THE EFFECT OF MAGNESIUM SULFATE ON DELAYED ONSET MUSCLE SORENESS

THESIS

Presented to the Graduate Council of
Texas State University-San Marcos
in Partial Fulfillment
of the Requirements

for the Degree

Master of SCIENCE

By

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San Marcos, Texas
August 2010

ACKNOWLEDGEMENTS

I would first like to sincerely thank my beautiful loving wife, Amy Byerley. I love you with all that I am. I thank her for devoting her time, energy, and support to keeping me on the straight and narrow. Thank you for being my support and mentor through the hard times we have encountered. Without you, I would not be who or where I am today and can never thank you enough.

I would also like to thank the individuals who helped me accomplish this great feat. I would like to thank my committee members, Dr. Jack Ransone, Dr. Luzita Vela, and Dr. Jim Williams for providing the guidance and support I needed through this process. I would like to thank the members of the Boerne Samuel V. Champion High School for allowing me to perform my study. To David Stelmazewski, Principal of Boerne Champion High School, I thank you for allowing me the opportunity for completing my study. I thank Terry Gault for helping set up meetings with coaches and students and his assistance in the study.

This thesis was submitted on July 9, 2010.

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ABSTRACT

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Delayed onset muscle soreness (DOMS) is a common condition experienced in athletes due to unaccustomed work loads. Symptoms of this condition are usually exacerbated between 24-48 hours post exercise and include decreased muscular strength and range of motion, and increased edema, perceived pain, and perceived disability. Typical treatment protocol for DOMS is cryotherapy; however, evidence supports the lack of recovery following such treatments. Magnesium sulfate (Epsom salt) has been used for many years to treat muscle soreness, but has only been anecdotally proven to

decrease muscle soreness. The purpose of this study was to determine if magnesium sulfate (Epsom salt) and thermotherapy are effective treatments for DOMS. Twenty-six healthy young males and females (n_m= 14, n_f=12, 16.04±1.08 yrs, 172.54±8.13 cm, 72.42±18.99 kg) volunteered to participate in this research. Subjects were randomly selected to be in one of three groups. Group 1 was the control group and received no treatment ($n_{Control}$=8). Group 2 was treated with hot water immersion (HWI) (n_{HWI}=9). Group 3 was treated with Epsom salt dissolved in hot water (EHWI) (n_{EHWI}=9). There were significant decreases in perceived pain (GPRS), $F(2,23) = 8.98$, $p<0.01$, and perceived disability (DASH), $F(2,23) = 3.89$, $p=0.035$. Tukey's Post Hoc Test showed significant decreases in perceived pain (GPRS) from the control in HWI, $p=0.002$, and in EHWI, $p=0.007$. There was a significant decrease in perceived disability (DASH) from the control in HWI, $p=0.027$; however, not with EHWI. Neither perceived pain nor perceived disability was seen when comparing HWI and EHWI. It was concluded that both thermotherapy and Epsom salt soak reduces perceived pain and disability as opposed to receiving no treatment. However, no differences were seen between HWI and EHWI; therefore, the Epsom salt had no effect in the treatment.

Key Words: Epsom salt, thermotherapy, hot water immersion, magnesium, calcium.

CHAPTER I

THE EFFECT OF MAGNESIUM SULFATE ON DELAYED ONSET MUSCLE SORENESS

Introduction

Delayed onset muscle soreness (DOMS) is a condition that occurs when inactive individuals begin physically demanding exercise or physically active individuals attempt increases in loads of exercise that are not what they are accustomed to. In 1902, Theodore Hough first suggested the pain that occurs after exercise is caused from damage to the muscle fibers.[1] This suggestion has lead to investigations on the mechanisms, prevention strategies, measurable outcomes of, and treatments for DOMS or exercise-induced muscle soreness.[2-6]

Delayed onset muscle soreness has been generally described as a physical damage to muscle fibers located within the active muscle. The damage to these fibers creates symptoms that develop over a period of several days after the bout of exercise is performed. Even though DOMS can occur after performing concentric exercise, in many studies, the use of eccentric exercise bouts has been the focalized point as the type of exercise that exacerbates this condition.[2-7] The symptoms that are commonly associated with DOMS include increased edema, decreased range of motion, decreased muscular strength, and increased perceived pain and disability.[6,7] Common treatments for this

conditions include several techniques including cryotherapy, massage, and electrotherapeutic modalities.[5] Delayed onset muscle soreness is considered common in physical activity and the risk factors need to be identified. The nature of this condition and its debilitating effects marks the importance to many different professionals such as coaches, physical therapists, athletic trainers, and any other sport medical personnel. One risk factor is decreased cushioning abilities of muscles while landing after a jump or when running. The normal range of motion of a joint is decreased, thus reducing the ability to absorb shock during impact and places unaccustomed loading on joints and tissues.[6] Delayed onset muscle soreness may alter muscle sequencing, changing coordination and motion while placing unaccustomed strain on muscles, ligaments, and tendons during functional activity.[8] Strain on muscles are caused by a reduction in force output causing compensatory activation of other muscles.[8]

Purpose

The purpose of this study was to determine the effectiveness of magnesium sulfate (Epsom Salt) in reducing the restrictions and limitations of exercise-induced DOMS including decreased range of motion, edema, increased perceived soreness and disability, decreased muscle strength, and patient reported disablement. A secondary purpose was to determine the effectiveness of thermotherapy in reducing the restrictions and limitation of DOMS.

Research Hypothesis

It is hypothesized that magnesium sulfate treatment will decrease the effects of DOMS including decreased range of motion, edema, increased perceived soreness and disability, and decreased muscle strength. Secondly, it is hypothesized that the use of thermotherapy will reduce the effects of DOMS.

Operational Definitions

Anthropometric Measurements: Quantitative measurements taken of a body segment to determine the amount of edema or swelling to the area.

Delayed Onset Muscle Soreness (DOMS): A condition defined as muscle pain or soreness that manifests between 24 and 48 hours after a series of eccentric contractions.

EHWI (Epsom Salt and Hot Water Immersion): Treatment of Epsom salt dissolved in hot water and the body portion will be completely submerged under water.

Delimitations

This experiment has certain delimitations or boundaries that could affect the collection and interpretation of data. These delimitations include:

1. Subjects were physically active male and female high school students between the ages of 15 and 18 years old.
2. To be considered physically active, subjects must participate in at least 30 minutes of moderate level exercise, 3 to 4 days a week.

3. Subjects must perform upper body strength training, but no more than 4 days per week.

Limitations

This experiment has certain inherent limitations that could have an effect on the collection and interpretation of data. Generalizations made from the results are compromised by the following limitations:

1. Results cannot be applied to those that are not physically active outside the age range of 15 to 18 years old.
2. Results cannot be applied to those who do not participate in at least 30 minutes of moderate level exercise, 3 to 4 days a week.
3. Results cannot be applied to individuals who do not perform upper body strength training or perform upper body strength as a regular exercise routine.

Assumptions

There are basic assumptions that the principle investigator assumed to be true in this study. The basic assumptions for this study include:

1. All subjects were randomly selected to participate in one of the three treatment groups and representative of the general population.
2. All subjects performed the tests and exercises with maximum effort.
3. Subjects completed the medical health questionnaire, questions regarding neurological screening, physical fitness, and treatment forms accurately and honestly.
4. Subjects were initially asymptomatic; presenting no upper body soreness or pain.

5. Eccentric loading was consistent throughout the study to help ensure the target muscle (biceps brachii) was isolated.
6. The eccentric loading exercise provided an adequate intensity to elicit DOMS.
7. The concentration of the solution of magnesium sulfate remained consistent for all subjects being treated with magnesium sulfate. The solution was replaced for each subject and each treatment.
8. Subjects did not receive any other forms of treatment during this study.
9. All treatments and procedures were equal and unbiased.

Significance of the Study

Delayed onset muscle soreness is a limiting condition that affects athletic performance by reducing strength, function, and range of motion.[3,5,7] It has been suggested that cryotherapy treatments, such as ice immersion, only temporarily masks the pain symptoms felt by the athlete; thus, not treating the cause of this condition.[9] Magnesium sulfate, or Epsom salt, could be used in soaking baths to potentially help decrease the limitations and restrictions of DOMS. Few studies have investigated the effects of magnesium sulfate soaking bath on decreasing these limitations and restrictions of DOMS. This study will determine the effectiveness of magnesium sulfate and the effectiveness of thermotherapy as a treatment for DOMS.

CHAPTER II

LITERATURE REVIEW

Delayed onset muscle soreness (DOMS) is a condition that occurs when inactive individuals begin physically demanding exercise or physically active individuals attempt increases in loads of exercise that are not what they are accustomed to. This has lead to several investigations on the mechanisms of injury and methods of treatment for DOMS or exercise-induced muscle soreness.[2-6] The symptoms, which are exacerbate between 24 and 48 hours post exercise, that are commonly associated with DOMS include increased edema, decreased range of motion, decreased muscular strength, and increased perceived pain and disability.[6,7]

Delayed onset muscle soreness is considered common in physical activity and the risk factors need to be identified. The nature of this condition and its debilitating effects marks the importance to many different professionals such as coaches, physical therapists, athletic trainers, and any other sport medical personnel. One risk factor is decreased cushioning abilities of muscles while landing after a jump or when running. The normal range of motion of a joint is decreased, thus reducing the ability to absorb shock during impact and places unaccustomed loading on joints and tissues.[6] Delayed onset muscle soreness may alter muscle sequencing, changing coordination and motion while placing unaccustomed strain on muscles, ligaments, and tendons during functional

activity.[8] Strain on muscles are caused by a reduction in force output causing compensatory activation of other muscles.[8]

This chapter will discuss the different topics surrounding DOMS such as the mechanism, measuring tools, and the treatments used in this study. This literature review was performed using the EBSCO Host database, searching in MEDLINE, CINAHL, and SPORTDiscus. Searched terms included: delayed onset muscle soreness (DOMS), exercise-induced muscle damage, calpain, effects of calcium on muscle damage, Epsom salt, magnesium sulfate, and thermotherapy.

Mechanisms of DOMS

The theory that muscle soreness is caused from damaged tissue, initially described by Theodore Hough[1] in 1902, has lead to generalized theories including lactic acid build-up, tissue spasm, connective tissues disruption, inflammation, and damaged or torn tissues.[2-7] The exact mechanism of injury is still unknown, but there have been different theories postulated. However, it is important to note that some theories have been disproved and others have been supported with increasing amounts of evidence. This section will discuss these different theories that are suggested for the mechanism of DOMS.

Lactic Acid

The theory of lactic acid creating DOMS is due to accumulating lactic acid within the muscle tissues from anaerobic glycolysis. However, levels of lactic acid were found to be higher in runners who ran on a flat surface without increased muscle soreness.[3]

Running downhill showed increased muscle soreness, but do not have significant levels of lactic acid. This theory is unequivocal because concentric contractions produce higher degrees of metabolic activity than eccentric contractions, but does not produce the same soreness experienced with eccentric contractions.[10-13] Lactic acid does produce temporary pain during exercise bouts, but does not produce the symptoms of DOMS.[9] Lactic acid levels have been shown to return to normal pre-exercise levels within one hour after exercise.[14]

Muscle Spasm

The muscle spasm theory was initially introduced by de Vries in 1961, after noticing increased muscular activity recorded with surface electromyography (EMG).[15] It was thought that resting muscle spasm leads to compression of local blood vessels, causing ischemia and the build up of "pain substance", stimulating localized pain nerve endings, creating pain, and thus causing a reflex spasm cycle.[16] De Vries[16] found there to be a direct relationship between the level of pain and the EMG recording activity. However, no other studies have been able to show increased EMG activity associated with sore muscles.[17-20]

Connective Tissue

Damage to connective tissues surrounding the muscle fibers or their bundles includes the sheaths that surround each muscle fiber, bundles, and the musculotendinous junction forming the tendon. Subsequently, it has been found that muscle fiber types differ in their composition of connective tissue. Type I, or slow twitch, fibers are a larger

fiber type than that of the type II, fast twitch, fiber type.[9] It has been found that type II muscle fibers are more susceptible to this form of injury.[20]

Abraham[17] found a link between urinary excretion of hydroxyprolin and muscular soreness. Hydroxyprolin is a product of the breakdown of connective tissues and can be used as an indicator of collagen metabolism.[17] It was found to reach maximal secretion in subjects recording muscle soreness approximately 48 hours after activity. There have also been increased measurements of urine excreted hydroxyproline and the amino acid hydroxylysine, markers of collagen degradation, after exercise.[20,21]

Torn Tissue or Muscular Damage

The torn tissue theory was first introduced in 1902 by Hough.[1] This hypothesis is based on the direct relationship of the mechanical loading on individual myofibrils that occur in response to eccentric contractions and leads to a cascade of damaging events.

In muscle force production, eccentric contractions activate fewer motor units than in concentric contractions.[22-27] This equates to a smaller cross-sectional area of muscle to perform the same load amount in eccentric contractions than that of concentric contractions.[28] During eccentric contractions, the sarcomeres become stretched in a non-uniform progression, not allowing a normal overlapping of the actomyosin structures.[29,30] This damage occurs when the muscle fibers are lengthened farther than the normal actomyosin overlap. This hypothesis is supported by studies that show there to be greater damage to tissues when the exercise intensities are equal but at longer muscle lengths.[31,32] In another study, Lieber and Friden[33] systematically altered muscle strain during lengthening contractions of the tibialis muscles in rabbits. These results provided

evidence that muscle length is more of a factor on the degree of damage on muscular tissues than amount of stressors placed on the muscle.

Sarcomere structures present a non-homogenous characteristic seen when the actomyosin structures reach a point where they do not maintain correct overlapping within the sarcomere; creating a pop of weaker sarcomeres, known as Z-band or Z-line streaming.[34-37] This creates a mechanical disruption within the fiber, by either broadening the Z-Band or by complete disruption.[38] This mechanism of disruption causes damage to the membrane as well as other structures such as the sarcoplasmic reticulum and surrounding myofibrils and sarcolemmas.[34] The damage of the integrity of the sarcoplasmic membrane, which acts as a barrier for the concentrations between the extra-cellular and intracellular spaces, leads to a calcium leakage or loss of calcium homeostasis.[39]

The sarcoplasmic reticulum acts as a barrier between extra-cellular and intracellular spaces. Trauma or damage to this structure may increase intracellular calcium levels, creating an imbalance in calcium homeostasis and enabling calcium-sensitive degradative pathways to take place. Duan et al.[40] found increased mitochondrial calcium levels in animal muscular tissues after eccentric contractions following downhill walking. It has been suggested that calcium concentrations exacerbate muscle damage following eccentric exercise.[41-44] Normal levels in a resting muscle of extra-cellular free calcium concentrations is between 2 and 3 mmol/L and intracellular free cytosolic calcium levels is only 0.1 μmol/L.[2] This creates a large concentration gradient and influx of calcium in the event of disruption in the sarcoplasmic reticulum. Intracellular calcium concentrations have been shown to increase in both individual muscle fibers and in whole

muscles in response to this disruption.[45,46] Increased intracellular calcium levels have also been known to cause smooth muscle contractions, possibly creating an ischemic condition within the muscle.[47]

Calcium influx has been shown to progress the degradation of tissues. Removal of extra-cellular calcium from an incubated medium, decreases the amount of damage to tissues.[48] In the event of damaged membranes, there are also losses of intracellular constituents such as enzymes, myoglobin, adenine nucleotides, potassium and magnesium, along with the increased concentrations of sodium and calcium.[49-54]

Calpain is a non-lysomal calcium activated neural protease located in the I and Z regions of skeletal muscle and is thought to be directly related to muscle damage after eccentric contractions.[55] Calpain has been found to split substrates such as cytoskeletal proteins (i.e. desmin, α-actinin, synemin, and vimentin) and begin degrading them. The role of desmin is to attach adjacent myofibrils at the Z-dics.[56] Lieber et al.[42] found in an animal study a significant loss of desmin labeling from muscle tissue after a bout of eccentric contractions. Synemin and vimentin are found along with desmin at the Z-disc, and α-actinin anchors actin to the Z-disc.[56] Belcastro et al.[57] found a loss in the Z-disc structure as well as a loss of two proteins, with a molecular weight consistent with desmin and α-actinin. This serves as the potential of the degradation of the Z-disc (i.e. Z-line streaming) seen with eccentric exercise.[36,37] Actin and myosin are left alone while the Z-disc is targeted by calpain because actin and myosin are not substrates for calpain.[3] The utilization of the protease inhibitor leupeptin, inhibiting the activation of calpain shows calpain is involved in the early damage of muscular tissue after eccentric contractions.[58] These calcium activated proteases have been suggested to specifically

degrade the Z-discs[59-62] or particular contractile filament components.[60,61,63] Calpain attacks the Z-discs by digesting two proteins, zeelin 1 and zeelin 2. These two proteins are thought to anchor α-actinin in the disc.[64]

Inflammation

The final theory involves the inflammatory process resulting from damage to the tissues within the muscle. The inflammatory process is considered to be the normal reaction in response to damaged tissues that initiates the repairing process of the muscle.[65] Acute inflammation is marked by increases in blood flow, permeability of vascular tissue, and increased circulation of white blood cells.[66,67] Neutrophils have been suggested to be the first to arrive at the damaged muscle tissues.[68-70] Raj et al.[71] found a relationship between the calcium-stimulated cysteine protease and neurtrophil accumulation. After three to four days, the neutrophils had performed their duties; macrophages began to mobilize in the area of damage and remove the neutrophils and necrotic tissues.[72] Macrophages are capable of producing oxygen radicals and cytotoxic enzymes, which are capable of tissue degradation.[72] There is evidence supporting the inflammatory theory; however, there are many different aspects to the inflammatory process that still remain unanswered.[73]

Measuring DOMS

There have been several defining characteristics in the response to eccentric exercise. These defining characteristics make up either signs or symptoms commonly exacerbated with the DOMS condition. These characteristics normally develop within

the first 24 hours after eccentric exercise and may last for several days. It is important to note that the outcomes discussed are only specific to this study. The elbow flexors were selected as the target muscle group for this study because of the ease of induction of DOMS and this muscle has been utilized in multiple previous studies.[73-82]

Swelling or Edema

Determining swelling and edema is a useful measurement technique to determine certain characteristics of DOMS as a result to eccentric exercise.[83-85] Anthropometric readings of girth measurements of the bicep muscle were taken to determine the amount of swelling within the muscle belly, musculotendinous juncture, and the tendon of the biceps brachii muscle. Measurements were taken using a standard anthropometric retractable tape measure (MEDCO, Tonawanda, NY). The use of upper arm anthropometric measurements have been used in multiple studies to determine edema within these three locations.[86-88] It could be suggested that other forms of determining swelling or edema (i.e. MRI, Doppler ultrasound, or sonographic methods) would be far more accurate. However, due to time and monetary reasons, the use of circumference measurements was used in this study.

Range of Motion - Resting Angle

A decrease in range of motion is another characteristic of DOMS.[3] The subjects stood with their hands and arms by their sides in a relaxed anatomical position. The angle was measured using a standard transparent goniometer. Important landmarks for goniometric measurements were marked using a marker to help standardize

measurements.[89] This process is considered an indirect method of measuring muscle tightness in the event of tissue shortening and has been previously utilized by in other studies.[86-91] Resting angle was determined with a standard plastic twelve and a half inch goniometer (MEDCO, Tonawanda, NY). There are other, more reliable methods for determining a joint's range of motion; which include isokinetic machinery, video analysis software technology, or the use of an inclinometer. However, due to time and monetary reasons, the use of circumference measurements was used in this study.

Strength

Strength is negatively affected after eccentric exercise and the induction of DOMS.[3] The condition presents the loss of contractile force production.[36,92-96] Strength may be determined in different ways. This study utilized a multiple repetition max to approximate the subject's one repetition maximum (1-RM). An ideal measurement for muscular strength is to utilize an isokinetic machine to test maximal voluntary contraction torque; however, this method was not be utilized because of the inability to obtain this machinery. The reliability of this test is considered high; however, the torque output is affected by fatigue, motivation, and pain of the subject.[96] Another alternative method is to utilize an isometric measurement to determine maximal voluntary contraction torque, which are both valid and reliable in measuring muscular damage.[96] One drawback to measuring isometric force is the single angle being set, not considering function throughout the entire range of motion. Using a multiple repetition maximum for determining the 1-RM allows for function of the muscle to be considered and the decreases in function are more easily seen than a simple one repetition max. The

subject's maximum was estimated using the table found in Appendix A.[97] If the subject is unable to achieve maximal exertion before ten repetitions, they were asked to return the following day to complete the testing to allow for adequate recovery of the phosphocreatine energy system.[98]

Perceived Soreness

Soreness and pain could be the most self noted reactions to eccentric exercise in DOMS. A graphic pain rating scale (GPRS) was developed particularly for DOMS by Denegar et al.[77] Denegar and Perrin developed this scale based on the verbal descriptive scale used by Talag[19] and consisted of a 12 cm line (Appendix B). This study followed the designer's protocol for quantifying the ratings. The GPRS was utilized as a pain measure in response to physical activity. This study utilized a slightly modified version of this scale to be more directed to pain experienced during physical exertion.

Perceived Disability

Subjects also completed a survey that measures the disability of the arm, shoulder, and hand (Quick-DASH).[99] The Quick-DASH is a series of questions developed to determine the physical disabilities of the arm, shoulder, and hand (Appendix C).[99] Results will be utilized to determine overall disability of the subjects to participate in normal everyday quality of living.

Alternate Forms of Measurement Techniques

Recruitment patterns are altered after bouts of eccentric exercise and in DOMS by using electromyography (EMG).[100-102] Decreased maximal voluntary contracts have been correlated to levels of certain blood markers such as creatine kinase, lactate dehydrogenase, and myoglobin.[103]

Muscular Damage Inducing Protocol

Delayed onset muscle soreness has been more prominent in the events of several exercise bouts of eccentric loading of a muscle because it has been found that fewer motor units are recruited during this type of contraction.[28] To control the variable of inducing and increase the occurrence of DOMS, a combination of several aspects to different studies will be implemented.[104,105] The extent of the damage will be related to the length of the contraction and not the force generated by the muscle.[33] For this investigation, subjects completely extended their elbow through to the end of their full range of motion while completing the inducing exercise.

Treatment of DOMS

Magnesium is considered an essential mineral that is needed in the human body for multiple physiological functions. The importance of magnesium to animals was first described in 1926.[106] Magnesium is important in the calcium uptake in the sarcoplasmic reticulum and stimulates the rate limiting step of the ATPase activity associated with calcium transport.[107,108] Increased intracellular calcium above normal physiological levels may cause further calcium induced release of calcium from the sarcoplasmic

reticulum.[109] This mechanism of influx of calcium into the cells is also sensitive to the concentration level of magnesium within the cell. It has been demonstrated that magnesium lowers the calcium concentration to inhibit the induction of further calcium released in skinned muscle fibers[110] and from sarcoplasmic reticulum vesicles.[111] Magnesium helps to accelerate the rate of phosphorylation of the calcium ATPase during the calcium uptake mechanism of the sarcoplasmic reticulum.[112] Evidence shows an increase of total calcium levels in rat skeletal muscles that were magnesium deficient.[113] Increased intracellular calcium in smooth muscle may cause increased smooth muscle contraction, thus creating an ischemic condition.[47] Magnesium can decrease this from occurring and allow for non-resistant blood flow.[114] With the imposed scenario of calcium influx from the previous section, it may be possible for the removal of increased calcium concentrations from within the cell by restoring uptake mechanisms by the sarcoplasmic reticulum; thus, reducing the damaging effects of increased concentrations of calcium to the muscle fibers. Magnesium also reduces both nerve and muscle excitability[115], therefore there is the possibility that this may decrease pain or muscle stiffness that is associated with DOMS.

Even with the importance of magnesium to the body, it has been noted that the dietary selection of western societies cause individuals to be magnesium deficit, when compared to the US Recommended Daily Allowance for Magnesium.[116] The US Institute of Health: Office of Dietary Supplements (2009)[117] recommends magnesium intake for individuals 14 to 18 years of age to be 360 mg/day (females) and 410 mg/day (males). For adults over 18 years of age, the recommended daily magnesium intake is 300 to 420 mg/day. However, the true intake of a normal western diet has been

determined to be about 200 mg/day (females) and 260 mg/day (males).[118] Therefore, it can be assumed that the normal diets of athlete's may be deficient enough to predispose them to exercise-induced DOMS.

Standard treatment protocol for most, if not all, acute inflammation after a soft tissue injury is rest, ice, compression, and elevation (R.I.C.E. principle).[119-121] Also, the standard treatment of DOMS has been the use of some form of cryotherapy.[6] Cryotherapy would be warranted because the general consensus is that DOMS does have some form of an inflammatory response component to the process.[2-5,9] However, recent reviews have illustrated the lack of effectiveness of cryotherapy as a treatment of DOMS. Evidence has shown there to be minimal reduction in overall soreness or an increase in muscle function; therefore, it has been suggested that cold application provides a temporary analgesic effect and not beneficial in treating DOMS.[6,9] However, unlike an acute traumatic injury, DOMS may develop a smaller magnitude of inflammatory response.[9]

The use of thermotherapy on acute injuries is considered to be a contraindication because it acts in opposition to cryotherapy by increasing heart rate, cardiac output, tissue temperatures, and may increase the inflammatory response.[122] Studies on the effectiveness of thermotherapy on DOMS are scarce. However, the inflammation that occurs with DOMS is not considered to be analogous to the inflammatory response seen with acute injuries and the use of thermotherapy to treat DOMS would be accepted.[9] The use of a thermal modality is important because thermoreceptors on the skin are thought to help alleviate muscle soreness or pain[123-124] and heat is required for the passing of magnesium through the skin. Waring et al.[125] performed a study to determine the

absorption of magnesium sulfate across the skin and provided two conclusions. For individuals to have a significant rise in their magnesium plasma levels, the required level of Epsom salt concentration must be 1%, equal to approximately 600g Epsom salt per 15 gallons of water, the approximate volume of the extremity whirlpool to be used.[125] Secondly, there is a significant increase of magnesium sulfate absorption through the skin at a temperature of 50 to 55 degrees C (or 122 to 131 degrees F) for 12 minutes. However, these temperatures may be quite extreme; therefore, for this study, the temperature of the warm bath will be set at 43 to 45 degrees C (109 to 113 degrees F) as demonstrated by common treatment parameters for treatment of the arm or hand.[126]

Alternate Treatment Methods

A common treatment of DOMS is the use of non-steroidal anti-inflammatory drugs (NSAIDs). NSAIDS decrease pain and edema experienced in DOMS through inhibition of cyclo-oxygenase (COX) pathways.[127-128] Massage is a widely used modality used for treating DOMS.[6] Massaging techniques have shown to decrease pain and girth measurements; however, have not demonstrated improvements in muscular strength.[129-130]

Conclusion

Delayed onset muscle soreness has had several purposed mechanisms, but tissue damage has been best supported by current literature that has resulted from eccentric loading.[1-7,22-38] This damage creates an influx of calcium into the muscle that could be removed in the presence of magnesium.[39,107-110] The standard treatment protocol for

treating the symptoms exacerbated by DOMS with cryotherapy has shown to be ineffective in reducing these symptoms.[119-121] The use of magnesium sulfate (Epsom salt) may provide a superior treatment for DOMS.

CHAPTER III

METHODOLOGY

The purpose of this study was to determine the effectiveness of magnesium sulfate (Epsom Salt) in reducing the symptoms and effects of exercise-induced DOMS. These restrictions and limitations include decreased range of motion, inflammation, increased perceived soreness and disability, and decreased kinetic muscle strength. A secondary purpose is to determine the effectiveness of thermotherapy in reducing the restrictions and limitation of DOMS. Each subject performed a series of eccentric exercises to produce exercise-induced DOMS. Subjects went through one of three protocols for treatment and for obtaining necessary measurements. This investigation was performed in the weight room and athletic training room facilities at Boerne-Samuel V. Champion High School, in Boerne, Texas.

Subjects

Thirty, healthy young males and females participants, between 15 to 18 years of age, participated in this investigation. This age range was selected because of the accessibility of individuals in this age range. The number of subjects needed was estimated using a previous study.[131] At 24 hours post exercise, the investigators found an effect size of 0.87 and an observed power of 0.66 between the control and heat wrap

groups. Using a 95% confidence level and an 80% power, the necessary sample size per group is ten. To avoid a Type II error, a more conservative sample size per group (n=15) was used. To have been included in this study, subjects must participate in at least 30 minutes of moderate level exercise, 3 to 4 days a week. Subjects must perform upper body strength training, but no more than 4 days per week. Permission to perform this investigation was granted by the Boerne Independent School District (Appendix D) and the Texas State University-San Marcos Institutional Review Board (Appendix E). Each subject provided an informed written assent and a parent or legal guardian provided written consent before beginning the study (Appendix F). Subjects performed a neurological screening (Appendix G) administered by the principle investigator before participation in the study. A medical history was conducted and reviewed by the principle investigator, a licensed healthcare provider (Appendix G). Subjects were excluded from the study for any medical problems including: a failed neurological screening, any history of upper limb pathology, undiagnosed pain, a history of cardiopulmonary problems, pregnancy, epilepsy, or diabetes. Subjects volunteered to be selected to participate in one of three blind controlled study groups. Randomization was done by the sequencing of the subjects sign-up. Beginning with the first subject to sign up, the principle investigator counted 1, 2, and 3 (the group number) before subjects reported to the testing site. All groups performed the same bouts of damaging eccentric exercise to the non-dominant arm. Group 1, or control group, received no form of treatment or interventions. Group 2 was treated using the hot water immersion (HWI) treatment. Group 3 was treated using the Epsom salt and hot water immersion (EHWI) treatment. During the treatment protocols, subjects were asked not to drink or taste the

water solutions. The principle investigator monitored the entire treatment to ensure subjects did not try to determine their treatment protocol by tasting the water. Subjects were not allowed to perform any other forms of exercise or therapy during the period of the study. Forms of rehabilitative therapy include modalities massage, electrical stimulation, cryotherapy or thermotherapy, use of non-steroidal anti-inflammatory drugs (NSAIDs) or pain relievers, and the use of pain relieving creams. Subjects were also asked to wear relaxed clothing, including a short sleeved t-shirt, and asked not to eat or exercise at least four hours prior to participation in this investigation.

Subject Demographics

Subjects were asked to complete a questionnaire examining their personal medical history. This questionnaire focused on the history of injury and health of the subject (Appendix G). The subject's demographic information including the subject's height, weight, athletic involvement, arm dominance, gender, and age were obtained (Appendix H). Once subjects were cleared for participation, each subject received a thorough explanation of the experimental procedures by the principle investigator. The subjects then reported to the testing site prior to mentioning the treatment protocol.

Internal and External Validity

An attempt was made to ensure that the results were not influenced by factors other than the independent variables. Internal validity was accounted for by:

1. Randomly assigning subjects to each groups by the principle investigator.

2. Controlling the administration of procedures by the principle investigator through monitoring the procedures, adhering to ethical practices, and maintaining an unbiased position.

The ability to generalize the results of this study was limited by several factors. Since all subjects were homogenously selected from a specific area and participated on a voluntary basis, generalizations beyond the scope of this study should not be attempted. External validity was accounted for by:

1. Controlling for the Hawthorne Effect by providing consistent and equal motivation to the subjects.
2. Maintaining a blind status of the subject to their treatment by not informing the subjects which treatment (other than the control) they are receiving.

Procedural Sequencing

1. Subjects signed-up and provided contact information prior to reporting to the testing site.
2. The principle investigator contacted the subjects and informed them of the time and location of where they would report.
3. Subjects reported to the testing area prior to start of the study to receive and review the consent form from the principle investigator.
4. Subjects were randomly allocated to one of three groups.
5. Subjects were informed of principle investigator's expectations of the subject during the testing period.

Day 1: Start of Testing

1. Subject returned to the testing site, with consent form signed by proper individuals.
2. Subjects completed neurological examination and medical history forms. A "Pass or Fail" status was given by the principle investigator. Receiving a "Fail" status prohibited the continuation of that subject in the investigation.
3. Subject demographics information was recorded.
4. Baseline measurements for the study then began.
    a. Anthropometric measurements of the upper arm were taken using a non-stretch measuring tape.
    b. Resting angle of the relationship between the humerus and forearm was taken using a standard goniometer.
    c. Muscular strength of the biceps brachii muscle was determined using a multiple repetition max.
    d. Subjects performed a perceived soreness scale, GPRS, immediately following the muscular strength test.
    e. Subjects performed the perceived disability, Quick-DASH (disability of the arm, shoulder, and hand), following the GPRS.
5. Following all baseline measurements, all subjects went through the inducing protocol.
6. All groups retested measurements for hour 0.
7. Subjects treated based on group protocol.

Day 2: 24 hours post inducing exercise

1. Subjects reported back to the testing site.

2. All subjects had measurement retaken at this time.
    a. Anthropometric measurements of the upper arm
    b. Resting angle of the relationship between the humerus and forearm
    c. Muscular strength of the biceps brachii muscle
    d. Subjects performed perceived soreness scale, GPRS, immediately following the muscular strength test.
    e. Subjects will perform the perceived disability, Quick-DASH (disability of the arm, shoulder, and hand), following the GPRS.
3. Subjects treated based on group protocol.

Day 3 (48 hours) and Day 4 (72 hours) post inducing exercise

Procedures for days 3 and 4 followed the procedures explained for Day 2.

Measurements

When cleared for participation, each subject received a thorough explanation of the experimental procedures for the study. Baseline measurements of the subject's non-dominate arm were taken prior to the investigation. Subjects performed the inducing exercise and measurements were retaken. Each group (excluding Group 1) then received their designated treatments. All groups returned for measurements to be taken at 0, 24, 48, and 72 hours post inducing exercise. Groups 2 and 3 received treatments following the measurements. To ensure repeatability and reliability of anthropometric and resting angle measurements, the designated sites were marked using a black permanent marker.

Anthropometric Measurements

Anthropometric readings (Anth) of girth measurements of the bicep muscle were taken to determine the amount of swelling within the muscle and tendon of the biceps brachii. A non-stretch anthropometric measuring tape (MEDCO, Tonawanda, NY) was used to measure the circumference while the elbow was fully extended at three sites: the mid-bicep belly, the musculotendinous juncture (MTJ), and the distal bicep tendon. These sites were measured at 1, 3, and 5 centimeters from the crease on the cubital fossa. Each site was measured (in centimeters) three times and the averages were calculated and recorded. The use of a standard non-stretch anthropometric measuring tape has been shown to be highly reliable with a coefficient of reliability (r=0.97).[132]

Resting Angle

Resting angle (RA) of the elbow was measured using goniometric readings from a universal 12.5 inch transparent plastic goniometer (MEDCO, Tonawanda, NY). The subjects stood with their arms hanging freely by their sides in the anatomical position to allow elbow extension (degrees) to be obtained three times and averaged out. The goniometer fulcrum was located over the lateral epicondyle, the stationary arm pointing toward the greater tubercle of the humerus, and the moving arm was aligned along the lateral border of the radius pointing toward the styloid process of the distal radius. The use of a standard plastic goniometer has been shown to be highly reliable and valid with a coefficient of reliability (r=0.94).[133]

Muscular Strength

Muscular strength (1-RM) of the subject's non-dominant elbow flexors (biceps brachii) was determined using an estimated 1-repetition maximum (1-RM) of a dumbbell curl. Subjects performed a multiple repetition max to estimate their 1-RM. To isolate the biceps brachii muscle, the subjects sat on a preacher's curl bench facing forward, with their triceps resting over the front of the stationary bench and their forearm fully supinated.[86] The principle investigator monitored the subjects to ensure the subjects were performing the lifts in the correct manner. The subjects began the strength test with an initial weight estimated based on previous trials for both males and females. The subjects performed multiple repetitions until the subject could not complete any more lifts. The subject's 1-RM or muscular strength was determined utilizing a multiple one rep max chart (Appendix A).[97] If the subject completed 10 repetitions without achieving a maximal level of exertion, they were asked to return the following day to complete the testing to allow for adequate recovery of the phosphocreatine energy system.[98]

The subject's muscular strength was evaluated in the following days for all three groups after Anth and RA is taken. Each subject sat on the preacher's curl bench and repeated the multiple 1-RM test. The starting weight of the dumbbell began at the same weight initially used to determine the 1-RM. Subjects performed as many repetitions at the given weight for each test day.

Perceived Soreness

Perceived soreness was assessed using a GPRS (Appendix B) that was developed to assess DOMS.[19] Subjects were asked to rank their perceived soreness on the GPRS

between "No pain nor discomfort" and "Unbearable pain or discomfort" with descriptive sensations located between these two extremes.[77] The GPRS was performed immediately after the initial eccentric workload and before the treatment (Groups 2 and 3) on day one. Each subject was then asked to complete the GPRS in response to their symptoms during the testing for muscular strength in the following days thereafter. Subjects placed a line on the scale in the correct corresponding location in response to their pain. The perceived pain was quantified by measuring the distance from the far left to the subject's line (to the nearest ½ centimeter) and then was multiplied by 2 to eliminate fractional scores. This yielded scores between 0 and 24; where increased scores represented increased perceived pain.

Perceived Disability

Perceived disability was assessed by having subjects fill out the Quick DASH, an outcome measure developed to determine the physical disabilities of the arm, shoulder, and hand.[99] The Quick DASH (Appendix C) was given to the subjects to answer as a baseline measurement and at hours 24, 48, and 72 before treatments began on that day. This measured the disability of the subject's arm, shoulder, and hand for the previous 24 hour time period. The scores for each section was tallied up and recorded for each day. This yielded scores between 11 and 55; where increased scores represented increased perceived disability. The use of the Quick DASH has been shown to be highly reliable and valid with an ICC=0.96.[134]

Muscular Damage Inducing Protocol

The eccentric load for each subject was based on the subject's estimated curl 1-RM. The DOMS-inducing exercise had been performed in other studies and had been found to be effective in the induction of DOMS.[104,105] Subjects performed 5 sets of 10 repetitions of eccentric contractions with a load 120% of their estimated curl 1-RM. This was followed by 2 sets of 10 repetitions of eccentric contractions with a load of 100% of their estimated curl 1-RM. During each of the eccentric contractions, the subject resisted the weight throughout their full range of motion (ROM). The eccentric contractions lasted between 3 and 5 seconds and were monitored by the principle investigator. A metronome, set at 60 beats per second, was utilized to maintain timing of each life. After each eccentric contraction was completed, the dumbbell was lifted back into its starting position by the principle investigator. The subjects had a 3 minute rest period between sets to allow for recovery of the phosphocreatine system.[98] The steps were repeated until all the sets and repetitions were completed. Times between sets and length of time during eccentric contractions were measured using a stopwatch.

Treatment Protocol

Subjects were randomly allocated into one of three groups. Randomization was performed by the sequencing of the subjects sign-up. Beginning with the first subject to sign up, the principle investigator counted 1, 2, and 3 (the group number) before subjects report to the testing site. The control group, Group 1 did not receive any forms of modalities or treatments for DOMS. Subjects reported back for measurements each

following day for 72 hours. The principle investigator stressed, to the subjects, the importance of not utilizing any forms of modalities or treatments.

Group 2 was treated using thermotherapy, specifically hot water immersion (HWI). Following their follow-up measurements each day, subjects in Group 2 were treated. The protocol called for the hot water bath temperature to be maintained between 43 to 45 °C (109 to 113°F).[125] Water temperatures were maintained by monitoring a temperature gauge located on the whirlpool. The subject's limb was completely submerged in the water bath for 20 minutes.[126]

Group 3 was treated using Epsom salt and thermotherapy, specifically Epsom salt and hot water immersion (EHWI). Following their follow-up measurements each day, subjects in Group 3 were treated. The protocol called for Epsom salt to be completely dissolved in warm water. An Epsom salt concentration of 1% was used, equal to approximately 600g Epsom salt per 15 gallons of water, the approximate volume of the extremity whirlpool.[125] The subject's limb was completely submerged in the hot water. The water temperature was maintained between 43 to 45 °C (109 to 113 °F) and each treatment lasted for 20 minutes.[125-126] Water temperatures were maintained by monitoring a temperature gauge located on the whirlpool.

Special Consideration

Salt Concentration

The concentration of the salt and water mixture was formulated using a concentration of 1%; allowing for adequate absorption of magnesium sulfate into the

body.[125] This equates to 1g MgSO4/100 mL of water or 600 g Epsom salt per 15 gallons.[125] The immersions of the limbs was in a 15 gallon whirlpool.

Questionnaires

For this study, it was important for the subjects to follow the protocol and their treatments. To help ensure the subjects did not utilize any other forms of modalities to treat their DOMS, subjects completed a quick questionnaire before their treatments each day that determined if they had been following protocol (Appendix H). If the subjects deviated from the protocol, they were excluded from the study.

Statistical Analysis

Data analysis was performed using the Statistical Package for Social Sciences, version 17 (SPSS, Inc, Chicago, IL). Descriptive statistics were assessed for central tendencies. A 3 x 4 Repeated Measures Analysis of Variance (ANOVA) was run to detect significant differences between the groups. Where there were significant differences, a Tukey's Post-Hoc statistical analysis was performed to determine where those significant differences were located. In addition, the effect size was determined using a Cohen's d with a 95% confidence interval. Anthropometric measurements at centimeter 1, 3, and 5 were combined and averaged for calculating effect size. The alpha level was set at a $p < 0.05$ for all analysis.

CHAPTER IV

MANUSCRIPT

Introduction

Muscle fatigue and soreness are common afflictions affecting athletes each season. Delayed onset muscle soreness (DOMS) is a condition that occurs when inactive individuals begin physically demanding exercise or physically active individuals attempt increases in loads of exercise that are not what they are accustomed to. It was first suggested that pain occurs after exercise was due to damage of the muscle fibers.[1] This has lead to several investigations on the mechanisms of injury and methods of treatment for DOMS or exercise-induced muscle soreness.[2-6] Delayed onset muscle soreness has been generally described as damage to muscle fibers located within the active muscle after performing eccentric contractions.[2-7] The symptoms, which are exacerbate between 24 and 48 hours post exercise, that are commonly associated with DOMS include increased edema, decreased range of motion, decreased muscular strength, and increased perceived pain and disability.[6,7] Delayed onset muscle soreness is considered common in physical activity and the risk factors need to be identified. One risk factor is decreased cushioning abilities of muscles because normal range of motion of a joint is decreased; thus, reducing the ability to absorb shock during impact and places unaccustomed loading on joints and tissues.[6] Delayed onset muscle soreness may alter muscle sequencing,

changing coordination and motion while placing unaccustomed strain on muscles, ligaments, and tendons during functional activity.[8]

The damage to the integrity of the sarcoplasmic membrane, which acts as a barrier for the concentrations between the extra-cellular and intracellular spaces, leads to a calcium leakage or loss of calcium homeostasis.[39] It has been suggested that calcium concentrations exacerbate muscle damage following eccentric exercise by increasing intracellular calcium concentration.[41-46] Magnesium is considered an essential mineral that is needed in the human body for multiple physiological functions such as increased calcium uptake in the sarcoplasmic reticulum and stimulates the rate limiting step of the ATPase activity associated with calcium transport.[106-108] It has been demonstrated that magnesium lowers the calcium concentration to inhibit the induction of further calcium released in skinned muscle fibers and from sarcoplasmic reticulum vesicles.[110,111,113] Magnesium also reduces both nerve and muscle excitability; therefore, there is the possibility of decreased pain or muscle stiffness associated with DOMS.[115]

The purpose of this study was to determine the effectiveness of magnesium sulfate (Epsom Salt) in reducing the effects of exercise-induced DOMS on range of motion, edema, perceived soreness and disability, and muscle strength. A secondary purpose was to determine the effectiveness of thermotherapy in reducing the effects of DOMS.

Key Words: Epsom salt, thermotherapy, hot water immersion, magnesium, calcium.

Methods

Subjects

Twenty-six healthy and physically active males and females (n_m= 14, $n_{f=}$12, 16.04±1.08 yrs, 172.54±8.13 cm, 72.42±18.99 kg) volunteered to participate in this research. There were no dropouts from this study; however, this study was unable to get the initial 15 subjects per group due to time constraints. Subjects were randomly selected to be in one of three groups ($n_{Control}$=8, $n_{HWI=}$9, and n_{EHWI}=9). Inclusion criteria was limited to 14 to 18 y/o who participate in at least 30 minutes of moderate level exercise 3 to 4 days a week, and must perform upper body strength training but not more than 4 days per week. Subjects were excluded from the study for any medical problems including: a failed neurological screening, history of upper limb pathology, pain, a history of cardiopulmonary problems, pregnancy, epilepsy, or diabetes. Permission to perform this investigation was granted by the Boerne Texas Independent School District and the Texas State University-San Marcos Institutional Review Board. After receiving a complete verbal and written description of the experimental protocol and potential risks, each subject provided an informed written assent and a parent or legal guardian provided written consent before beginning the study. Subjects performed a neurological screening administered by the principle investigator before participation in the study. Additionally, medical history was conducted and reviewed by the principle investigator, a licensed healthcare provider.

Procedures

Subjects reported to the testing area prior to start of the study to receive and review the consent form from the principle investigator. Subjects were then randomly allocated to one of three groups but were blinded to intervention. Randomization was done by the sequencing of the subjects sign-up. Beginning with the first subject to sign up, the principle investigator counted 1, 2, and 3 (the group number) before subjects report to the testing site. Each was informed of the investigational methodology and asked to report to the testing location the following day in their designated time periods. All testing was performed on subject's non-dominant arm. To ensure repeatability and reliability of anthropometric and resting angle measurements, the designated sites were marked using a black permanent marker.

Measurements

Anthropometric Measurements

Anthropometric girth (Anth) measurements of the bicep muscle were taken to determine the amount of swelling within the muscle and tendon of the biceps brachii. A non-stretch anthropometric measuring tape (MEDCO, Tonawanda, NY) was used to measure the circumference with the elbow fully extended at three sites: the mid-bicep belly, the musculotendinous juncture, and the distal bicep tendon. These sites were measured at 1, 3, and 5 centimeters from the crease on the cubital fossa. Each site was measured (in centimeters) three times and the averages were calculated and recorded. The use of a standard non-stretch anthropometric measuring tape has been shown to be highly reliable with a coefficient of reliability (r=0.97).[132]

Resting Angle

Resting angle (RA) of the elbow was measured with subjects standing in the anatomical position to allow elbow extension (degrees) and averaged out from three trials using a universal 12.5 inch transparent plastic goniometer (MEDCO, Tonawanda, NY). The goniometer fulcrum was located over the lateral epicondyle, the stationary arm pointing toward the greater tubercle of the humerus, and the moving arm was aligned along the lateral border of the radius pointing toward the styloid process of the distal radius. The use of a standard plastic goniometer has been shown to be highly reliable and valid with a coefficient of reliability (r=0.94).[133]

Muscular Strength

Muscular strength (1-RM) of the subject's non-dominant elbow flexors (biceps brachii) was determined using an estimated 1-repetition maximum (1-RM) of a dumbbell curl. To isolate the biceps brachii muscle, the subjects sat on a preacher's curl bench facing forward, with their triceps resting over the front of the stationary bench and their forearm fully supinated.[86] The principle investigator monitored the subjects to ensure the subjects were performing the lifts in the correct manner. The subjects performed multiple repetitions until the subject could not complete any more lifts. The subject's 1-RM or muscular strength was determined utilizing a multiple one rep max chart (Appendix A).[97] If the subject completed 10 repetitions without achieving a maximal level of exertion, they were asked to return the following day to complete the testing for recovery.[98]

Perceived Soreness

Perceived soreness was assessed using a graphic pain rating scale (GPRS) (Appendix B) that was developed to assess DOMS.[19] Subjects were asked to rank their perceived soreness on the GPRS between "No pain nor discomfort" and "Unbearable pain or discomfort", with descriptive sensations located between these two extremes.[77] The GPRS was performed immediately after the initial eccentric workload and before the treatment (Groups 2 and 3) on day one. Each subject was then asked to complete the GPRS in response to their symptoms during the testing for muscular strength in the following days thereafter. The perceived pain was quantified by measuring the distance from the far left to the subject's line (to the nearest ½ centimeter), then multiplied by 2 to eliminate fractional scores; yielding scores between 0 and 24.

Perceived Disability

Perceived disability was assessed by having subjects fill out the Quick DASH, an outcome measure developed to determine the physical disabılities of the arm, shoulder, and hand.[99] The Quick DASH (Appendix C) was given to the subjects to answer as a baseline measurement and at hours 24, 48, and 72 before treatments began on that day. This measured the disability of the subject's arm, shoulder, and hand for the previous 24 hour time period. The scores for each section was tallied up and recorded for each day. This yielded scores between 11 and 55; where increased scores represented increased perceived disability.

Muscular Damage Inducing Protocol

The eccentric load for each subject was based on the subject's estimated curl 1-RM. The eccentric loading protocol had been found to be effective in the induction of DOMS.[104,105] Subjects performed 5 sets of 10 repetitions of eccentric contractions with a load 120% of their estimated curl 1-RM. This was followed by 2 sets of 10 repetitions of eccentric contractions with a load of 100% of their estimated curl 1-RM. During each of the eccentric contractions, the subject resisted the weight throughout their full range of motion (ROM). The eccentric contractions lasted between 3 and 5 seconds and were assisted by the principle investigator. A metronome, set at 60 beats per second, was utilized to maintain timing of each lift. The subjects had a 3 minute rest period between sets to allow for recovery of the energy systems.[98] The steps were repeated until all the sets and repetitions were completed.

Treatment Protocol

Day 1: Start of Testing

Subject returned to the testing site, with consent form signed by proper individuals. Subjects completed neurological examination and medical history forms. A "Pass or Fail" status was given by the principle investigator. Receiving a "Fail" status prohibited the continuation of that subject in the investigation. Subject demographics information was recorded.

Anthropometric measurements, resting angle, muscular strength, and perceived soreness and disability (GPRS and DASH) were taken as baseline measurements. Following all baseline measurements, the subjects went through the eccentric inducing

protocol. All groups retested measurements for hour 0. For the treatment protocol, Group 1 was allowed to leave after their retesting was completed (Control). Group 2 was treated using hot water immersion (HWI). Group 3 was treated using Epsom salt and hot water immersion (EHWI).

Day 2-4: 24-72 Hours Post Inducing Exercise

Subjects reported back to the testing site at their designated time. All subjects had measurement retaken at this time. The treatment protocol was repeated for each group. Group 1 was allowed to leave after their measurements were completed. Group 2 was treated using HWI. Group 3 was treated using EHWI.

The control group, Group 1 did not receive any forms of modalities or treatments for DOMS. Subjects reported back for measurements each following day for 72 hours. The principle investigator stressed, to the subjects, the importance of not utilizing any forms of modalities or treatments.

Group 2 was treated using thermotherapy, specifically HWI following their follow-up measurements each day. The protocol called for the hot water bath temperature to be maintained between 43 to 45 °C (109 to 113°F).[125] Water temperatures were maintained by monitoring a temperature gauge located on the whirlpool. The subject's limb was completely submerged in the water bath for 20 minutes.[126]

Group 3 was treated using EHWI following their follow-up measurements each day. An Epsom salt concentration of 1% was used, equal to approximately 600g Epsom salt per 15 gallons of water, the approximate volume of the extremity whirlpool.[125] The subject's limb was completely submerged in the hot water. The water temperature was

maintained between 43 to 45 °C (109 to 113 °F) and each treatment lasted for 20 minutes.[125-126] Water temperatures were maintained by monitoring a temperature gauge located on the whirlpool.

Statistical Analysis

Data analysis was performed using the Statistical Package for Social Sciences (v.17, SPSS, Inc, Chicago, IL). Descriptive statistics were assessed for central tendencies. A 3 x 4 Analysis of Variance (ANOVA) with repeated measure on days were used to analyze all measures. Where there were significant differences, a Tukey's Post-Hoc statistical analysis was performed to determine where those significant differences were located. In addition, the effect size was determined using a 95% confidence interval. The alpha level was set at a $p < 0.05$ for all analysis.

Results

Multivariate tests showed there to be no significant main effect between subjects for treatments, $F(14,36) = 1.58$, $p = 0.132$. There was a main effect within subjects with respect to days, $F(3,21) = 13.196$, $p = 0.028$. There was no interaction within subjects for days and treatment, $F(8,42) = 1.465$, $p = 0.296$. Means and standard deviations are recorded in Table 3.

Mauchly's Test of Sphericity was not violated for the GPRS and DASH tests, but degrees of freedom for all other measurements were adjusted using the Greenhouse-Geisser correction to avoid a Type I error. As expected, there were significant differences in measurements in respect to within-subjects (days). There were significant

differences ($p<0.05$) between baseline and 24 hours post inducing exercise suggesting DOMS had occurred. At 72 hours post inducing exercise, all measures were significantly different ($p<0.05$), showing there were significant differences for all measure relative to the baseline measurement. There was no main effect between-subjects effect in respect to treatment except for two measures (Table 4). There were significant differences in the GPRS, $F(2,23) = 8.95$, $p<0.01$, and DASH measures, $F(2,23) = 3.89$, $p=0.035$. These two measures also demonstrated moderate to strong observed power (GPRS: 0.952 and DASH: 0.643) with a 95% CI.

Tukey's Post Hoc Test for multiple comparisons was utilized to determine where significant differences lay for the between-subjects (treatment groups) effects on individual measures (Table 1). The GPRS scores are significantly different when comparing the control versus HWI group ($p=0.002$) and when comparing the control versus EHWI group ($p=0.007$). This shows there was an effect with the use of either treatment group (HWI or EHWI). There was a decrease in GPRS scores for both treatment groups (HWI and EHWI) at 48 hours post exercise. However, significant differences were not seen until 72 hours post exercise. There was no significant difference when comparing HWI and EHWI groups ($p=0.804$). Therefore, there was no effect of the Epsom salt on the treatment (Figure 1). The DASH scores were significantly different when comparing the control versus HWI group ($p=0.027$). After 72 hours post exercise, the control group had the highest DASH score, followed by EHWI, and then HWI with the lowest amount of perceived disability. This suggests there is an effect of HWI treatment on DASH scores. However, there were no significant differences when

comparing control versus EHWI group or the HWI and EHWI group (Figure 2). Means and standard deviations for GPRS and DASH scores are represented in Table 2.

Table 1: Tukey's Post Hoc Values

Variable	Control (n=8)	vs HWI (n=9)	vs EHWI (n=9)
Anth1	25.2188	26.79; 0.613	25.19; 1.0
Anth3	25.8	27.3; 0.684	25.73; 0.99
Anth5	26.47	28.17; 0.659	26.39; 0.99
RA	154.21	156.51; 0.799	156.13; 0.855
RM	13.12	13.2; 0.99	12.15; 0.891
GPRS	11.16	7.39; 0.002*	7.97; 0.007*
DASH	20.84	16.33; 0.27*	18.64; 0.377

Averaged means over time, significant difference versus control
Based on observed means
*. Significantly different at $p<0.05$

Table 2: Means and Standard Deviations for GPRS and DASH Scores

Variable	Control (n=8)	HWI (n=9)	EHWI (n=9)
GPRS			
Baseline	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
24 hr post ex	11.63 ± 4.44	10 89 ± 2.71	10.56 ± 3.78
48 hr post ex	16.13 ± 3.44	12.22 ± 3.11	13.56 ± 3.09
72 hr post ex	16.88 ± 3.0	6.44 ± 4.04	7.78 ± 4.87
DASH			
Baseline	11.0 ± 0.0	11.0 ± 0.0	11.0 ± 0.0
24 hr post ex	18.38 ± 2.83	20.0 ± 5.07	20 89 ± 8.95
48 hr post ex	24.63 ± 2.77	19.11 ± 4.04	24.11 ± 8.40
72 hr post ex	29.38 ± 3.25	15.22 ± 4.12	18.56 ± 5.32

Mean and Standard Deviation (Mean ± SD)

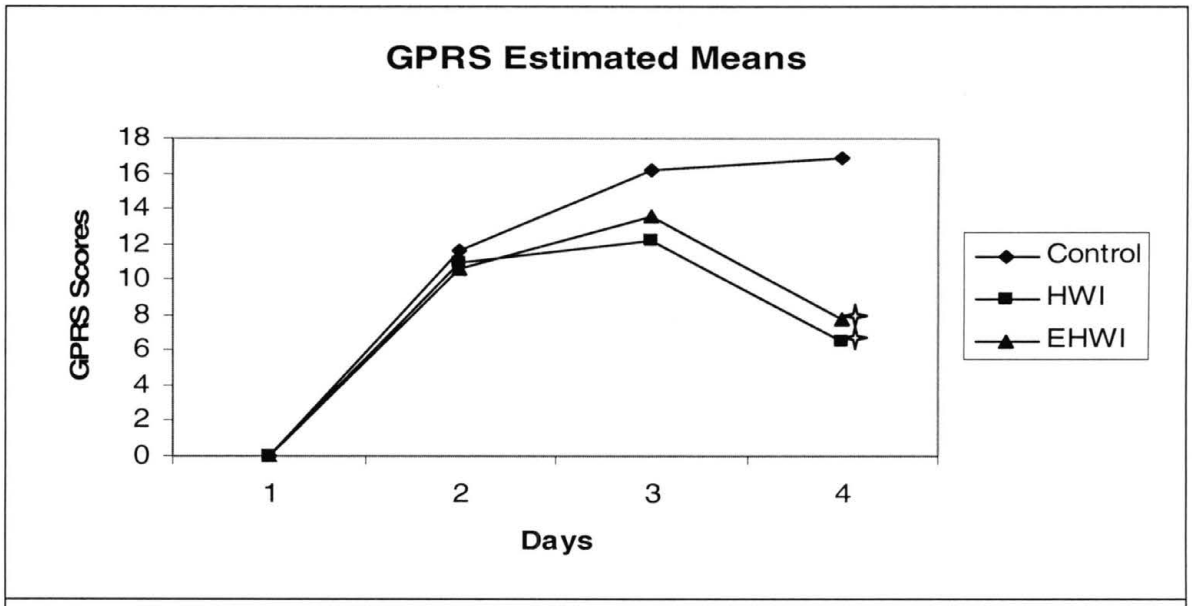


Figure 1: GPRS Estimated Means

✧. Significant difference ($p<0.05$) from Control Group

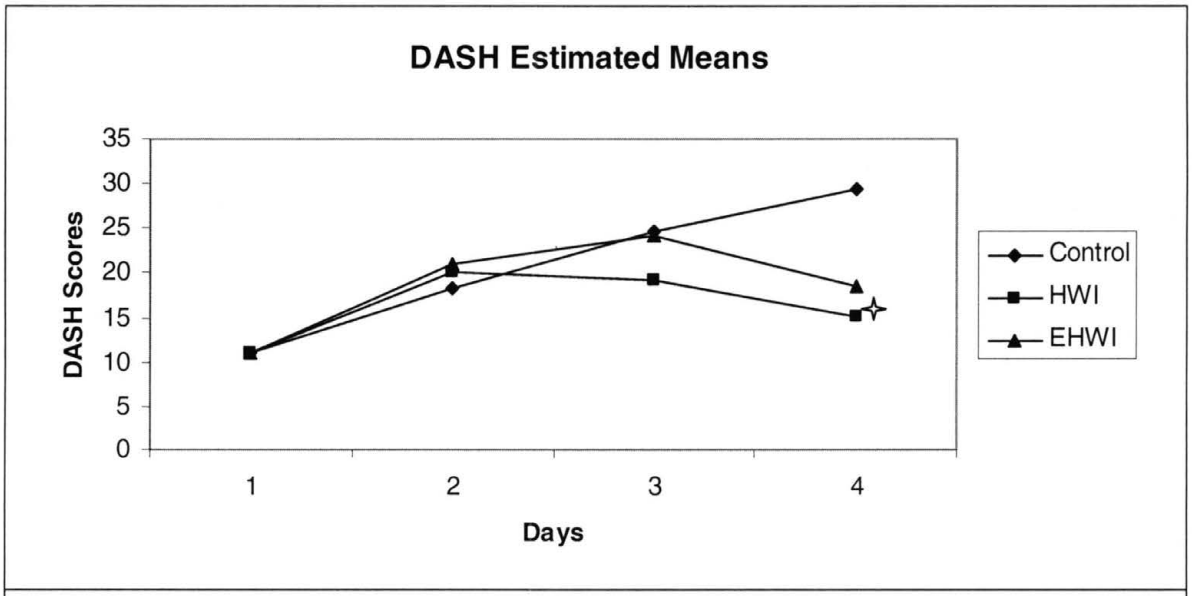


Figure 2: DASH Estimated Means

✧. Significant difference ($p<0.05$) from Control Group

The effect size analyses of anthropometric measurements for control versus treatment groups (HWI and EHWI) were calculated for each dependent measure with a 95% confidence interval. Anthropometric measurements at centimeter 1, 3, and 5 were

combined for determining effect size. Effect size analyses showed no clinically significant effects between control and treatment groups. However, the effect size analysis showed large, clinically significances in both the GPRS and DASH effects. Clinical significant for GPRS effects sizes at 72 hours post inducing exercise were found in both control versus HWI, d=2.94 (95% CI, 0.86-5.57) and control versus EHWI, d=2.28 (95% CI, 0.2-5.46). Effect sizes analyses for DASH also showed significant clinical differences at 72 hours post inducing exercise for control versus HWI, d=3.81 (95% CI, 1.56-6.5) and control versus EHWI, d=2.49 (95% CI, 0.23-5.96).

Discussion

The purpose of this study was to determine the effectiveness of magnesium sulfate (Epsom Salt) in reducing and limiting the effects of exercise-induced DOMS, including decreased range of motion, edema, muscle strength, and increased perceived soreness and disability. A secondary purpose was to determine the effectiveness of thermotherapy in reducing the effects of DOMS. Additionally, it was hypothesized that the use of thermotherapy will reduce the effects of DOMS.

Magnesium sulfate has no effect in reducing DOMS following muscle injury for all measures except perceived pain and disability. The GPRS and DASH demonstrated significant differences for treatment with moderate to strong levels of observed power. This suggests treatments of HWI or EHWI was an effective treatment of pain following onset of DOMS. There were no significant differences found in the other measurements, however, the observed powers for these measures were weak. This suggests the number of participants may have been too small to have possibly found a significant difference.

Determining swelling and edema by anthropometric measurements is a useful measurement technique to determine certain characteristics of DOMS as a result to eccentric exercise and has been used in multiple studies.[83-88] The use of thermotherapy on acute injuries is considered to be a contraindication because it acts in opposition to cryotherapy by increasing heart rate, cardiac output, tissue temperatures, and may increase the inflammatory response.[122] Therefore, it was expected to have increases in edema in the area of tissue damage and the results showed there to be a moderate effect size at 24 and 48 hours post exercise with the HWI treatment. However, we found no significant differences for therapeutic treatment on anthropometric measurements. All anthropometric measurements were significantly increased over time, but were not significantly higher than the control group. This is similar to a previous investigation that found no significant difference for HWI versus control group over time.[105]

Decreases in range of motion is a sign of DOMS and resting angle was used in this study as an indirect method of measuring muscle tightness due to tissue shortening.[3,86-91] Due to the lack of previous research on thermotherapy on DOMS, it was difficult to analyze and compare the results of this study. A study by Kuligowski et al. reported no significant differences in active elbow extension with the use of warm whirlpool on range of motion. However, their range of motion for extension was measured through active range of motion and not passively.[79] Range of motion, in this study, did decrease over time; however, it did not differ between treatment groups.

Strength is decreased after eccentric exercise and the induction of DOMS.[3] The condition presents the loss of contractile force production, thus not allowing for full contractile potential.[36,92-96] This hypothesis is based on the direct relationship of the

mechanical loading on individual myofibrils that occur in response to eccentric contractions and leads to a cascade of damaging events. In muscle force production, eccentric contractions activate fewer motor units than in concentric contractions.[22-27] This equates to a smaller cross-sectional area of muscle to perform the same load amount in eccentric contractions than that of concentric contractions.[28] Due to the lack of previous research on DOMS, only one study was found to compare muscular strength with thermotherapy. Kuligowski et al.[79] reported no significant differences in maximal voluntary isometric contraction values between treatment groups. This investigation agrees with the findings of the present study which utilized multiple repetitions to calculate the subject's one repetition max as opposed to utilizing isometric contractions.[79]

Perceived pain and disability are common symptoms experienced in the presence of DOMS.[6,7] This present investigation found significant decreases in perceived pain and disability for both treatment groups (HWI and EHWI) in the GPRS and DASH scores when comparing the control group. This is contradictory to a similar studies that found there to be no significant difference in perceived pain when comparing hot water immersion and a control group.[79,105] One study compared the effect of whirlpool therapy on DOMS and utilized the same GPRS and the another that utilized a visual analogue scale.[79,105] A slightly modified GPRS to fit the pain experienced by the subject during the physical exertion (muscular strength) testing was designed toward physical activity due to the descriptors found within the test. The use of a thermal modality is important because thermoreceptors on the skin are thought to alleviate muscle soreness or pain.[123-124] Mayer et al. found a 138% improvement of pain relief with a heat wrap treatment in comparison to the use of a cold pack at 24, 48, and 56 hours post exercise.[131]

No significant differences were found between the HWI and EHWI treatment groups for any measure, including the GPRS and DASH measures. One explanation is the lack of absorption of magnesium through the skin, potentially due to the difference in water temperatures utilized in this study as compared to Waring's study.[125] Waring's investigation reported significant increases of magnesium sulfate absorption through the skin at a temperature of 50 to 55 degrees C (or 122 to 131 degrees F) for 12 minutes.[125] However, these temperatures may be quite extreme; therefore, the temperature of the warm bath in the present study was set at 43 to 45 degrees C (109 to 113 degrees F) as demonstrated by common treatment parameters for treatment of the arm or hand.[126]

Conclusion

There were significant decreases between treatment groups (HWI and EHWI) versus the control group in respects to GPRS and DASH scores. There were no significant differences for any other measures with respect to treatment versus control, possibly because the sample size may have been too small to demonstrate a significant difference. More importantly, there were no differences between the HWI versus EHWI treatment groups. The lack of significant difference may be due to the lack of magnesium absorption across the skin or because magnesium levels did not effect the calcium influx and absorption in the muscle.

Based on the results of this study, it was concluded that the protocols utilized did not produce complete relief from DOMS to the biceps muscle to be considered an effective treatment. The results also show that the use of thermotherapy could be utilized to treat perceived pain and disability. This study did not result in any adverse or

damaging effects as result to the use of thermotherapy. Therefore, a clinician may feel safe in utilizing thermotherapy as a treatment for DOMS to reduce perceived pain and disability in an "acute" incident. Future investigations should incorporate less assistance of the spotter during the eccentric loading phase or a protocol that would remove this from the inducing protocol. The use of more subjects per group will increase the power to the study and may produce significant differences between treatment groups. Future investigations should utilize isokinetic instruments for more accurate muscular strength measurements. The estimated one repetition maximum may produce inaccuracies when determining values. Future investigations should include a measure to determine magnesium absorption through the skin such as blood draws or urine sampling. Future investigations could also utilize higher water temperatures to facilitate magnesium absorption through the skin. However, it is advised not to exceed the safety limits of water temperature for how water immersion of an extremity.

CHAPTER V

CONCLUSION, APPLICATION, AND RECOMMENDATIONS

Conclusion

There were significant decreases between treatment groups (HWI and EHWI) versus the control group in respects to GPRS and DASH scores. There were no significant differences for any other measures in respect to treatment versus control; however, the observed powers for these measures were weak. This suggests the number of participants may have been too small of a sample to identify a significant difference. More importantly, there were no differences between the hot water immersion (HWI) and the hot water and Epsom salt (EHWI) treatments. Additionally, the lack of significant difference may be due to the lack of magnesium absorption across the skin or because magnesium levels did not effect the calcium influx and absorption in the muscle.

Application and Recommendations

Based on the results of this study, it was concluded that the protocols utilized did not produce complete relief from DOMS to the biceps muscle to be considered an effective treatment. The results also show that the use of thermotherapy could be utilized to treat perceived pain and disability. This study did not result in any adverse or damaging effects as result to the use of thermotherapy. Therefore, a clinician may feel safe in utilizing thermotherapy as a treatment for DOMS to reduce perceived pain and

disability in an "acute" incident. Future investigations should incorporate less assistance of the spotter during the eccentric loading phase or a protocol that would remove this from the inducing protocol. The use of more subjects per group will increase the power to the study and may produce significant differences between treatment groups. Future investigations should utilize isokinetic instruments for more accurate muscular strength measurements. The estimated one repetition maximum may produce inaccuracies when determining values. Future investigations should include a measure to determine magnesium absorption through the skin such as blood draws or urine sampling. Future investigations could also utilize higher water temperatures to facilitate magnesium absorption through the skin. However, it is advised not to exceed the safety limits of water temperature for how water immersion of an extremity.

Table 3: Means and Standard Deviations

Variable	Control (n=8)	HWI (n=9)	EHWI (n=9)
Anth1			
Baseline	24.27 ± 2.36	25.28 ± 3 08	24.81 ± 4.35
24 hr post ex	25.25 ± 2 16	26.93 ± 3.3	25.2 ± 4.33
48 hr post ex	25.56 ± 1.99	27.06 ± 3.14	25.6 ± 4.62
72 hr post ex	25.79 ± 1.98	26.89 ± 3.2	25.13 ± 4.38
Anth3			
Baseline	24.77 ± 2.65	26.76 ± 3 67	25.31 ± 4.3
24 hr post ex	25.77 ± 2.43	27.43 ± 3.81	25.67 ± 4.68
48 hr post ex	26.3 ± 2.37	27.56 ± 3.68	26.11 ± 4.82
72 hr post ex	26.38 ± 2.31	27.44 ± 3.78	25.81 ± 4.29
Anth5			
Baseline	25.61 ± 3.13	27.6 ± 4.2	25 8 ± 4.67
24 hr post ex	26 6 ± 2 51	28.28 ± 4.15	26.46 ± 5.03
48 hr post ex	26.81 ± 2.44	28.5 ± 4 14	26.87 ± 5.06
72 hr post ex	26.85 ± 2.32	28 32 ± 4 23	26.44 ± 4 58
RA			
Baseline	165.88 ± 4.02	160.51 ± 10.79	162 93 ± 6.88
24 hr post ex	157.0 ± 6.28	154.52 ± 9.05	152.85 ± 6.83
48 hr post ex	149.13 ± 9.25	153.11 ± 8.08	153.56 ± 7.83
72 hr post ex	144.83 ± 12.44	157.89 ± 7.78	155.18 ± 9.06
RM			
Baseline	14 91 ± 4.08	13.61 ± 3 89	13.73 ± 5.92
24 hr post ex	13.18 ± 3.68	12 47 ± 4.2	10.56 ± 4.66
48 hr post ex	11.76 ± 3 64	12.98 ± 3 31	11.71 ± 5.85
72 hr post ex	12.62 ± 3.4	13 73 ± 4.02	12.6 ± 5.47
GPRS			
Baseline	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
24 hr post ex	11.63 ± 4.44	10.89 ± 2.71	10.56 ± 3.78
48 hr post ex	16.13 ± 3.44	12.22 ± 3.11	13.56 ± 3.09
72 hr post ex	16.88 ± 3 0	6.44 ± 4.04	7.78 ± 4.87
DASH			
Baseline	11.0 ± 0.0	11.0 ± 0.0	11.0 ± 0.0
24 hr post ex	18.38 ± 2.83	20.0 ± 5.07	20.89 ± 8.95
48 hr post ex	24.63 ± 2.77	19.11 ± 4.04	24.11 ± 8.40
72 hr post ex	29.38 ± 3.25	15.22 ± 4.12	18.56 ± 5.32

Mean and Standard Deviation (Mean ± SD)

Table 4: Tests of Between-Subjects (Treatment) Effects

Measure	F-Ratio Value	Observed Power[a]
Anth1	F(2,23) = 0.646, p=0.533	0.145
Anth3	F(2,23) = 0.514, p=0.605	0.124
Anth5	F(2,23) = 0.561, p=0.578	0.132
RA	F(2,23) = 0.232, p=0.794	0.082
1-RM	F(2,23) = 0.159, p=0.854	0.072
GPRS	F(2,23) = 8.95, p<0.01	0.952
DASH	F(2,23) = 3.89, p=0.035	0.643

[a]. Computed using alpha = 0.05

APPENDIX A

ESTIMATED 1-RM TABLE[97]

Table 26.1 Estimating One-Repetition Maximum

% of 1RM:	100.0	93.5	91.0	88.5	86.0	83.5	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	37.6	36.5	35.3	34.2	33.1
	50.0	46.8	45.5	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	68.3	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	106.0	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	132.0	128.3	124.7	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	141.3	136.8	132.3
	185.0	173.0	168.4	163.7	159.1	154.5	149.9	145.2	140.6	136.0
	190.0	177.7	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 1RM:	100.0	93.5	91.0	88.5	86.0	83.5	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	209.5
	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	265.5	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	299.7	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

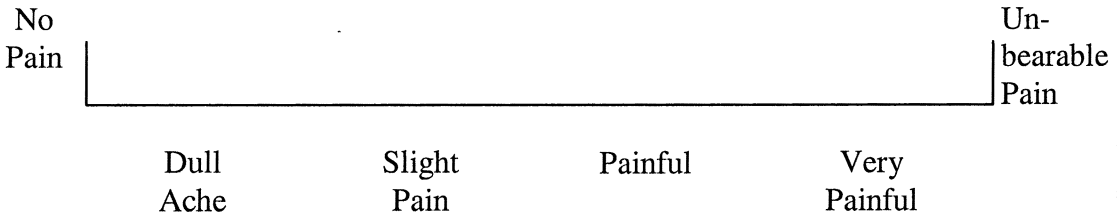
(continued)

APPENDIX B

GRAPHIC PAIN RATING SCALE

Graphic Pain Rating Scale (GPRS)	**Subject Identification Number: _____** **Test Session: _____**

Dull Ache	A feeling of discomfort during activity
Slight Pain	An awareness of pain without distress
Painful	Pain distracts attention from routine physical exertion
Very Painful	Pain fills the field of consciousness to the exclusion of exertional events
Unbearable Pain	Comparable to the worst pain you can imagine



GPRS: Filled out in response to pain experienced during physical exertion (ie muscular strength test). The scale for this study was based on the graphic pain rating scale developed by Denegar and Perrin (1992).[77]

APPENDIX C

THE QUICK-DASH[99]

THE Quick DASH
OUTCOME MEASURE

INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer *every question*, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your best estimate of which response would be the most accurate.

It doesn't matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.

Quick DASH

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar	1	2	3	4	5
2. Do heavy household chores (e g , wash walls, floors)	1	2	3	4	5
3 Carry a shopping bag or briefcase	1	2	3	4	5
4. Wash your back	1	2	3	4	5
5 Use a knife to cut food	1	2	3	4	5
6 Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
7. During the past week, *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 LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
8. During the past week, 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 week. (circle number)	NONE	MILD	MODERATE	SEVERE	EXTREME
9. Arm, shoulder or hand pain	1	2	3	4	5
10. Tingling (pins and needles) 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
11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? (circle number)	1	2	3	4	5

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is _____

☐ I do not work (You may skip this section)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Using your usual technique for your work?	1	2	3	4	5
2 Doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3 Doing your work as well as you would like?	1	2	3	4	5
4 Spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you

Please indicate the sport or instrument which is most important to you _____

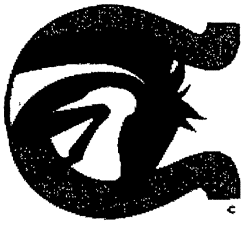
☐ I do not play a sport or an instrument (You may skip this section)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1 Using your usual technique for playing your instrument or sport?	1	2	3	4	5
2 Playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. Playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4 Spending your usual amount of time practicing or playing your instrument or sport?	1	2	3	4	5

APPENDIX D

BOERNE-SAMUEL V. CHAMPION HIGH SCHOOL APPROVAL FORM



Boerne–Samuel V. Champion High School
An Exemplary School

201 Charger Blvd. Boerne, Texas 78006
Phone: 830.357.2600 Fax: 830.357.2699

February 17, 2010

Texas State University-Institutional Review Board
Texas State University
Department of Health, Physical Education and Recreation
San Marcos, TX 78666

Dear. Texas State University-Institutional Review Board

Mr. Nathan Byerley has my permission to perform research at Champion High School for his thesis.

If you have questions or concerns, please let me know

Sincerely,

David Stelmazewski
Principal

APPENDIX E

IRB APPROVAL FORM

TEXAS STATE UNIVERSITY
SAN MARCOS
The rising STAR *of Texas*

Institutional Review Board Application

Certificate of Approval

Applicant: Nathan Byerley

Application Number : 2010P2005

Project Title: Effects of Magnesium Sulfate on Delayed Onset Muscle Discomfort

Date of Approval: 05/13/10 14:24:33

Expiration Date: 05/13/11

Assistant Vice President for Research and Federal Relations

Chair, Institutional Review Board

APPENDIX F

CONSENT FORM

Department of Health, Physical Education, and Recreation
Texas State University – San Marcos, Texas

The Effects of Magnesium Sulfate (Epsom Salt) on Delayed Onset Muscle Discomfort

IRB #: 2010P2005

The principle investigators are Nathan Byerley (nb1158@txstate.edu or 210-860-2883) and Dr. Jack Ransone (ransone@txstate.edu or 512-245-8176) at Texas State University. If you have any questions or concerns regarding this research study, please contact us by either email or phone provided.

Research Intent and Purpose

The purpose of this study is to determine the effectiveness of magnesium sulfate (Epsom salt) in reducing the restrictions and limitations of exercise-induced delayed onset muscle discomfort including decreased range of motion, inflammation, increased perceived discomfort, and decreased isotonic muscle strength. A secondary purpose is to determine the effectiveness of a warm bath in reducing the restrictions and limitation of induced delayed onset muscle discomfort. You have been asked to participate in this research study to help us enhance our understanding of the effects of Epsom Salt and a warm bath on delayed onset muscle discomfort.

Procedures

Subjects will be selected based on their age (15-18 years of age) and athletic involvement (at least 30 minutes of moderate exercise a day, 3-4 days per week) and must not lift

upper body weights more than 4 days per week. You will be instructed to wear a t-shirt during the testing to allow for exposure of the arm. The following procedures for this experimental study will be conducted in the Boerne-Samuel V. Champion High School Athletic Training and weight rooms. It will take 4 days and approximately 30-35 minutes to conduct tests and provide the treatment protocol.

1. You will answer the Quick-DASH and health questionnaires.
    a) Quick-DASH: a quality of life questionnaire which assess your ability to perform certain daily activities. Questionnaire will be performed as a baseline, at 0, 24, 48, and 72 hours post exercise. The questionnaire should take less than 1 minute to complete.
    b) Health Questionnaire: assesses the medical history and upper body neurological status of the subject. It will assess the range of motion, strength, and nervous system of the upper body. The health questionnaire will also determine any complications such as difficulty breathing with mild exertion, dizziness, fainting, and irregular or rapid heartbeats. This questionnaire will be performed once at the beginning prior to starting the research. It will take 2 minutes to complete. The name of a contact individual in case of an emergency and a signature will be required from the participant.
2. An examination of proper functioning or the arm will be performed in the athletic training room by the principle investigator (Nathan Byerley, a licensed and certified Athletic Trainer/healthcare provider) as a part of the Health Questionnaire. Tests to determine proper arm function include:
    a. Range of Motion: The ability to perform normal shoulder, elbow, and hand and wrist motions.
        i. Shoulder should be raised forward, backward, and to the side to normal limits with no pain.
        ii. Elbow should flex and extend to normal limits with no pain.
        iii. The hand and wrist should provide normal movement up, down, and side-to-side with no pain.

b. Muscular Strength: The ability to perform a normal strength of both arms with no pain.
    i. Shoulder should be raised forward, backward, and to the side to normal limits with no pain.
    ii. Elbow should flex and extend to normal limits with no pain.
    iii. The hand and wrist should provide normal movement up, down, and side-to-side with no pain.

3. Information will be gathered regarding your height, weight, athletic involvement, gender, and age.
4. Measurements of the following are done before, right after, and at 24, 48, and 72 hours after the exercise is administered
    a. Muscle Size: Your muscle size will be measured using a measuring tape around different parts of the biceps muscle.
    b. Angle of Elbow: Your elbow resting angle will be determined by hanging your arm by your side and with the palms facing forward.
    c. Muscular Strength: You will perform as many bicep curls as possible with a given amount of weight. Your maximum will be determined using a weight chart.
5. The initiating exercise consists of different motions using different dumbbell weight loads.
    a. After finding your maximal strength, a weight of 120% will be given to you.
    b. You will be sitting comfortably in the exercise chair with your elbow completely bent (Starting Position).
    c. You will lower your arm (slowly) until it reached the end of motion and the principle investigator will pick the weight back up to the starting position.
    d. Step C will be done 10 times.
        i. After the 10 times, a 3 minute rest will be given,
        ii. You will repeat for a total of 5 times (this equals a total of 50 lifts).
        iii. Followed by a 3 minute rest after each 10 times.
    e. You will then be handed a weight (100% maximum strength) while in the starting position

f. You will lower your arm (slowly) until it reaches the end of motion and the principle investigator will pick the weight back up to the starting position.
g. Step F will be bone 10 times
    i. After the 10 times, a 3 minute rest will be given.
    ii. You will repeat for a total of 2 times (this equals a total of 20 lifts).
    iii. This is the end of the exercise.

6. You will fill out the Quick-DASH each time before your treatments; then fill out a graphic pain rating scale (GPRS) after testing muscular strength each day.
    a. Graphic Pain Rating Scale (GPRS): This is a measure to determine the amount of discomfort experienced during physical activity. You will perform the strength test and make a single mark along the 12 cm line in response to your discomfort. This will be performed as a baseline, at 0, 24, 48, and 72 hours post exercise.
7. You will be treated one of three ways at 24, 48, and 72 hours:
    a. Control Group: No treatment given. This group will be used to determine a baseline of muscle discomfort felt for the other two treatment groups.
    b. Warm Bath:
        i. The water is set to a given temperature (110° Fahrenheit)
        ii. You will put your arm in the water for 20 minutes.
        iii. This group will be used to determine if the Epsom salt is the true factor that affects the symptoms following eccentric muscle contractions.
    c. Warm Bath with Epsom Salt:
        i. The water is set to a given temperature (110° Fahrenheit) and is mixed for a 1% concentration solution of Epsom salt.
        ii. You will put your arm in the water for 20 minutes.
        iii. This group will determine the effectiveness of Epsom salt on the symptoms experienced following eccentric muscle contractions.
    d. Subjects will return to be treated at a designated time schedule set up by the principle investigator. This will be discussed and determined in the initial meeting with the subject.

Possible Benefits

1. The subjects will have completed a complete orthopedic examination of their arm by a certified and licensed healthcare provider.
2. The subjects will see the possible benefits of the use of Epsom salt on muscle discomfort.

Potential Risks

1. The subjects will experience discomfort in his/her arm during testing and several days following the initial protocol. Such discomfort includes soreness, swelling, and decreased range of motion.
2. The subjects may experience discomfort or skin irritation of the arm during the warm bath treatment protocol. Such discomfort includes increased temperatures or redness of the skin.

These inherent risks are not considered to be life threatening and will resolve within 5 to 6 days following the exercise bouts. These potential risks will be minimized to the best of the principle investigator's ability. Nathan Byerley, a Certified and Licensed Athletic Trainer/healthcare provider, will monitor the research at all times. In the event of an irritation from the treatment, you will be examined by the Certified and Licensed healthcare provider to determine necessary steps to be taken. In the event of an emergency, emergency personnel (9-1-1) will be contacted. No other physical or psychological risks are associated with this investigation.

Confidentiality

The data collected during this research study will be kept confidential by issuing each subject a number. This number will be used for tracking the subject's record throughout the study. All the data will be kept in the principle investigator's possession, locked in a cabinet within a restricted area. This area is located within a lockable closet in the athletic training room. Access to these files is only for the principle investigator (Nathan

Byerley) and the Boerne Champion athletic trainer (Terry Gault). Other individuals to have access to this data include Dr. Jack Ransone (Committee Chair), Dr. Luzita Vela (Committee Member), and Dr. Jim Williams (Committee Member). All the data with the personal information will be destroyed immediately after the study is completed.

Participation

Your participation is voluntary and you will not be penalized if you decide not to participate. You are also free to withdraw at any point of time without prejudice or jeopardy to your standing with Texas State University and Boerne Samuel V. Champion High School. If you withdraw from the study, the information sheets and data provided will be returned to you or destroyed. Participants may choose to refuse to answer any question at any time without prejudice or jeopardy to your standing with Texas State University and Boerne Samuel V. Champion High School. Questions regarding participant's rights and/or questions about research-related injuries can be answered by contacting the IRB chair, Dr. Jon Lasser, (512) 245-3413, lasser@txstate.edu or Compliance Specialist, Ms. Becky Northcut, (512) 245-02102.

Results

Participants may receive the summary of the study upon completion of the study, if requested. To receive summary information, please contact the principle investigator via phone or email.

Authorization

I have received a copy of this consent form, and I have read and fully understood the consent form. I have been given sufficient opportunity to ask any questions about this study. I also understand that I am free to withdraw from the project and end my participation at any time.

For any questions or concerns, please contact Nathan Byerley (Email: nb1158@txstate.edu or Phone: 210-860-2883).

IRB Approval #: 2010P2005

Participant's Name (Please Print)	Phone Number
Signature	Date
Participant's Parent or Legal Guardian (Please Print) **(Please State Relationship to Participant)**	Phone Number
Signature	Date
Principle Investigator Signature	Date

APPENDIX G

NEUROLOGICAL EXAMINATION AND MEDICAL HEALTH QUESTIONNAIRE

Upper Extremity Neurological Examination

Pass	Fail	Shoulder
O	O	Range of Motion
O	O	Strength
Pass	**Fail**	**Upper Arm (Biceps/Triceps)**
O	O	Range of Motion
O	O	Strength
Pass	**Fail**	**Lower Arm (Forearm/Wrist/Hand/Finger)**
O	O	Range of Motion
O	O	Strength
Pass	**Fail**	**General Health Issues**
O	O	Do you experience any weakness in your arms throughout any point of the day?
O	O	Do you experience any numbness, tingling, or burning sensations during any time?

Medical Health Questionnaire – Athletic Training Research Laboratory

YES	NO	Current Activity Level
O	O	Are you physically active (i.e. do you get at least 30 minutes of physical activity on at least 3 days per week?)?
O	O	Have you been physically active for at least the past 6 months?
YES	**NO**	**Symptoms – Do you…**
O	O	Experience chest discomfort with exertion?
O	O	Experience unreasonable breathlessness or unusual fatigue at rest, with mild exertion, or during usual activities?
O	O	Experience dizziness, fainting, or blackouts?
O	O	Experience difficulty breathing when lying flat or when asleep?
O	O	Experience ankle swelling?
O	O	Experience forceful or rapid heart beats?
O	O	Experience numbness in legs or arms from time to time?
YES	**NO**	**Other health issues that may warrant physician approval before engaging in physical activity.**
O	O	Have you ever been told not to exercise by a health care provider?
O	O	Do you have problems with you muscles, bones, or joints?

Emergency Contact Information

Name: _____ **Relationship:** _____ **Phone Number:** _____

I certify that the information included on this form is correct and factual.

_____ _____

Date **Signature of Participant**

_____ _____

Date **Signature of Primary Investigator**

APPENDIX H

SUBJECT INFORMATION SHEET

Date: _____ **Subject Identification Number:** _____

Randomly Assigned Group: Control / Group 1 / Group 2

Height (cm): _____ **Weight (lbs):** _____ **Gender :** MALE / FEMALE

Age: _____ **Arm Dominance:** RIGHT / LEFT

Ortho-screen of Upper Extremity: PASS / FAIL

Athletic Involvement: _____

Initial Measurements:

Anthropometric Measurements (cm):

	1st	2nd	3rd	Average
Mid-Muscle Belly				
Musculotendinous Juncture				
Distal Bicep Tendon				

Resting Angle (deg):

1st	2nd	3rd
Average		

Muscular Strength (lbs):

Selected Weight (lbs)	
Number of Lifts	
Estimated 1-RM	

Eccentric Protocol:

Estimated 1-RM	
Bout 1: 5 sets of 10 reps 120%	
Bout 2: 2 sets of 10 reps 100%	

Immediately Following Eccentric Protocol

Anthropometric Measurements (cm):

	1st	2nd	3rd	Average
Mid-Muscle Belly				
Musculotendinous Juncture				
Distal Bicep Tendon				

Resting Angle (deg):

1st	2nd	3rd
Average		

Muscular Strength (lbs):

Selected Weight (lbs)	
Number of Lifts	
Estimated 1-RM	

*Perform GPRS after Strength Test

24 Hours Post Eccentric Protocol

YES	NO	**Question:** Since the beginning of this study, have you
○	○	Utilized any form of medication to the discomfort you are experiencing?
○	○	Utilized any form of treatments, including: • Electrical stimulation • Massage (you or other individual) • Cryotherapy (ice bag, ice immersion, etc)

Anthropometric Measurements (cm):

	1st	2nd	3rd	Average
Mid-Muscle Belly				
Musculotendinous Juncture				
Distal Bicep Tendon				

Resting Angle (deg):

1st	2nd	3rd
Average		

Muscular Strength (lbs):

Selected Weight (lbs)	
Number of Lifts	
Estimated 1-RM	

*Perform GPRS after Strength Test

48 Hours Post Exercise

YES	NO	**Question:** Since the beginning of this study, have you
O	O	Utilized any form of medication to the discomfort you are experiencing?
O	O	Utilized any form of treatments, including: • Electrical stimulation • Massage (you or other individual) • Cryotherapy (ice bag, ice immersion, etc)

Anthropometric Measurements (cm):

	1st	2nd	3rd	Average
Mid-Muscle Belly				
Musculotendinous Juncture				
Distal Bicep Tendon				

Resting Angle (deg):

1st	2nd	3rd
Average		

Muscular Strength (lbs):

Selected Weight (lbs)	
Number of Lifts	
Estimated 1-RM	

*Perform GPRS after Strength Test

72 Hours Post Eccentric Protocol

YES	NO	**Question:** Since the beginning of this study, have you
O	O	Utilized any form of medication to the discomfort you are experiencing?
O	O	Utilized any form of treatments, including: • Electrical stimulation • Massage (you or other individual) • Cryotherapy (ice bag, ice immersion, etc)

Anthropometric Measurements (cm):

	1st	2nd	3rd	Average
Mid-Muscle Belly				
Musculotendinous Juncture				
Distal Bicep Tendon				

Resting Angle (deg):

1st	2nd	3rd
Average		

Muscular Strength (lbs):

Selected Weight (lbs)	
Number of Lifts	
Estimated 1-RM	

*Perform GPRS after Strength Test

YES	NO	
O	O	This subject has completely finished all aspects to this study?

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