment protocol consisted of 200 Hz for 10 minutes and 15 Hz for 5 minutes with an output of 90% for a total treatment time of 15 minutes on four consecutive days. These durations and frequencies were selected based upon manufacture suggestions and resembles a reasonable treatment duration in therapeutic rehabilitation.[2] It is impossible to infer the inconsistent results upon the set frequencies because no other studies reported the frequencies used.

This investigation has several limitations which should to be suggestions for improvements in future studies. An increase in the number of participants would increase the power of the study and possibly result in significant differences between treatment groups. Two single specific frequencies were set for the treatment protocol. Future studies should investigate the effects of a high scan frequency (120-200 Hz) on DOMS. This frequency setting is also recommended for acute pain and edema.[2] It would be beneficial to record all dependent variable measurements before and after treatment in order to determine both acute and long term effects. The chosen resistance of 80% of the participants estimated 1 RM is also a limitation. With a lower level of resistance, the time to fatigue is increased. Therefore, it takes more self-motivation and verbal cues to complete the task properly.

Conclusion

We investigated the effects of STO on the signs and symptoms of perceived muscle soreness, edema, perceived functional disability, and elbow range of motion associated with DOMS. The eccentric exercise protocol implemented effectively induced muscle soreness and decreased self-reported functional ability and elbow range of motion. However, there were no significant differences between the STO treatment group and the control group in respects to DOMS. Based upon the results of this study, it was concluded that STO treatment is not an effective treatment modality in alleviating DOMS.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

The purpose of this study was to determine the effectiveness of STO in reducing the signs and symptoms of perceived muscle soreness, muscle edema, perceived functional disability, and joint range of motion associated with DOMS. Thirty-one healthy and physically active individuals with at least 150 minutes of moderate aerobic exercise per week volunteered to participate in this study. A randomized control trial was performed to compare the effects of STO versus a control group on DOMS after a bout of unaccustomed eccentric exercise, which targeted the elbow flexors. The dependent variables of perceived muscle soreness, upper arm circumference, self-reported functional ability, and elbow range of motion were measured at baseline, immediately after, and on days 1, 2, 3, 4, and 7 post-exercise.

The data were analyzed through a repeated measures ANOVA to determine differences between treatment group and control group in terms of altering the time to recovery from DOMS. Perceived soreness, self-reported functional ability, and elbow extension and flexion range of motion measurements were increased up to 96 hours after the eccentric exercise protocol indicating that DOMS was effectively induced. However, there were no differences between the treatment group and control group across trials indicating STO is not effective in alleviating DOMS.

Recommendations

Given the results of this investigation, it was concluded that STO treatment is not effective in relieving DOMS. Caution should be observed in generalizing from these results. Future research needs to investigate STO in treating the signs and symptoms of DOMS in order to efficiently analyze and compare the results of this study. Future investigations should compare the effects of STO on DOMS in large muscle groups and small muscle groups. An increase in the number of participants recruited for the study should be increased to strengthen the power and could produce significant differences between treatment groups. Measurements for dependent variables should be recorded at baseline and immediately pre and post STO treatment until return to baseline in order to determine if the treatment produces an acute and/or long term effect. At the current time, it is concluded that STO treatment is not effective in relieving DOMS.

APPENDIX A
CONSENT FORM

The Effects of Soft Tissue Oscillation Therapy on Delayed Onset Muscle Soreness

Department of Health and Human Performance
Texas State University

The principle investigators are Kelsey Henry (kelsey_henry@txstate.edu or 417-342-0074) and Dr. Jack Ransone (ransone@txstate.edu or 512-245-8176) at Texas State University. Should you have any questions or concerns regarding this research study, please contact us by email or phone.

Purpose of the Study

The purpose of this study is to determine the effects the effectiveness of soft tissue oscillation therapy (Dynatron X5) in reducing the signs and symptoms of delayed onset muscle soreness including perceived muscle soreness, edema, perceived functional disability, and elbow range of motion. You have been asked to voluntarily participate in this research study to assist us in understanding the effects of Soft Tissue Oscillation Therapy on delayed onset muscle soreness.

Procedures

Subjects will voluntarily be selected to participate in the study based upon their age (18-30 years old) and their physical activity (a minimum of 150 minutes of moderate aerobic exercise per week). Participants will be asked to refrain from strenuous exercise, anti-inflammatory or analgesic medications, ice, compression, and stretching for the duration of the study. Please wear loose fit clothing, including a short sleeve shirt, to all sessions. Your participation in the study will take 6 days for approximately 30-45 minutes per day in order to conduct tests and provide the assigned treatment. The following procedures will be conducted in the fitness center and athletic training room facilities at Texas

Lutheran University located in Seguin, Texas.

1. Demographic measurements, consisting of gender, age, height, weight, and arm dominance, will be recorded. A medical health history questionnaire must be filled out and reviewed by the principal investigator before acceptance is granted. The medical health history questionnaire will assess your medical history and upper extremity orthopedic exam. This form will be completed one time before the start of research and will take 2 minutes to finish.
    a. Orthopedic Exam – testing to ensure you have no injuries to the upper extremity with range of motion and general strength examined.
    b. Range of motion:
        i. Shoulder – raise arm forward, backward, and to the side within the normal limits with no pain
        ii. Elbow – flex and extend within the normal limits with no pain
        iii. Wrist/hand – move up, down, and to the sides within the normal limits with no pain
    c. Strength:
        i. Shoulder – raise arm forward, backward and to the side within the normal limits while resistance is applied by the principal investigator
        ii. Elbow – flex and extend within the normal limits while resistance is applied
        iii. Wrist/hand – move up, down, and to the sides within the normal limits while resistance is applied
2. You will be instructed to complete baseline measurements for:
    a. Visual Analog Scale (VAS) – This is a measure of the amount of perceived muscle soreness during physical activity. You will mark a line on the 10 cm line in response to the soreness you feel. This will be performed at baseline, immediately, 24, 48, 72, 96 hours, and 7 days after exercise.
    b. Upper arm circumference – This is a measure of your muscle size along the elbow flexors at 3, 5, 7, 9, and 11 centimeters above the fold in the

elbow. Two measurements will be takes at each site. This measurement will be taken at baseline, immediately, 24, 48, 72, 96 hours, and 7 days after exercise.

   c. DASH – This is a 30 question questionnaire which asks about your symptoms and ability to perform certain daily activities. The questionnaire should take less than 5 minutes to complete. This will be performed at baseline, immediately, 24, 48, 72, 96 hours, and 7 days after exercise.
   d. Elbow range of motion – This is a measure of your ability to perform normal elbow motions. You will be instructed to lie on your back and keep the elbow as straight as possible. Three trials will be performed and recorded. Then, you will be instructed to flex your elbow by bringing the forearm towards the upper arm. Three trials will be performed and recorded. This will be performed at baseline, immediately, 24, 48, 72, 96 hours, and 7 days after exercise.

3. Eccentric Exercise Protocol
   a. The first step will be determining your maximal strength.
   b. You will perform as many bicep curls as many times as possible.
   c. Your maximal strength will be determined using a weight table.
   d. The initial exercise will consist of performing certain motions of a bicep curls using a dumbbell at 80% of your maximal strength.
   e. You will begin by sitting behind an inclined bench with the elbow fully flexed (start position).
   f. The investigator will place the dumbbell in your hand.
   g. You will slowly lower the weight, in a controlled manner, until your arm is fully extended (end position).
   h. The investigator will return the dumbbell back to the start position.
   i. You will continue this process until you can no longer lower the dumbbell in a slow and controlled manner.

4. Treatment
   a. You will be treated at 24, 48, 72, and 96 hours after the exercise.

i. Soft Tissue Oscillation:

1. The investigator will provide a massage to the elbow flexors with the Dynatron X5 device.
2. You will lie on a table with the involved arm elevated for the duration of the treatment.
3. Each treatment will be applied for 15 minutes.

ii. Control:

1. No treatment will be received.

b. Participants will return for treatment at a designated time set up by the principal investigator after having discussed mutual availability on the initial day.

<u>Foreseeable Risks/Discomforts</u>

1. The subject may experience discomfort in the arm during testing and several days after the exercise. Discomfort may include muscle soreness, swelling, and decreased range of motion.
2. The subject's skin may become irritated from the soft tissue oscillation treatment. This irritation may include a reaction to the nitrile gloves worn by the investigator during treatment.

These risks are not considered to be life threatening and should resolve within 7 days following the exercise. The risks will be minimized as much as possible by the principal investigator who is a licensed healthcare provider. Participants may seek medical aid at any time during the duration of the study. If a medical emergency arises, emergency services will be contacted. The participant will be responsible for covering any medical expenses. No other physical or psychological risks are associated with this study.

<u>Benefits</u>

The benefits from this study will provide information for the medical community and the participants by:

1. Seeing the possible benefits of soft tissue oscillation
2. Discovering a possible treatment for delayed onset muscle soreness

3. You will be compensated by means of a $10 gift card when you have fully completed the study.

Confidentiality

Participants will be issued a number in order to track each participant's data collection through the course of the study. Personal information (ie. name and contact information) and collected data will be kept in separate, restricted locations. These locations will be in locked cabinets in the Texas Lutheran University athletic training room/offices. Access to these files is only for the principal investigator Kelsey Henry, Texas Lutheran University athletic trainer Brian Coulombe, and committee members Dr. Jack Ransone, Dr. John Walker, and Dr. Robert Pankey. All information will be destroyed after the completion of the study.

Participation

Your participation is voluntary. You have the right to discontinue the study at any time without penalty or loss of benefits to which you are otherwise entitled. If you do withdraw, personal information and data will be returned to you or destroyed. You may choose to not to answer any question for any reason.

If requested, participants will receive a summary of the study upon completion of the study.

This project IRB [#2014W5927] was approved by the Texas State IRB on [01/06/15]. Pertinent questions or concerns about the research, research participants' rights, and/or research-related injuries to participants should be directed to the IRB chair, Dr. Jon Lasser (512-245-3413 - lasser@txstate.edu) and to Becky Northcut, Director, Research Integrity & Compliance (512-245-2314 - bnorthcut@txstate.edu).

Authorization

“I have read and received a copy of this consent form. I have been given sufficient opportunity to ask any questions about this study. I understand that I can withdraw from the study at any time without penalty.”

For any questions or concerns, please contact Kelsey Henry by phone 417-342-0074 or email kelsey_henry@txstate.edu.

______________________________	________________________
Participant Name Printed	Phone Number
______________________________	________________________
Signature	Date
______________________________	________________________
Principle Investigator Signature	Date

APPENDIX B

TEXAS STATE UNIVERSITY IRB APPROVAL FORM

TEXAS STATE UNIVERSITY

SAN MARCOS

The rising STAR of Texas

Institutional Review Board Application

Certificate of Approval

Applicant: Kelsey Henry

Application Number : 2014W5927

Project Title: The Effects of Soft Tissue Oscillation Therapy on Delayed Onset Muscle Soreness

Date of Approval: 01/06/15 12:57:07

Expiration Date: 01/06/16

Assistant Vice President for Research and Federal Relations

Chair, Institutional Review Board

APPENDIX C

TEXAS LUTHERAN UNIVERSITY APPROVAL FORM

ATHLETIC TRAINING

TEXAS LUTHERAN UNIVERSITY

1000 WEST COURT STREET • SEGUIN, TEXAS 78155 • FAX: 830-372-8135 • WEB: www.tlu.edu

Brian Coulombe, Program Director • 830-372-6952 • bcoulombe@tlu.edu
Tim Kent, Head Athletic Trainer • 830-372-8133 • tkent@tlu.edu

December 10, 2014

Texas State University
Graduate Research Department

Thesis Committee,

I am aware that Kelsey Henry will be using facilities at Texas Lutheran University to collect data for a Masters level thesis research project. Use of these facilities has been authorized pending institutional review approval through the appropriate process at Texas State University. In the event that the subject pool for this research will be from TLU students, Ms. Henry will have to complete an abbreviated institutional review on this campus. I have discussed this project and its different aspects with Ms. Henry and have agreed to be her liaison on this campus .

If the committee requires further information from me, I can be contacted via email at bcoulombe@tlu.edu

Brian Coulombe
Director, Athletic Training Education

APPENDIX D

MEDICAL HISTORY AND UPPER EXTREMITY

ORTHOPEDIC EXAM

Please answer the following questions to the best of your abilities.

Physical Activity

1.	Are you physically active (i.e. do you exercise at least 30 minutes on at least 5 days per week)	Yes	No
2.	Have you been physically active for at least the past 6 months?	Yes	No
3.	Have you participated in weight training during the past 6 months?	Yes	No

Symptoms – Do you:

1.	Experience chest discomfort during exercise	Yes	No
2.	Experience shortness of breath with exercise	Yes	No
3.	Have unexplained dizziness/fainting	Yes	No
4.	Have extra or skipped heart beats?	Yes	No
5.	In the past year, have you been told that you have		
6.	high blood pressure?	Yes	No
7.	Have swelling in the legs or feet?	Yes	No
8.	Experience numbness or weakness in the legs or arms?	Yes	No

Other Health Issues

1.	Have you recently been diagnosed with an infection?	Yes	No
2.	Have you ever been diagnosed with a cardiovascular disorder?	Yes	No
3.	Are you or do you think you may be pregnant?	Yes	No
4.	Are there any other conditions that may impede		
5.	your ability to exercise?	Yes	No
6.	Have you ever been told not to exercise by a health care provider?	Yes	No

Upper Extremity Orthopedic Exam

	Range of Motion		**Strength**	
	Pass	Fail	Pass	Fail
Shoulder				
Flexion				
Extension				
Abduction				
Elbow				
Flexion				
Extension				
Wrist/Hand				
Flexion				
Extension				
Ulnar Deviation				
Radial Deviation				

I verify that the information included on this form is correct and factual to the best of my knowledge.

______________________________ ______________

Signature of Participant **Date**

______________________________ ______________

Signature of Principal Investigator **Date**

APPENDIX E

SUBJECT INFORMATION SHEET

Date:______________ **Subject Identification Number:________________**

Demographic Information:

Height (cm):________ **Weight (lbs):_______** **Arm Dominance:** Right/Left

Age:_________ **Gender:** Male/Female

Ortho-screen of Upper Extremity: Pass/Fail

<u>Baseline Measurements</u>:

Edema (cm)

	1st	2nd	Average
3 cm			
5 cm			
7 cm			
9 cm			
11 cm			

Range of Motion

	1st	2nd	3rd	Average
Extension				
Flexion				

Estimated 1 RM (lbs)

Selected Weight	
Number of Lifts	
Estimated 1 RM	

VAS:______________

DASH:_____________

Immediately Following Eccentric Exercise Protocol

Edema (cm)

	1st	2nd	Average
3 cm			
5 cm			
7 cm			
9 cm			
11 cm			

Range of Motion

	1st	2nd	3rd	Average
Extension				
Flexion				

VAS:______________

DASH:____________

<u>24 Hours Post Eccentric Exercise Protocol</u>

Yes	No	**Question:** Since the beginning of this study, have you
		Utilized any form of medication to alleviate the discomfort you are experiencing?
		Utilized any form of treatment, including: • Ice • Compression • Massage • Stretching

Edema (cm)

	1st	**2nd**	**Average**
3 cm			
5 cm			
7 cm			
9 cm			
11 cm			

Range of Motion

	1st	**2nd**	**3rd**	**Average**
Extension				
Flexion				

VAS:______________

DASH:____________

<u>48 Hours Post Eccentric Exercise Protocol</u>

Yes	No	**Question:** Since the beginning of this study, have you
		Utilized any form of medication to alleviate the discomfort you are experiencing?
		Utilized any form of treatment, including: • Ice • Compression • Massage • Stretching

Edema (cm)

	1st	2nd	Average
3 cm			
5 cm			
7 cm			
9 cm			
11 cm			

Range of Motion

	1st	2nd	3rd	Average
Extension				
Flexion				

VAS:______________

DASH:____________

72 Hours Post Eccentric Exercise Protocol

Yes	No	**Question:** Since the beginning of this study, have you
		Utilized any form of medication to alleviate the discomfort you are experiencing?
		Utilized any form of treatment, including: • Ice • Compression • Massage • Stretching

Edema (cm)

	1st	**2nd**	**Average**
3 cm			
5 cm			
7 cm			
9 cm			
11 cm			

Range of Motion

	1st	**2nd**	**3rd**	**Average**
Extension				
Flexion				

VAS:______________

DASH:____________

<u>96 Hours Post Eccentric Exercise Protocol</u>

Yes	**No**	**Question:** Since the beginning of this study, have you
		Utilized any form of medication to alleviate the discomfort you are experiencing?
		Utilized any form of treatment, including: • Ice • Compression • Massage • Stretching

Edema (cm)

	1st	**2nd**	**Average**
3 cm			
5 cm			
7 cm			
9 cm			
11 cm			

Range of Motion

	1st	**2nd**	**3rd**	**Average**
Extension				
Flexion				

VAS:______________

DASH:____________

7 Days Post Eccentric Exercise Protocol

Yes	No	**Question:** Since the beginning of this study, have you
		Utilized any form of medication to alleviate the discomfort you are experiencing?
		Utilized any form of treatment, including: • Ice • Compression • Massage • Stretching

Edema (cm)

	1st	2nd	Average
3 cm			
5 cm			
7 cm			
9 cm			
11 cm			

Range of Motion

	1st	2nd	3rd	Average
Extension				
Flexion				

VAS:______________

DASH:____________

Yes	No	
		Has the subject completed all aspects of the study?

APPENDIX F

VISUAL ANALOG SCALE

Subject Identification Number: ___________ Test Session: _____________

Visual Analog Scale (VAS)*

No pain Worst Pain Possible

*Adapted from: Cleather DJ, Guthrie SR. Quantifying delayed-onset muscle soreness: A comparison of unidimensional and multidimensional instrumentation. *J Sports Sci.* 2007; 25(8): 845-850

APPENDIX G

THE DASH

Disabilities of the Arm, Shoulder and Hand (The DASH)*

Instructions:

This questionnaire asks about your symptoms along with your ability to perform a variety of activities.

Please answer every question based upon your condition in the past day by circling the corresponding number.

If you have not had the opportunity to perform the activity in the past day, please make the best estimated guess as to what response would be the most accurate.

Please answer accurately and honestly based upon your ability.

Please rate your ability to do the following activities in the past day by circling the number found below the corresponding response.

	No Difficulty	Mild Difficulty	Moderate Difficulty	Severe Difficulty	Unable
1. Open a tight or new jar	1	2	3	4	5
2. Write	1	2	3	4	5
3. Turn a key	1	2	3	4	5
4. Prepare a meal	1	2	3	4	5
5. Push open a heavy door	1	2	3	4	5
6. Place an object on a shelf above your head	1	2	3	4	5
7. Do heavy household chores (e.g., wash walls, wash floors)	1	2	3	4	5
8. Garden or do yard work	1	2	3	4	5
9. Make a bed	1	2	3	4	5
10. Carry a shopping bag or briefcase	1	2	3	4	5
11. Carry a heavy object (over 10 lbs.)	1	2	3	4	5
12. Change a lightbulb overhead	1	2	3	4	5
13. Wash or blow dry your hair	1	2	3	4	5
14. Wash your back	1	2	3	4	5
15. Put on a pullover sweater	1	2	3	4	5
16. Use a knife to cut food	1	2	3	4	5
17. Recreational activities which require little effort (e.g., cardplaying, knitting)	1	2	3	4	5
18. Recreational activities in which you take some force or impact through your arm, shoulder, or hand (e.g., golf, hammering, tennis)	1	2	3	4	5
19. Recreational activities in which you move your arm freely (e.g., playing Frisbee, badminton)	1	2	3	4	5
20. Manage transportation needs (getting from one place to another)	1	2	3	4	5
21. Sexual activities	1	2	3	4	5

	Not At All	Slightly	Moderately	Quite A Bit	Extremely
22. During the past day, to what extent has your arm, shoulder, or hand problem interfered with your normal social activities with family, friends, neighbors, or groups?	1	2	3	4	5
	Not At All	**Slightly**	**Moderately**	**Quite A Bit**	**Extremely**
23. During the past day, were you limited in your work or other regular daily activities as a result of your arm, shoulder, or hand problem?	1	2	3	4	5
Please rate the severity of the following symptoms in the last day					
	None	**Mild**	**Moderate**	**Severe**	**Extreme**
24. Arm, shoulder or hand pain	1	2	3	4	5
25. Arm, shoulder or hand pain when you performed any specific activity	1	2	3	4	5
26. Tingling (pins and needles) in your arm, shoulder or hand	1	2	3	4	5
27. Weakness in your arm, shoulder or hand	1	2	3	4	5
28. Stiffness in your arm, shoulder or hand	1	2	3	4	5

	No Difficulty	Mild Difficulty	Moderate Difficulty	Severe Difficulty	So Much Difficulty That I Can't Sleep
29. During the past da, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand?	1	2	3	4	5
	Strongly Disagree	**Disagree**	**Neither Agree Nor Disagree**	**Agree**	**Strongly Agree**
30. I feel less capable, less confident, or less useful because of my arm, shoulder or hand problem	1	2	3	4	5

DASH Disability/Symptom Score = $\left[\left(\frac{\text{sum of n responses}}{n}\right) - 1\right] \times 25$

Where n is equal to the number of completed responses

A DASH score may **not** be calculated if there are greater than 3 missing items.

*Adapted from: Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: The DASH (disabilities of the arm, shoulder, and head). Am J Ind Med. 1996; 29: 602-608

APPENDIX H

ESTIMATED 1 RM

Table 26.1 Estimating One-Repetition Maximum

% of 1 RM:	100.0	93.5	91.0	88.5	86.0	83.8	81.0	78.5	76.0	73.5
Repetitions	1	2	3	4	5	6	7	8	9	10
Weight lifted (lb):	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	5.0	4.7	4.5	4.4	4.3	4.2	4.1	3.9	3.8	3.7
	10.0	9.4	9.1	8.9	8.6	8.4	8.2	7.9	7.6	7.4
	15.0	14.0	13.7	13.3	12.9	12.5	12.2	11.8	11.4	11.0
	20.0	18.7	18.2	17.7	17.2	16.7	16.2	15.7	15.2	14.7
	25.0	23.4	22.8	22.1	21.5	20.9	20.2	19.6	19.0	18.4
	30.0	28.1	27.3	26.6	25.8	25.1	24.3	23.6	22.8	22.1
	35.0	32.7	31.9	31.0	30.1	29.2	28.4	27.5	26.6	25.7
	40.0	37.4	36.4	35.4	34.4	33.4	32.4	31.4	30.4	29.4
	45.0	42.1	41.0	39.8	38.7	3706	36.5	35.3	34.2	33.1
	50.0	46.8	45.4	44.3	43.0	41.8	40.5	39.3	38.0	36.8
	55.0	51.4	50.1	48.7	47.3	45.9	44.6	43.2	41.8	40.4
	60.0	56.1	54.6	53.1	51.6	50.1	48.6	47.1	45.6	44.1
	65.0	60.8	59.2	57.5	55.9	54.3	52.7	51.0	49.4	47.8
	70.0	65.5	63.7	62.0	60.2	58.5	56.7	55.0	53.2	51.5
	75.0	70.1	683.	66.4	64.5	62.6	60.8	58.9	57.0	55.1
	80.0	74.8	72.8	70.8	68.8	66.8	64.8	62.8	60.8	58.8
	85.0	79.5	77.4	75.2	73.1	71.0	68.9	66.7	64.6	62.5
	90.0	84.2	81.9	79.7	77.4	75.2	72.9	70.7	68.4	66.2
	95.0	88.8	86.5	84.1	81.7	79.3	77.0	74.6	72.2	69.8
	100.0	93.5	91.0	88.5	86.0	83.5	81.0	78.5	76.0	73.5
	105.0	98.2	95.6	92.9	90.3	87.7	85.1	82.4	79.8	77.2
	110.0	102.9	100.1	97.4	94.6	91.9	89.1	86.4	83.6	80.9
	115.0	107.5	104.7	101.8	98.9	96.0	93.2	90.3	87.4	84.5
	120.0	112.2	109.2	106.2	103.2	100.2	97.2	94.2	91.2	88.2
	125.0	116.9	113.8	110.6	107.5	104.4	101.3	98.1	95.0	91.9
	130.0	121.6	118.3	115.1	111.8	108.6	105.3	102.1	98.8	95.6
	135.0	126.2	122.9	119.5	116.1	112.7	109.4	105.0	102.6	99.2
	140.0	130.9	127.4	123.9	120.4	116.9	113.4	109.9	106.4	102.9
	145.0	135.6	132.1	128.3	127.7	121.1	117.5	113.8	110.2	106.6
	150.0	140.3	136.5	132.8	129.0	125.3	121.5	117.8	114.0	110.3
	155.0	144.9	141.1	137.2	133.3	129.4	125.6	121.7	117.8	113.9
	160.0	149.6	145.6	141.6	137.6	133.6	129.6	125.6	121.6	117.6
	165.0	154.3	150.2	146.0	141.9	137.8	133.7	129.5	125.4	121.3
	170.0	159.0	154.7	150.5	146.2	142.0	137.7	133.5	129.2	125.0
	175.0	163.6	159.3	154.9	150.5	146.1	141.8	137.4	133.0	128.6
	180.0	168.3	163.8	159.3	154.8	150.3	145.8	141.8	137.4	132.3
	185.0	173.0	168.4	163.7	159.1	154.5	149.9	145.2	140.6	136.0
	190.0	171.7	172.9	168.2	163.4	158.7	153.9	149.2	144.4	139.7
	195.0	182.3	177.5	172.6	167.7	162.8	158.0	153.1	148.2	143.3

(continued)

Table 26.1 (continued)

% of 1 RM:	100.0	93.5	91.0	88.5	86.0	83.8	81.0	78.5	76.0	73.5
Repetitions	1	2	3	4	5	6	7	8	9	10
Weight lifted (lb):	200.0	187.0	182.0	177.0	172.0	167.0	162.0	157.0	152.0	147.0
	205.0	191.7	186.6	181.4	176.3	171.2	166.1	160.9	155.8	150.7
	210.0	196.4	191.1	185.9	180.6	175.4	170.1	164.9	159.6	154.4
	215.0	201.0	195.7	190.3	184.9	179.5	174.2	168.8	163.4	158.0
	220.0	205.7	200.2	194.7	189.2	183.7	178.2	182.7	167.2	161.7
	225.0	210.4	204.8	199.1	193.5	187.9	182.3	176.6	171.0	165.4
	230.0	215.1	209.3	203.6	197.8	192.1	186.3	180.6	174.8	169.1
	235.0	219.7	213.9	208.0	202.1	196.2	190.4	184.5	178.6	172.7
	240.0	224.4	218.4	212.4	206.4	200.4	194.4	188.4	182.4	176.4
	245.0	229.1	223.0	216.8	210.7	204.6	198.5	192.3	186.2	180.1
	250.0	233.8	227.5	221.3	215.0	208.8	202.5	196.3	190.0	183.8
	255.0	238.4	232.1	225.7	219.3	212.9	206.6	200.2	193.8	187.4
	260.0	243.1	236.6	230.1	223.6	217.1	210.6	204.1	197.6	191.2
	265.0	247.8	241.2	234.5	227.9	221.3	214.7	208.1	201.4	194.8
	270.0	252.5	245.7	239.0	232.2	225.5	218.7	212.0	205.2	198.5
	275.0	257.1	250.3	243.4	236.5	229.6	222.8	215.9	209.0	202.1
	280.0	261.8	254.8	247.8	240.8	233.8	226.8	219.8	212.8	205.8
	285.0	266.5	259.4	252.2	245.1	238.0	230.9	223.7	216.6	209.4
	290.0	271.2	263.9	256.7	249.4	242.5	234.9	227.7	220.4	213.2
	295.0	275.9	268.5	261.1	253.7	246.3	239.0	231.6	224.2	216.8
	300.0	280.5	273.0	264.4	258.0	250.5	243.0	235.5	228.0	220.5
	305.0	285.2	277.6	269.9	262.3	254.7	247.1	239.4	231.8	224.2
	310.0	289.9	282.1	274.4	266.6	258.9	251.1	243.4	235.6	227.9
	315.0	294.5	286.7	278.8	270.9	263.0	255.2	247.3	239.4	231.5
	320.0	299.2	291.2	283.2	275.2	267.2	259.2	251.2	243.2	235.2
	325.0	303.9	295.8	287.6	279.5	271.4	263.3	255.1	247.0	238.9
	330.0	308.6	300.3	292.1	283.8	275.9	267.3	259.1	250.8	242.6
	335.0	313.2	304.9	296.5	288.1	279.7	271.4	263.0	254.6	246.2
	340.0	317.9	309.4	300.9	292.4	283.9	275.4	266.9	258.4	249.9
	345.0	322.6	314.0	305.3	296.7	288.1	279.5	270.8	262.2	253.6
	350.0	327.3	318.5	309.8	301.0	292.3	283.6	274.8	266.0	257.3
	355.0	331.9	323.1	314.2	305.3	296.4	287.6	278.7	269.8	260.9
	360.0	336.6	327.6	318.6	309.6	300.6	291.6	282.6	273.6	264.6
	365.0	341.3	332.2	323.0	313.9	304.8	295.7	286.5	277.4	268.3
	370.0	346.0	336.7	327.5	318.2	309.0	299.37	290.5	281.2	272.0
	375.0	350.6	341.3	331.9	322.5	313.1	303.8	294.4	285.0	275.6
	380.0	355.3	345.8	336.3	326.8	317.3	307.8	298.3	288.8	279.3
	385.0	360.0	350.4	340.7	331.1	321.5	311.9	302.2	292.6	283.0
	390.0	364.7	354.9	345.2	335.4	325.7	315.9	306.2	296.4	286.7
	395.0	369.3	359.5	349.6	339.7	329.8	320.0	310.1	300.2	290.3

* Adapted from: Baechle TR, Earle RW. Essentials of Strength Training and Conditioning/National Strength and Conditioning Association. Third Edition. Champaign, IL: Human Kinetics; 2008

APPENDIX I

TABLE 1

Table 1. Mean (SD) for Dependent Variables

	Baseline	Immediately Post-exercise	24 h Post-exercise	48 h Post-exercise	72 h Post-exercise	96 h Post-exercise	7 Days Post-exercise
Upper Arm Circumference							
Treatment	27.9±3.5	28.0±3.9	27.8±3.3	28.4±3.8	28.3±3.7	28.2±3.6	27.8±3.5
Control	28.2±4.7	28.5±4.1	27.9±4.0	28.3±4.2	28.8±4.1	28.5±3.9	28.1±4.0
ROM Extension							
Treatment	-0.8±3.3	3.3±8.6*	5.4±6.6*	21.1±33.4*	10.3±12.9*	2.5±7.4*	-0.3±3.6
Control	0.2±3.2	2.7±4.2*	5.8±6.3*	10.1±11.1*	12.2±12.7*	3.8±6.2*	0.1±1.5
ROM Flexion							
Treatment	143.1±5.4	137.5±8.1*	139.5±6.4*	137.9±6.6*	138.0±7.5*	141.4±5.7*	143.9±5.5
Control	144.2±6.1	137.1±6.5*	139.6±6.4*	135.8±7.4*	135.9±6.8*	139.7±6.1*	142.8±6.5
VAS							
Treatment	1.3±4.7	18.0±16.9*	20.3±17.2*	30.2±22.5*	17.6±21.5*	7.4±13.2*	0.3±0.9
Control	1.2±4.6	25.0±19.3*	31.9±28.5*	43.1±29.4*	35.8±31.2*	16.1±21.0*	3.0±7.5
DASH							
Treatment	4.0±5.6	20.6±10.6*	17.2±11.2*	22.9±17.6*	15.7±16.0*	8.4±13.2*	2.6±4.2
Control	3.1±4.3	20.8±17.4*	21.0±18.9*	28.8±20.8*	24.8±25.2*	12.0±13.5*	2.2±4.5

* $p < .05$ for test of significance compared to Baseline

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