COMPEX USE WITH DELAYED ONSET MUSCLE SORENESS: A COMPARISON TO CRYOTHERAPY

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Kinesiology- Master of Science

2014

ABSTRACT

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The study was designed to test the efficacy of the Compex electronic muscular stimulation unit's Active Recovery® and Recovery Plus® programs at relieving the symptoms of delayed-onset muscle soreness compared to cryotherapy and control conditions. A visual analog scale was used to examine perceived muscle soreness, a flexible tape measure was used to measure muscular girth, and an improvised algometer was used to assess pain pressure threshold. A Biodex isokinetic dynamometer was used to induce delayed-onset muscle soreness and capture pre-test and post-test data on peak torque, muscular fatigue, and time to peak torque. Significant effects for time were found for perceived soreness, pain pressure threshold at six inches, and six inch muscular girth. No significance was found between groups or in group by time interactions. The study protocol of six sets of 10 repetitions of knee extension at 300º/s and knee flexion at 30º/s with two minutes of rest between sets was able to produce muscular soreness study subjects. All study methods of treating the symptoms of DOMS were found to be equal to one another. No treatment modality was found in this study to increase recovery speed or restore muscular function more than the other conditions. The Compex unit may not be most indicated for recovery but future research could examine the use of its muscular strength, endurance and power training programs for use with a geriatric population.

ACKNOWLEDGEMENTS

Thanks to all of the people who made this thesis possible, foremost my committee members: Dr. Tracey Covassin, Dr. Sally Nogle, and Dr. Tom Mackowiak. Thank you for your time reading my sentences/paragraphs and contributing to my education while I have spent time at Michigan State. Thank you to my research assistants for your efforts on my behalf. Thanks to my parents for supporting me at home and from afar, pushing and praising me when I needed it. Special thanks to Curtis Gemmel for procuring the Compex units used in this study.

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CHAPTER 1

INTRODUCTION

1.1 SIGNIFICANCE OF THE PROBLEM

Sports come in many forms and levels, are played on different surfaces, and for variable lengths of time. Though there are many differences between sports in terms of the size of field, the number of participants and amount of protective gear, the human factor remains constant. As individuals, humans exhibit superficial variations like hair length, skin color, and language; however, physiologically every athlete's muscles are similar when they are used in unaccustomed ways. Exercise is a fundamental part of health and comes in a variety of forms, giving a wide range of possibilities to choose from for the individual. Beginning a new exercise regimen can have consequences as the human body has to become accustomed to the demands imposed by the new activity. That internal acclimatization initially presents as sore muscles that can be painful to touch.

This soreness, which may not be displayed until about 24 hours and last 5-7 days after activity, is known as delayed-onset muscle soreness (DOMS) (Cheung, Hume & Maxwell, 2003). DOMS can produce a variety of side effects like decreased range of motion (Sayers & Dannecker, 2004; Kuligowski, Lephar, Giannatonio, & Blanc, 1998), decreased strength (Aminian-Far, Mohammad-Reza, Olyaei, Talebian, & Bakhtiary, 2011), increased tenderness and pain (Cheung et al., 2003). This soreness is commonly seen with athletic participation, especially in periods of intense training or returning to training from a sedentary lifestyle. This phenomenon cannot be quantified in a single dimension because the effects of DOMS are psychological and physiological. Physiological factors include soreness and damage to muscle tissue at a microscopic level while psychological factors are the emotional response to the

activity, the feelings about the soreness, and the ability to push past the symptoms and the continuation of training.

DOMS has the potential to occur from everyday activities, but doesn't because of the specificity of each individual's life. An athlete trains a specific way for his or her event and a factory worker follows the same process- building endurance by doing the same task over and over again; however, DOMS presents when an alteration to the normal loading pattern occurs accidentally or by intent (Baechle & Earle, 2008). Whether or not the individual is accustomed to constantly changing training, soreness and other side effects of DOMS are not desirable and must be treated. There is no unilaterally effective way to relieve DOMS, but many different interventions and professions try and elicit a therapeutic effect as quickly and effectively as possible. Current treatments for DOMS include, but are not limited to:

- Electronic stimulation
- Cryotherapy and thermotherapy
- Massage/foam rolling
- Acupuncture
- Vibration
- Magnetic therapy
- Dietary supplementation
- Light activity or stretching
- Homeopathic remedies
- Compression
- Laser therapy
- Pharmacotherapy

(Cheung et al., 2003; Hume, Cheung & Weerapong, 2004; Sayers & Dannecker, 2004; Udani, Singh, Singh, & Sandoval, 2009).

Research and technology are becoming more sophisticated, utilizing prior technology supplemented by new ideas. From this paradigm new electrical modalities, magnetic therapy, vibration therapy have evolved. Donjoy Global has followed that trend and has produced a new device known as Compex which uses electricity to facilitate recovery and help retrain muscles (Donjoy Orthopedics, 2012). Compex is different from previous modalities of electronic stimulation for pain control or medication delivery (Compex, 2012). Methods that require only a

half hour of time that restore muscular function or decrease pain are necessary for athletes who wish to recover faster or patients with chronic back pain who struggle to live a normal life every day (Compex, 2012).

Compex units are handheld electronic stimulation units with a variety of programs to help foster better athletic performance and assist the body in recovery after exercise without the impact on joints that a traditional weightlifting, running or warm-up would create (DonJoy Orthopedics, 2012). These units are available to anyone and the method of their integration is based on each individual's training philosophy and goals. There are six different programs that come with the most versatile of these units: potentiation, endurance, resistance, strength, explosive strength and Active Recovery®. The goal and method of these programs are delineated below in Table 1.

Figure 1-1 Compex Program Descriptions

PROGRAMS	
Potentiation	Optimizes muscle potential before a workout or competition. Especially effective for sports requiring speed and velocity. Should be used 10 minutes prior to activity.
Endurance	Targets slow twitch muscle fibers. Increases capillarization of the muscles and establishes a working regimen for developing the oxidative power of the endurance muscle fibers.
Resistance	Targets both slow and fast twitch muscle fibers. Builds muscle size, strength and density.
Strength	Targets fast twitch muscle fibers. Increases sheer strength and works the muscles at maximum power with less risk of injury to joints and tendons and virtually no cardiovascular or mental fatigue.
Explosive Strength	Targets fast twitch fibers located in large muscle tissue. Improves jumping, sprinting or "explosive" muscle movements.
Active Recovery®	Produces a muscle twitch. Clears lactic acid, increases blood flow, promotes muscle relaxation and enables a faster recovery.
Recovery Plus	Produces a muscle twitch. Runs at a lower frequency and clears lactic acid, increases blood flow and promotes muscle relaxation when muscles are fatigued after a vigorous workout or competition.
Pre-Warmup	Produces a muscle twitch. Runs at a low frequency and increases blood flow and oxygenates the muscles prior to a workout or competition.
Massage	Produces a muscle twitch. Runs at the lowest frequency possible to relax muscles that are severely fatigued after a workout or competition.

Figure1-1 (cont'd)

(Donjoy Orthopedics, 2012)

All of the programs are useful to athletes, but unless an athlete is coming back from a surgical procedure, electronic stimulation is not always needed to help build strength and increase endurance. It is needed to help combat the effects of DOMS because an effective treatment needs to be found. For this reason, this study will address the Active Recovery® and Recovery Plus® programs to see if this protocol can speed recovery compared to other remedies used to treat DOMS.

Typically, external techniques like ice or massage are employed to help counteract the symptoms of DOMS. These treatments are employed hours or even days after the exercise has been done as symptoms may peak anywhere from one to three days after activity (Cleather & Guthrie, 2007). The Active Recovery® program is intended to be used in the first three hours after damaging activity to help speed recovery, removing cellular waste and relax the affected musculature, possibly preventing the pain-spasm-pain cycle that can be found with DOMS (DonJoy Orthopedics, 2012). The Recovery Plus® program is intended for use three hours after activity to stimulate further recovery (DonJoy Orthopedics, 2012). Substances like prostaglandin that encourages intracellular swelling may be flushed out or reduced by the contractions produced by twitches triggered by the Compex unit. As Compex is user controlled and does not physically damage the muscle tissue further as massage or foam rolling may, research is warranted to determine its efficacy compared to other therapeutic modalities.

1.2 PURPOSE OF THE STUDY

The purpose of this study was to determine the efficacy of the Compex unit's Active Recovery® and Recovery Plus® programs at alleviating the physical symptoms of DOMS compared to no treatment and the traditional recovery method of ice.

1.3 HYPOTHESES

This study examines the following hypotheses:

H1: There will be no difference in pressure pain threshold between the Compex, cryotherapy and control groups.

H2: There will be no difference in perceived soreness between the Compex, cryotherapy and control groups**.**

H3: There will be no difference in muscular girth between the Compex, cryotherapy and control groups**.**

H4: There will be no difference in peak torque between the Compex, cryotherapy and control groups**.**

H5: There will be no difference in muscular fatigue between the Compex, cryotherapy and control groups.

H6: There will be no difference in time to peak torque between the Compex, cryotherapy and control groups.

1.4 OPERATIONAL DEFINITION OF TERMS

Actin and myosin- the two basic proteins that make the components of a sarcomere in a muscle cell.

Algometry- the measurement of pain sensitivity through the use of direct pressure (Merriam-Webster, 2013).

Biceps femoris- the most lateral of the three "hamstrings" muscles that creates knee flexion and assists with hip extension.

Compex- an electrical stimulation unit manufactured and retailed by Donjoy Orthopedics .

Cryotherapy- the use cold as a therapeutic modality.

Delayed-onset muscle soreness (DOMS) – the feeling of soreness that is felt 1-7 days after intense physical activity, particularly eccentric muscle contractions.

Electronic stimulation- the use of electrical currents to produce muscular contractions; help decrease pain or other goals.

Isokinetic dynamometer- a machine used for therapeutic or diagnostic purposes can be set at a speed in order to measure a variety of muscular attributes or exercise a patient.

Isometric, concentric and eccentric (contractions)- the three different types of muscular contraction; respectively tension while a muscle retains the same length, tension while a muscle shortens, and tension created while a muscle elongates.

Pressure pain threshold- the amount of pressure a patient or subject can endure before pain is experienced.

Semitendinosus/semimembranosus- the medial two of the three "hamstrings" muscles that create knee flexion.

Visual analog scale (VAS)- a tool used to measure a quality or sensation, in this study the level of soreness on a 10 cm continuum.

CHAPTER 2

REVIEW OF LITERATURE

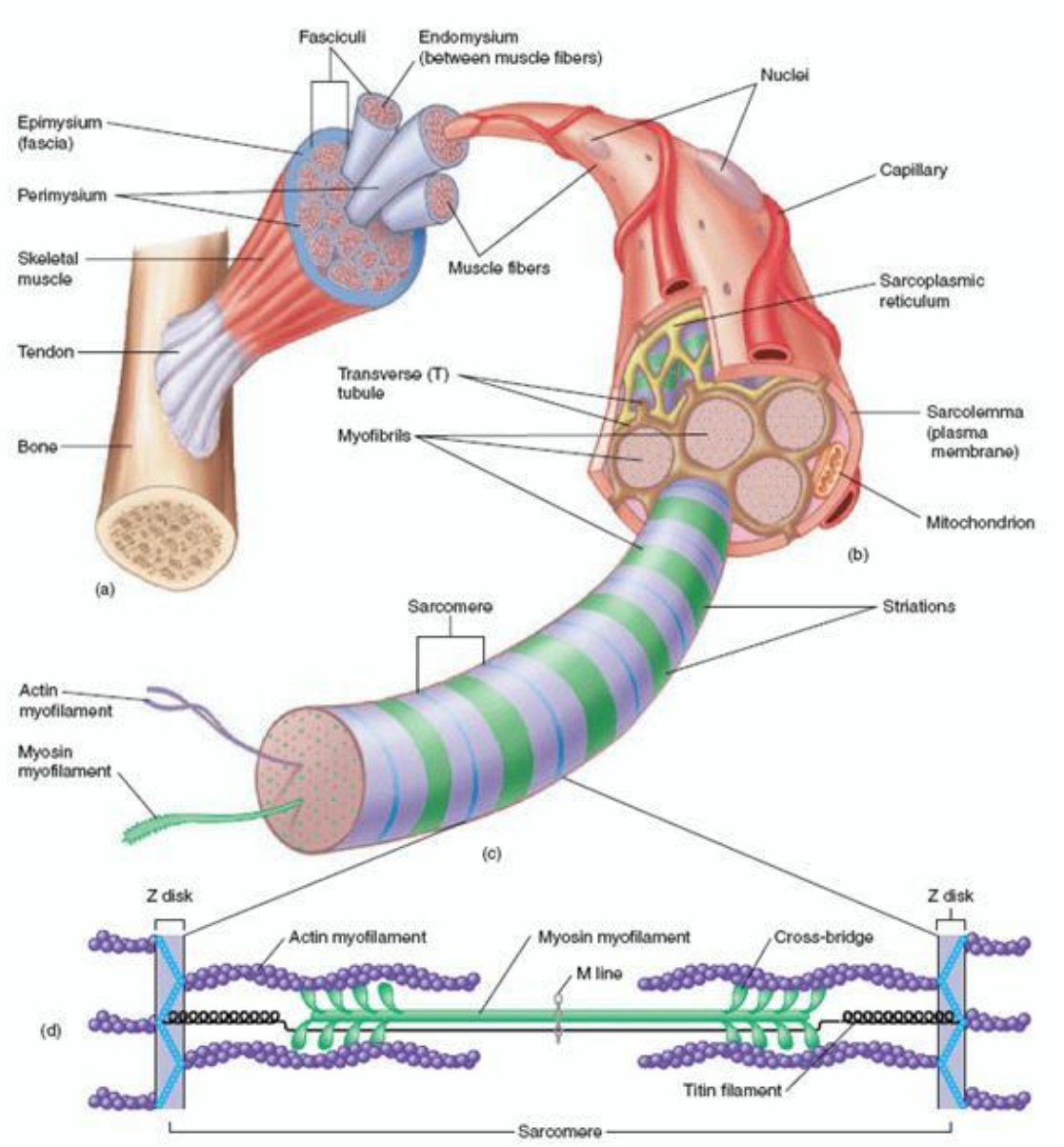
2.1 INTRODUCTION

As technological innovation increases so do the number of possibly untested means to combat the underlying physiological mechanisms of DOMS. Most individuals experience one or more of the many side effects of DOMS in their lifetime. However, the treatments commonly practiced to treat DOMS need to be understood to successfully mitigate those symptoms. The basic architecture of a motor unit plays a critical part in the process of creating DOMS because each fiber disruption has a cumulative effect on the way the muscle functions as a whole (Hume et al., 2004). The basic treatment for DOMS fall into the categories of mechanical intervention, pharmaceutical supplementation, external aids, dietary alterations, and the application of electronic current. Less common methods like vibration and magnetism have also been hypothesized to help reduce the sensations associated with muscle damage (Hume et al., 2004). Compex allows the user to choose electrical currents applied in a specified sequence and duration to induce muscle contractions with less risk than actual exercise to promote a variety of effects (DonJoy Orthopedics, 2012). Treatments for DOMS will be discussed in this chapter.

2.2 MUSCLE ANATOMY

A motor unit, the basic component of musculature, has many parts, each of which may be affected during intense exercise, especially eccentric type contractions. Figure 2 shows the basic composition of a muscle cell.

Figure 2- Muscle Cell Organization



(Bacherle & Earle, 2008)

Muscle cells are the distal component of the muscular contraction sequence that starts in the brain and undergo a process known as the sliding filament theory to create muscular contractions. According to Baechle and Earle (2008), the process of a muscle contraction follows several major steps: a) the motor cortex of the brain sends a signal to the end of a nerve where it

meets the muscle at the neuromuscular junction, b) neurotransmitters are released from the junction and lock onto receptors on the motor end plate of the muscle cell, where calcium is released, c) calcium causes conformational changes in cellular elements that block the receptor sites of myosin and actin cross bridging, d) when mysoin and actin connect, a single molecule of adenosine tri-phosphate (ATP) is utilized to create a shortening of the muscle cell. There are multiple types of muscle fiber types, and not all muscle cells possess the same inherent characteristics.

Muscle fiber composition varies from one athlete to another and helps add to an individual's genetic make-up that could determine which athletic activity one will be most suited for performing. This ratio is controlled by genetics and may be able to be slightly altered through the course of training specificity; however, even the most rigorous training cannot produce double digit percentage changes in muscle fibers (Baechle & Earle, 2008). Type I and Type II muscle fibers exist and perform very differently based on factors like capillary density, mitochondrial density and myoglobin content (Baechle & Earle, 2008). Fast twitch fibers are more suited for anaerobic activity such as short sprints found in sports like the 100m sprint in track and field, running the bases in baseball, or a receiver in American football. Slow twitch fibers are more useful for cross country runners, long distance swimmers or triathletes (Baechle & Earle, 2008). Just like there is more than one type of muscle fiber, there is more than one type of contraction a muscle can perform.

There are three major types of contraction: 1) isometric, 2) concentric, and 3) eccentric contractions. A concentric muscle contraction shortens the muscle while producing tension (Lieber, 2009). An isometric muscle contraction has no muscle length change while under tension (Lieber, 2009). Finally, when the muscle elongates while producing tension it is referred

to as an eccentric muscle contraction (Lieber, 2009). A biceps curl contains all these components. The narrowing of the joint angle from a fully extended arm to a curled arm is a concentric contraction, where the extending of the elbow under full control is the eccentric part of a contraction.

2.3 DELAYED-ONSET MUSCLE SORENESS (DOMS)

DOMS is classified as a Type I muscle strain and is self-induced, not the result of being put off balance by an opponent or hyperextension of a given muscle group (Hume et al., 2004; Cheung et al., 2003). Many theories have been proposed to explain the molecular interactions that change after heavy eccentric exercise and the primary etiology of DOMS formation. One theory suggests that there is physical separation and inflammation at the musculotendinous junction, an area where the tendon, composed of connective tissue that is elastic but not contractile, meets muscle tissue, which is contractile (Kuligowski et al., 1998; Mikesky & Hayen, 2005; Hume et al., 2004; Cheung et al., 2003). The tendon is made of collagen fibers, specifically Type II fibers that are more susceptible to injuries of excess strain or stretch (Cheung et al., 2003). The muscle damage theory contents that the Z line, the non-contractile part of a muscle unit, is damaged by the excess strain of eccentric activity. This leads to fewer motor units being involved than in concentric type contractions (Hume et al., 2004; Cheung et al., 2003; Bakhtiary, Ziaddin, & Aminian-Far, 2007; Sayers & Dannecker, 2004). That disparity of recruitment increases the tension on each individual unit, providing enough mechanical stress to damage the Z-line (Hume et al., 2004; Cheung et al., 2003; Bakhtiary, Ziaddin, & Aminian-Far, 2007; Sayers & Dannecker, 2004).

Eccentric contractions are primarily responsible for DOMS, as they challenge a muscle beyond its normal concentric lifting capacity (Bakhtiary et al., 2007; Aminian-Far et al., 2011;

Udani, et al., 2009; Cheung et al., 2003; Allen, Mattacola, & Perrin, 1999). This type of exercise occurs with plyometric activity; however, it can also be induced in a number of different ways. Loads beyond the normal in a weight training program, excess running, and a variety of factors create this sensation. In clinical research, the most common ways of inducing this condition are isokinetic dynamometry, downhill cycling, eccentric loads intentionally high, and ballistic stretching (Cheung et al., 2003; Bakhtiary et al., 2007).

Two theories assert a more indirect pathway to the soreness affiliated with DOMS. The inflammation theory contends inflammation from the breakdown of muscular and connective tissue lead to an increased level of bradykinin, histamine, and prostaglandins; consequently, edema forms around the site of injury and may apply pressure to Type III and IV pain receptors (nociceptors) and create the aching discomfort that is typical of DOMS (Cheung et al., 2003; Mikesky & Hayen, 2005; Kuligowski et al., 1998; Sayers & Dannecker, 2004; Aminian-Far et al., 2011; Hume et al., 2004; Hjortskov, Essendrop, Skotte, & Fallentin, 2005; Micklewright, 2009; Bakhtiary et al., 2007; Zainuddin, Newton, Sacco & Kazunori, 2005). The enzyme efflux theory supports the role of calcium, previously bound in the sarcoplasmic reticulum, is released into the cell uncontrollably, leading to secondary injury, sensitization of nerve endings, and edema (Cheung et al., 2003; Aminian-Far et al., 2011; Hume et al.,, 2004; Hjortskov et al., 2005; Sayers & Dannecker, 2004; Zainuddin et al., 2005; Pumpa, Fallon, Bensoussan, & Papalia, 2011). Another effect of swelling inside the muscle cell is mechanical inhibition of undamaged actin and myosin components, creating a decrease in overall function along with any damage from the aforementioned theories. Decreased muscular function, regardless of etiology, is one of the most influential symptoms of DOMS that impedes athletic performance, even if the athlete can tolerate the soreness.

DOMS is identified by many different symptoms, but each individual reports different symptoms. The most prevalent chemical markers of DOMS are the levels of bradykinin, creatine kinase, calpain, histamine, macrophages, myoglobin, monocytes, neutrophils, and prostaglandin (Udani et al., 2009; Cheung et al.,, Hume, & Maxwell, 2003; Cleather & Guthrie, 2007; Aminian-Far et al., 2011; Bakhtiary et al., 2007). Each of these aforementioned markers of DOMS correspond to a particular cellular process: creatine kinase and myoglobin concentrations indicate muscle damage, macrophages and monocytes produce bradykinin, histamine and prostaglandin, chemicals that preface edema, and calpain is a secondary chemical marker of necrosis as it degrades cellular proteins (Udani et al., 2009; Cheung et al., 2003; Cleather & Guthrie, 2007; Aminian-Far et al., 2011; Bakhtiary et al., 2007). Damage to muscles in musculature produces these microscopic changes that have detrimental effects on athletic performance as a whole.

Decreases in muscular attributes like strength, range of motion and athletic performance occur as a result of the intramuscular fiber tears at the level of the sarcomere while the blood markers increase as a result of that damage (Hume et al., 2004; Cheung et al., 2003). The stiffness, tenderness to touch and pain are a result of swelling at those sites of muscular damage, which in turn creates neural inhibition. The pain-spasm cycle makes the joint less mobile and immobilizes the joint via neural inhibition (Hjortskov et al., 2005). Elite athletes who are used to these sensations will not behave the same as novices who are experiencing the feelings of DOMS for the first time (Cleather & Guthrie, 2007; Stay, Draper, Schulthies & Durrant, 1998).

Despite all the factors that one must endure during this condition, DOMS is a necessary part of training programs because of the benefits one receives once one becomes asymptomatic. Strength training programs that incorporate heavy eccentric loading exercises produce strength

gains double that of programs of the same intensity, but done with concentric loading while utilizing less muscular energy (Sayers & Dannecker, 2004). Mild overloading exercises may reduce the amount and severity of injuries sustained in multiple settings by creating protective neurological, mechanical and cellular adaptations inside the body (Hjortskov et al., 2005; Hume et al., 2004). Athletes may see benefits from eccentric training because they may be less susceptible to hyperextension injuries like hamstring strains. In addition to athletes, the general population may profit as well, specifically older populations that are at greater risk for muscular degeneration, balance deficits, and cardiac stress. Eccentric training increases muscular strength and balance while placing fewer demands on the body than traditional training (Sayers & Dannecker, 2004). However, the implementation of such programs needs to be carefully considered.

2.4 MODALITY TYPES

With the high prevalence of DOMS comes the need to combat it. Though this may be a normal sensation during pre-season sport conditioning, the introduction of a new physical activity regimen, or an ADL like moving, the experience of DOMS can lead to complications. Sore muscles can lead to an alteration in the pattern of doing activities that require a harmonious balance of muscle groups like throwing or swimming. A new modality on the market is the Donjoy Compex unit. Each Compex machine is an electrical muscle simulation unit designed to help condition the muscles of whomever they are applied to produce a variety of results without needing to run, lift weights, or find a method to help enhance recovery. Compex should not be confused with transcutaneous electrical nerve stimulation (TENS). These units are not intended to address pain like an interferential or pre-modulated program or re-educate muscles like a Russian program. Interferential or pre-modulated programs are designed to produce a beat

frequency and desensitize nociceptors while Russian programs encourage atrophied muscles to begin to respond again. Compex units are designed to produce a muscular twitch and enhance the abilities of the targeted musculature. Since they are handheld, these devices can be taken anywhere an athletic trainer goes or be used at home by a patient without any specialized knowledge. There are many programs available (see Figure 2) and the one selected is based on the desired effect. The Massage program can help relax muscles after performing while the Endurance program targets slow twitch muscle fibers to help increase their ability to do work for extended periods of time (Donjoy Orthopedics, 2012). The Active Recovery® program is intended to promote the relaxation of muscle tissue and use the fluid pumping mechanism of muscles to help remove waste products that accumulate after physical activity (Donjoy Orthopedics, 2012).

Brocherie et al. (2005) suggest that electromyostimulation (EMS) training may increase the neural drive and promote greater motor unit recruitment without a long term rehabilitation program. Rehabilitation may be too much stress in addition to the normal lifting and practice schedule for sports or the busy life of an everyday person wishing for a way to help maintain muscular fitness with a busy work schedule.

Martin et al. (1993) applied electrical stimulation from a Compex unit to the triceps surae (gastrocnemius and soleus) of 12 subjects. Each was measured with an isokinetic dynamometer at different speeds in plantarflexion and the six experimental subjects showed increased torque production during voluntary isometric and concentric conditions compared to the control group. Martin et al. noted that the increased production was a result of neural adaptations because the actual muscle size didn’t change throughout the course of the study.

Compex programs can keep neurological and physiological enhancements throughout a season. Brocherie et al. (2005) used 17 ice hockey players to test the effect of Compex EMS on the quadriceps. They measured subject performance in one of three jumps (squat, drop or countermovement), isokinetic knee extensor strength on a Biodex isokinetic dynamometer and skate sprint (10m and 30m) testing before and after Compex use. The experimental group completed three weeks of three EMS sessions of 12 minutes each on the vastus medialis and lateralis while seated on a leg extension machine. Compared to the control group, the EMS group demonstrated statistically significant improvements in concentric and eccentric knee extensor strength and skating tests (Brocherie et al., 2005). Brocherie and colleagues (2005) concluded Compex use will increase the strength of targeted muscles and have a cumulative benefit on sport performance in hockey players.

Maffiuletti (2000) also targeted the knee extensors, but used the vertical jump performance of 20 basketball players as their performance measure. After four weeks of EMS training, the experimental group (n=10) had higher strength with all types of knee extensor contractions (eccentric, concentric, isometric) at higher velocities and increased jump height performance by over ten percent. These similar findings suggest EMS training may be a valuable tool in increasing performance with standard training methods.

During the middle of a season, athletes are looking to maintain their level of fitness and a way to increase their physical capabilities without extra workouts. The use of Compex is not limited to before a practice or after, its application for recovery during competition has been tested as well. Seven college pitchers applied Compex Active Recovery® (AR) (EMS group) between innings to the biceps brachii, triceps brachii, posterior deltoid, and upper trapezius and were compared to a jogging/active recovery (AR) recovery method or passive recovery (PR)

method of no activity group (Warren, Brown, Landers and Strahura, 2011). The speed of the pitches thrown by each pitcher was measured by a radar gun and compared during simulated games and practice time while blood lactate was measured twice, once at the end of the inning and immediately before the pitcher went out again. A 0-10 scale was administered prior to resuming pitching to assess subjective feelings of recovery. Significant differences were found in the blood lactate levels recorded for the EMS group compared to the AR and PR. Pitchers also perceived better recovery during the EMS and PR conditions. Recovery via electrical methods or regular activity that allow for the reservation of ATP and mental energy for the game or performance are desirable for any sort of physical activity that has an ebb and flow to the way it progresses (Warren et al., 2011).

Gondin et al. (2005) suggest EMS may be useful in both healthy and injured populations, stating that "EMS training programs may induce both neural and muscular adaptations." After applying EMS on 20 male subjects' quadriceps and rectus femoris and testing their torque production, EMG activation, and ultrasound visualization of pennation angle and cross-sectional area for 4 or 8 weeks after EMS training, multiple desirable alterations were found. After eight weeks, the following improvements were noted:

a. 27% increase in maximal contraction strength
b. 5-8% increase in cross sectional area of the quadriceps
c. 14% increase in pennation angle
d. 6% higher EMG activity after training

(Gondin et al., 2005)

These findings have implications for altering current thinking with rehabilitation protocols after immobilization from injuries like ACL reconstructions or large muscular tears. Compex units could be applied to the quadriceps before, during and after an ACL surgery in order to help maintain (during immobilization) and improve (during rehabilitation) strength and

muscular drive. Russian stimulation is used after reconstruction to help re-educate the VMO and quadriceps to retrain atrophied muscle tissue, but what if the tone was never lost? EMS from a Compex unit produces contractions that are not of enough amplitude to damage a graft after surgery and can be done in addition to the quadriceps contraction sets and other basic rehabilitation steps.

Three other methods of treating the effects of DOMS without placing additional mechanical stress to already damaged tissue rely on technology to produce their desired effect: electronic stimulation, vibration, and ultrasound. Electronic stimulation involves controlling the amplitude, frequency and intensity of electrical energy to stimulate the body in certain ways. Some applications of electronic stimulation are used to help retrain muscles after surgery and encourage voluntary contractions while others are designed to deliver anti-inflammatory medication to damaged tissue. Electronic stimulation for the control of pain utilizes long duration, low frequency waves to stimulate the anterior pituitary gland to release β-endorphin, a chemical which begins a metabolic cascade that ends with the production of cortisol, a chemical that suppresses inflammation, and others that increase protein synthesis, the basis of muscular repair (Hume et al., 2004; Cheung et al., 2003).

Other electrical/mechanical modalities like microcurrent electronic neuromuscular stimulation have been applied to treat DOMS. Eighteen subjects unfamiliar to weight training performed three second eccentric contractions with gradually decreasing weights to induce DOMS and were treated with microcurrent electrical neuromuscular stimulation (MENS) or a unit with the current off. A graphic rating scale was used to assess pain at rest as well as during elbow extension from a fully flexed position. The second way to measure sorness was a ball attached to a five pound ankle weight as it rolled along the biceps brachii (Allen et al,, 1999)

Results revealed the use of MENS did not produce significant differences in pain and range of motion in double-blinded patients with biceps brachii DOMS (Allen et al., 1999). While applications of MENS have a measureable effect, more research is needed to determine the best settings and waveforms of electronic stimulation to elicit anti-inflammatory and pain reduction.

Electronic stimulation and ultrasound are two functions of the same machine found at many physical therapy clinics or in athletic training rooms. In order to treat DOMS, three different treatment methods may be utilized. Non-thermal ultrasound does not produce resonance in the tissue sufficient to cause a rise in temperature. Non-thermal ultrasound instead produce cavitation and microstreaming which are processes that enhance cellular repair by restoring calcium and sodium balances across damaged cell membranes, reducing spasms (Stay et al., 1998; Hume et al., 2004).

A technique called phonophoresis uses ultrasound without a continuous duty cycle and a topical steroid medium with anti-inflammatory properties like dexamethasone or hydrocortisone instead of regular transmission gel to moderate the amount of swelling. An ultrasound treatment with a continuous production of sound waves and regular transmission gel aims to use cavitation to raise the temperature of the muscle tissue, decreasing stiffness and increasing blood flow to remove unwanted chemicals like prostaglandin and histamine. Ciccone, Leggin & Callamaro (1991) used phonophoresis with trolamine salicylate after biceps curls on a preacher bench with 30 eccentric repetitions at the one rep maximum weight for bilateral comparisons of biceps brachii soreness. Participants were divided into four groups of ten: 1) sham ultrasound and trolamine salicylate, 2) ultrasound and sham cream, 3) sham ultrasound and sham cream, and 4) ultrasound and trolamine salicylate cream. Subjects reported for three days of treatment and ROM assessment, as well as completing a survey regarding pain and tenderness. A final day of

assessments with no treatment also took place. Results revealed pulsed ultrasound through a medium may increase the perception of DOMS but if trolamine salicylate was used, the effects of DOMS were not increased. The authors concluded pulsed ultrasound with trolamine salicylate was not found to halt the progress of symptoms related to DOMS (Ciccone et al., 1991).

There are a broad variety of other interventions to help reduce the symptoms of DOMS; however, the availability of each depends on the resources available to the individual. While athletes on professional teams have wide ranges of modalities available to them, the general public has access to other methods that may be as effective. No single modality has been proven to be the answer to DOMS relative to all the others; as such, each individual discovers the best way to cope with DOMS, often through trial and error. By far the most popular and traditional method of alleviating tenderness and pain is cryotherapy, the standard ice bag or bath that is available to anyone. Cold therapy induces vasoconstriction, arresting edema formation by decreasing blood flow, which contributes the fluid that makes its way past the cell membrane, opened by histamine, prostaglandin and bradykinin, which in turn reduces the mechanical pressure on the free nerve endings (Sellwood, Brucker, Williams, Nichol & Hinman, 2007). Slowing down and reducing blood flow also delays the transportation of those chemical mediators that govern cell permeability, decreasing swelling (Sellwood et al., 2007). Cryotherapy results in a decrease in the temperature of the body also decreases nerve excitability, a principle maximized by ice immersion as compared to a single ice bag (Hume et al., 2004; Kuligowski et al., 1998; Bakhtiary et al., 2007).

Another physiological concept is the pain-spasm cycle that states pain creates spasm to guard the affected muscle which further increases the spasm, beginning the cycle anew. One advantage of cryotherapy is the relief of this cycle through either decreased swelling and

excitation of the Type III and IV nociceptors or cessation of the spasms (Kuligowski et al., 1998). The use of cold immersions as a superior treatment to hot immersions is a commonly held idea but may lack unilateral evidence.

In 2007, Sellwood et al. used a randomized double blind protocol to determine the effect of cycles of one minute immersions and one minute rest with ice water (39-42°F) or room temperature water (75°F) on 40 volunteers after eccentric quadriceps loading on a leg extension machine. One hundred and twenty percent of the maximum weight lifted was applied for five sets of 10 repetitions. Results revealed that there were no significant differences in the decline of muscular hop performance or thigh girth between the control and experimental groups. Pain with a sit to stand test after immersion revealed higher pain in the group immersed in room temperature than in the ice water group. The authors suggested ice water immersion may decrease pain associated with DOMS (Sellwood et al., 2007).

An older concept is contrast therapy, which uses both cold and heat to elicit healing in damaged tissue. This method involves alternating applications of heat and cold to create a blood pumping effect, removing residual swelling in order to decrease mechanical pressure on the muscle cells (Kuligowski et al., 1998). Kuligowski and colleagues (1998) compared the use of cold whirlpool at 55°F, hot whirlpool at 102°F, and contrast therapy with a 3 to 1 bias in favor of cryotherapy in relief of DOMS symptoms in 56 participants. Subjects performed biceps curls with increasingly heavy weights up to 50 repetitions to induce DOMS, and were then assigned to the control, contrast, cold whirlpool or hot whirlpool groups (Kuligowski et al., 1998). Statistical testing revealed that cold whirlpool and contrast therapy are more effective at restoring passive elbow flexion pain than hot whirlpool over a 96 hour window (Kuligowski et al., 1998). Cold immersion induces analgesia just like heat immersion, but is more clinically desirable as it can

stop secondary damage to muscles from exercise from vasoconstriction and the inhibition of edema formation.

Because human physiology is the same everywhere, one of the biggest differences that governs the experience of DOMS is the emotional component. As hypothesized by Cleather and Guthrie (2007), DOMs is "(a) a sensory dimension that includes temporal, spatial, pressure and thermal aspects; (b) an affective dimension that encompasses a person's emotional response to the pain; and (c) an evaluative dimension incorporating a person's cognitive interpretation of the pain". The physical issues faced with DOMS are similar because of muscle makeup, but athletes of different abilities and intelligence levels deal with them differently or perhaps not at all. Those individuals accustomed to training programs know DOMS indicates a workout beyond the normal load and progress toward getting bigger, faster or stronger. Novices may not be able to make it through intense workouts or maintain consistent levels of activity because of the immediate exhaustion or the later onset of DOMS (Sayers & Dannecker, 2004).

Untrained individuals may seek to use as many modalities to reduce their discomfort and return to as normal of function as possible by taking NSAIDs, icing constantly and foam rolling often. Trained individuals may be more used to muscle damage and have routines ready for the possibility, like ice baths every day regardless of soreness intensity, and will respond to one or two interventions better than untrained individuals trying to use the theory of more is better (Hume et al., 2004). Prior knowledge of DOMS and its effects leads to a more positive outlook in general and more effective outcome with each modality used.

2.5 SUMMARY

DOMS is a common phenomenon as physical activity in the form of sports or weight lifting is performed by most of the population. Despite the prevalence of this issue, there are a

variety of treatment philosophies and no unilaterally effective treatment. Simple methods like compression or cryotherapy are commonplace methods as both are readily available to the general population. More technological modalities like ultrasound and electrical stimulation have proven to be somewhat effective but not above some skepticism. The Compex unit is a new tool used for electrically based treatments, aiming to help improve muscular performance and recovery instead of blocking pain. However, there is little evidence of its efficacy and more research is warranted on the ability of Compex to help enhance post activity muscular recovery.

CHAPTER 3

METHODS

3.1 INTRODUCTION

This section will discuss the methodology used to investigate the efficacy of the Compex electrical stimulation unit at decreasing the symptoms associated with DOMS resulting from unaccustomed eccentric muscular contractions.

3.2 RESEARCH DESIGN

A randomized pre and post-test research design was used to determine the efficacy of the Compex unit's Active Recovery® and Recovery Plus® programs to alleviate the physical symptoms of DOMS compared to traditional methods and a control group. The independent variable of the study was treatment group (Compex group, cryotherapy, and control group) and the dependent variables were the muscular strength, perception of muscle soreness and girth measurements of the affected limbs. The protocol employed in this study was approved by the Michigan State Institutional Review Board.

3.3 SAMPLE POPULATION AND PARTICIPANT SELECTION

The studied population was composed of 75 physically active college students between the ages of 18-30 years old. Inclusionary criteria was participation in a physical activity as defined by the ACSM, which can be a mixture of moderate (i.e., sufficient to raise the heart rate and begin to sweat) and vigorous (i.e., breathing hard and fast with a rapidly rising heart rate) intensity aerobic activity and muscle strengthening (i.e., weights lifted to the point where another repetition cannot be completed without help) activities two or more time per week (ACSM, 2011.) Participants were randomly assigned to either a Compex (COM) group (n=25), cryotherapy (CRY) group (n=25), or a control (CON) group (n=25). Exclusionary criteria was

orthopedic surgery (ACL reconstruction, meniscus repair or removal, etc.) within the last six months requiring immobilization for more than four weeks, discomfort performing intense physical activity and current injury of the knees or hips.

3.4 INSTRUMENTATION

The Compex electrical stimulation system utilized in this study is intended for external application with electrodes to create a muscular contraction and help enhance recovery after eccentric muscular activity. The programs used were Active Recovery® and Recovery Plus®, with electrodes placed on the origin and insertions of the biceps femoris, semitendinosus and semimembranosus muscles- the ischial tuberosity, the head of the fibula, the proximal medial tibia and the posterior medial tibial condyle (Kendall et al., 2005). The intensity of the stimulation was adjusted to the highest comfortable level of the subject being treated.

The scale for measuring the intensity of muscle soreness was a 100 mm visual analog scale (Figure 3), spaced by one centimeter increments from one to ten. Ten will represent the maximum amount of soreness and zero represents no soreness at all. Subjects were asked to complete this scale once per day until the final day of testing.

The standard method for objectively measuring pain is known as algometry and the devices used to capture the amount of pressure needed vary. The method for measuring pain was a syringe containing a spring. The syringe was devoid of a needle so the pressure is driven by the spring force on the plunger. The plunger for the syringe was pushed into the skin of the subject to assess the amount of pressure required to elicit pain. The pressure exerted can be calculated by a mathematical formula, $P=kx$, where P is the pressure, k is the spring constant in pound force/inch and x is the distance the spring is compressed. This measurement was taken six and 12 inches above the popliteal fossa on the posterior thigh.

Girth measurements were taken six and 12 inches above the popliteal fossa with a flexible tape measure on the posterior thigh of both legs to assess intramuscular swelling.

Dynamometry is an objective method for obtaining reliable information on muscular force production. More useful than simple weight training devices, isokinetic dynamometers are machines that provide objective feedback on muscular qualities and have been used for a long time to evaluate muscle strength (Beck, Fejer, Philips, Stark, & Walker, 2011). Unlike traditional resistance based training, dynamometers have the ability to train both an agonist and antagonist of the same motion (Brodie & Baltzopoulos, 1989). Dynamometers can be set in CON/CON mode, CON/ECC, or any permutation of CON and ECC. ECC corresponds to eccentric contractions, which involve a muscle contraction as it elongates. The muscle length shortens as it produces force in a concentric contraction, CON mode. A concentric contraction would extend their leg, while an eccentric contraction would make the quadriceps work while allowing the knee to flex. Measurements are taken throughout the range of motion without being affected by which body part or speed is being investigated.

Isokinetic dynamometers can be set to have the arm of the machine move at a specified speed, anywhere from 60-500°/second, to measure inherent qualities of the force the patient is imparting during the range of motion. The range of motion exercised can also be restricted by the clinician or indicated by the stage of rehabilitation or specific exercise. Biodex systems have been found to be reliable and valid systems for quantifying muscular attributes (Beck et al., 2011; Drouin, Valovich, Schultz, Gasneder, & Perrin, 2004). Isokinetic dynamometry has been proven to be a safe way of gathering subject information in adults alike because machine resistance is terminated when the subject stops applying force to the test arm, reducing the likelihood of injury (Buckley, Grimshaw, Shield, & Tsiros, 2010).

Athletic trainers and physical therapists utilize the results of isokinetic dynamometry to screen athletes before, during, and after rehabilitation programs in order to get an object assessment of patients' strength. Buckly et al. (2010) found that the Biodex System 4 dynamometer is safe with pediatric populations as well as adult populations, and provides the ability to evaluate musculoskeletal activity in strength training, rehabilitation programs or muscular disorders. An athletic trainer, physical therapist, or other healthcare professionals with a patient 12 months past ACL reconstruction could, utilizing a Biodex System 3 dynamomter, compare the patients' strength before the injury and current strength to formulate a return to play decision and evaluate the validity of prior treatments or exercise programs. Such systems have "near perfect trial and day-to-day reliability… [with] mechanically reliable measures of torque, position and velocity on repeated trials performed on the same day as well as different days…acceptable for both clinical and research purposes" (Drouin et al., 2004).

Participants were recruited through word of mouth in kinesiology classes along with flyers posted around campus and in each athletic training room. At the first meeting, the study was described and informed consent obtained from all participants. The participants were then be given the opportunity to ask questions and discuss the details of the study at this time. Individuals then completed a health-history form and verbally asked if they fulfill the ACSM physical activity questionnaire. Participants gave the study author their class schedule and received their session times; upon the first day subjects completed the pre-test.

Participants first had their leg girth measured with a measuring tape. Pain measurement was taken using a syringe with spring in place of algometer six and 12 inches above the popliteal fossa for tenderness. After completing the visual analog scale, participants completed the induction DOMS protocol.

For consistent testing for all participants, the Biodex machine was used. Because the muscle targeted for activity is the hamstrings, a high concentric knee extension speed of 300°/s was selected while a speed of 30°/s was used for the concentric knee flexion phase. To induce DOMS, a uniform program was used:

- Warm-up Phase
    - The warm up phase consisted of five minutes at a speed of 4.5 miles per hour at 0% incline on a treadmill followed by the number of individually desired trial repetitions.
- DOMS Phase
    - To produce DOMS in the hamstrings, six sets of 10 concentric repetitions of knee flexion were performed. Between each set of ten repetitions two minutes of rest were given.

After exercise, all subjects had their leg girth, pain pressure threshold and perceived soreness measurements repeated. Information on peak torque, time to peak torque and muscular fatigue by the Biodex was stored to compare the performance of each subject during testing. Each participant was then randomly assigned to one of three groups. Subjects in the CRY group applied an ice bag to the hamstrings three times a day, each time for 20 minutes and spaced by at least an hour and a half per time. All routines were done until all symptoms subsided. The COM group used Compex machines set on the Active Recovery® program the first day and Recovery Plus® on the following days, each time for a full treatment cycle of around 25 minutes. The CON group did not use ice or do any other sort of therapy to help decrease DOMS. All subjects were informed about their treatments and asked not to do any of the following on the four days following pre-testing:

- Take ibuprofen, Tylenol or other anti-inflammatories
- Do lower body weightlifting or long distance running
- Foam roll, ice or use any treatment not dictated by their treatment group assignment

Subjects reported back each day for four days after DOMS was been induced. Each day, girth measurements, pain pressure threshold analysis, and a VAS for muscular soreness were done. On the fifth day, the subjects ran on a treadmill for five minutes at 4.5 mph at 0% incline. After this, they completed as many trial repetitions as desired then perform two sets of 10 repetitions of knee flexion and extension at the same speed as the pre-test. This post-test evaluated whether each subject has fully recovered from DOMS and regained their muscular strength.

3.5 DATA ANALYSIS

Descriptive and inferential statistics were used to analyze the data for this study. For each hypothesis the following statistics will be performed.

H1: There will be no difference in pain pressure threshold after using the Compex compared to the cryotherapy and control groups.

A 3 group (COM, CRY, CON) x 2 time (pre, post) x 2 position (6, 12 in) repeated-measures analysis of variance (ANOVA) will be performed to measure pressure pain threshold scores using the syringe with spring.

H2: There will be no difference in perceived soreness after using the Compex compared to the cryotherapy and control groups.

A 3 group (COM, CRY, CON) x 2 time (pre, post) repeated-measures ANOVA will performed on VAS data.

H3: There will be no difference in muscular size after using the Compex compared to the cryotherapy and control groups.

A 3 group (COM, CRY, CON) x 2 time (pre, post) x 2 position (6, 12 in) repeated-measures ANOVA will be performed to measure thigh girth.

H4: There will be no difference in peak torque after using the Compex compared to the cryotherapy and control groups.

A 3 group (COM, CRY, CON) x 2 time (pre, post) repeated-measures ANOVA will be performed to measure peak torque.

H5: There will be no difference in muscular fatigue after using the Compex compared to the cryotherapy and control groups.

A 3 group (COM, CRY, CON) x 2 time (pre, post) repeated-measures ANOVA will be performed to measure muscular fatigue.

H6: There will be no difference in time to peak torque after using the Compex compared to the cryotherapy and control groups.

A 3 group (COM, CRY, CON) x 2 time (pre, post) repeated-measures ANOVA will be performed to measure time to peak torque.

Data will be analyzed using Statistical Package for Social Sciences (SPSS) version 21.0. Significance level for all analyses was set at prior to $p < 0.05$.

CHAPTER 4

RESULTS

4.1 OVERVIEW

This research was conducted to investigate whether there were any differences in muscular recovery between Compex electrical stimulation recovery programs, cryotherapy treatments, or the control group. The following chapter will describe the demographics of the sample and depict the relationships between the three treatment groups' muscular leg girth, perceived soreness via a visual analog scale, pressure pain threshold, peak torque, muscular fatigue, and time to peak torque.

4.2 DEMOGRAPHIC DATA

A total of 75 (44 females, 31 males) participants began the study with 72 (42 females, 30 males) finishing the study by completing pretesting, four of five follow-up days and post-testing. The Compex group was made up of 25 participants, the control group was made up of 25 participants and the cryotherapy group was made up of 25 participants. The average age of the participants was 19.61 $\pm$ 1.68 years old. The average weight was 155 $\pm$ 26.57 pounds and the average height was 68 $\pm$ 3.6 inches.

4.3 Assessment of Hypotheses

H1: *There will be no difference between the three groups for pain pressure.*

The hypothesis was supported as there was no statistically significant difference in pain pressure at six inches [Wilks'=.907, $f_{(10.126)}$=.631, p=.787] and 12 inches [Wilks'=.869, $f_{(10.124)}$=.905, p=.513] for the interaction between time and group.

There was a significant difference for the main effect of time (i.e., pre, post day 1, 2, 3, 4, 5) for pain pressure at six inches [Wilks' = .829, $f_{(5,63)}$=2.60, p=.033], however, pain pressure at

12 inches was not significant for time [Wilks'=.976, $f_{(5,63)}$=.307, p=.907]. This suggests that six inches is the middle of the belly of the hamstring musculature and a site of more myosin-actin crossbridges that may be broken during the DOMS testing protocol. There were no statistically significant difference between groups (i.e., cryotheraphy, compex, control) for pain pressure at six inches [$f_{(2,67)}$=.276, p=.760] and 12 inches [$f_{(2,66)}$=.542, p=.584] . However, the Biodex protocol was sufficient to produce differences in pain pressure threshold, as all group means dropped from baseline.

The mean and standard deviation of pain pressure threshold in foot-pounds of pressure at six inches above the popliteal fossa are shown in Table 4-1 while those for 12 inches are found in Table 4-2. Table 4-3 details the pairwise comparisons of the pressure pain threshold data.

Table 4-1

Pain Pressure Threshold (ft. lbs) at Six inches for the Compex, Cryotherapy and Control Groups

Day	Group	Mean	Standard Deviation
1- Pre	Compex	17.5	0.00
	Cryotherapy	17.5	0.00
	Control	17.5	0.00
	Total	17.5	0.00
1- Post	Compex	16.90	2.21
	Cryotherapy	17.20	1.22
	Control	16.96	1.66
	Total	17.03	1.73
2-Post	Compex	16.77	2.37
	Cryotherapy	17.26	1.20
	Control	17.03	1.46
	Total	17.02	1.76
3-Post	Compex	17.31	0.52
	Cryotherapy	17.18	0.93
	Control	17.10	1.24
	Total	17.21	0.91

Table 4-1(cont'd)

4-Post	Compex	17.5	0
	Cryotherapy	17.09	0.76
	Control	17.23	1.21
	Total	17.35	0.78
5-Post	Compex	16.8	3.5
	Cryotherapy	17.39	0.54
	Control	17.5	0
	Total	17.21	2.11

Table 4-2

Pain Pressure Threshold (ft. lbs.) at 12 Inches for the Compex, Cryotherapy and Control Groups

Day	Group	Mean	Standard Deviation
1- Pre	Compex	16.74	2.40
	Cryotherapy	17.50	0.00
	Control	17.07	1.51
	Total	17.10	1.67
1- Post	Compex	16.64	3.00
	Cryotherapy	17.28	0.85
	Control	17.17	1.23
	Total	17.01	1.98
2-Post	Compex	17.07	2.16
	Cryotherapy	17.50	0.00
	Control	16.97	1.59
	Total	17.19	1.55
3-Post	Compex	17.45	0.26
	Cryotherapy	17.05	2.20
	Control	17.1	1.51
	Total	17.21	1.53
4-Post	Compex	17.45	0.26
	Cryotherapy	17.39	0.55
	Control	16.93	1.56
	Total	17.28	0.93

Table 4-2(cont'd)

5-Post	Compex	16.80	3.50
	Cryotherapy	17.28	1.10
	Control	17.23	1.21
	Total	17.09	2.28

Table 4-3

Pairwise Comparisons at Six Inches for the Compex, Cryotherapy and Control Groups for the Main Effect of Time

Time	Time	Mean Difference	Standard Error	Significance
1	2	0.48	0.21	0.03*
	3	0.48	0.21	0.03*
	4	0.30	0.11	0.01*
	5	0.16	0.10	0.09*
	6	0.27	0.26	0.29
2	1	-0.48*	0.21	0.03
	3	0.003	0.26	0.99
	4	-0.18	0.17	0.32
	5	-0.31	0.18	0.09
	6	-0.21	0.33	0.53
3	1	-0.48*	0.21	0.03*
	2	-0.003	0.26	0.99
	4	-0.18	0.20	0.37
	5	-0.32	0.19	0.09
	6	-0.21	0.26	0.43
4	1	-0.30*	0.11	0.01*
	2	0.18	0.17	0.32
	3	0.18	0.20	0.37
	5	-0.14*	0.05	0.01*
	6	-0.03	0.27	0.91
5	1	-0.16	0.10	0.09
	2	0.31	0.18	0.09
	3	0.32	0.19	0.09
	4	0.14*	0.05	0.01*
	6	0.1114	0.27	0.68
6	1	-0.27	0.26	0.29
	2	0.21	0.33	0.53
	3	0.21	0.26	0.43

Table 4-3 (cont'd)

4	0.03	0.27	0.91
5	-0.11	0.27	0.68

*The mean difference is significant at the .05 level.

H2: *There will be no difference in perceived soreness between the three treatment groups.* This hypothesis was supported as there were no significant time by group interactions [Wilks'=.947, $f_{(10,126)}$=.357, p=.965] for perceived soreness as measured using the visual analog score. In addition, there was also no between group differences for perceived soreness [$f_{(2,67)}$=.323, p=.726]. However, there was a significant difference for time for perceived soreness [Wilks'=.403 $f_{(5,63)}$=18.63, p=.000]. All means increased from pre-test to post-test, indicating an increase in soreness from the testing protocol. See Table 4-5 for specific significant differences for the main effect for time. Table 4-4 includes the mean and standard deviation of reported visual analog scores.

Table 4-4

Visual Analog Scale for Time for the Compex, Cryotherapy and Control Groups

Day	Group	Mean	Standard Deviation
1- Pre	Compex	0.76	1.33
	Cryotherapy	0.40	0.82
	Control	0.65	1.84
	Total	0.60	1.35
1- Post	Compex	2.64	2.21
	Cryotherapy	2.6	1.81
	Control	2.45	2.10
	Total	2.57	2.01
2	Compex	0.80	1.50
	Cryotherapy	0.72	1.24
	Control	0.85	1.50
	Total	0.79	1.39
3	Compex	0.40	0.82
	Cryotherapy	0.56	1.23
	Control	0.88	1.72

Table 4-4 (cont'd)

	Total	0.59	1.27
4	Compex	0.16	0.55
	Cryotherapy	0.44	0.92
	Control	0.70	1.78
	Total	0.41	1.15
5	Compex	0.04	0.20
	Cryotherapy	0.16	0.55
	Control	0.40	1.39
	Total	0.19	0.82

Table 4-5

Pairwise Comparisons for Visual Analog Scale

Time	Time	Mean Difference	Standard Error	Significance
1	2	-1.96*	0.227	0.00
	3	-0.19	0.22	0.40
	4	-0.01	0.217	0.97
	5	0.17	0.21	0.43
	6	.40*	0.19	0.04
2	1	1.96*	0.23	0.00
	3	1.77*	0.27	0.00
	4	1.95*	0.27	0.00
	5	2.13*	0.27	0.00
	6	2.36*	0.27	0.00
3	1	0.19	0.22	0.40
	2	-1.77*	0.27	0.00
	4	0.18	0.14	0.21
	5	.36*	0.17	0.04
	6	.59*	0.17	0.001
4	1	0.01	0.22	0.97
	2	-1.95*	0.27	0.00
	3	-0.18	0.14	0.21
	5	0.18	0.1	0.08
	6	.41*	0.13	0.002
5	1	-0.17	0.21	0.43
	2	-2.13*	0.27	0.00
	3	-.36*	0.17	0.04
	4	-0.18	0.1	0.08
	6	.23*	0.08	0.004

Table 4-5 (cont'd)

6	1	-.40*	0.20	0.045
	2	-2.36*	0.27	0.00
	3	-.59*	0.17	0.001
	4	-.41*	0.13	0.002
	5	-.23*	0.08	0.004

*The mean difference is significant at the .05 level.

H3: *There will be no difference in muscular girth between the three treatment groups.*

This hypothesis was supported as there were no significant time by group interactions for six inch girth [Wilks'=.922, $f_{(10,114)}$=.470, p=.906] and 12 inch girth [Wilks'=.876, $f_{(10,114)}$=.781, p=.647]. In addition, there were also no between group differences for six inch girth [$f_{(2,61)}$=1.6, p=.210] and 12 inch girth [$f_{(2,61)}$=1.76, p=.181]. However, there was a significant difference for time for six inch girth [Wilks'=.753 $f_{(5,57)}$=3.75, p=.005], but no significant difference for 12 inch girth [Wilks'=.916 $f_{(5,57)}$=1.05, p=.398]. Tables 4-6 and 4-7 include the means and standard deviations for girth measurements in inches performed at six and 12 inches above the popliteal fossa.

Table 4-6

Six Inch Girth (in.) for Time for the Compex, Cryotherapy and Control Groups

Day	Group	Mean	Standard Deviation
1- Pre	Compex	18.80	1.58
	Cryotherapy	19.12	1.62
	Control	19.51	1.87
	Total	19.09	1.66
1- Post	Compex	18.96	1.58
	Cryotherapy	19.52	1.58
	Control	19.93	1.46
	Total	19.40	1.57
2	Compex	18.87	1.38
	Cryotherapy	19.27	1.50
	Control	19.77	1.38

Table 4-6 (cont'd)

	Total	19.24	1.45
3	Compex	18.95	2.17
	Cryotherapy	19.34	1.43
	Control	19.55	1.51
	Total	19.24	1.77
4	Compex	18.72	1.48
	Cryotherapy	19.18	1.32
	Control	19.57	1.70
	Total	19.10	1.50
5	Compex	18.19	4.09
	Cryotherapy	19.17	1.38
	Control	19.45	1.54
	Total	18.86	2.81

Table 4-7

12 Inch Girth (in.) for the Compex, Cryotherapy and Control Groups

Day	Group	Mean	Standard Deviation
1- Pre	Compex	23.06	2.71
	Cryotherapy	23.43	2.01
	Control	23.58	1.57
	Total	23.32	2.20
1- Post	Compex	22.67	1.60
	Cryotherapy	23.54	1.93
	Control	23.45	2.14
	Total	23.18	1.88
2	Compex	22.59	1.65
	Cryotherapy	23.45	1.92
	Control	23.52	1.59
	Total	23.13	1.77
3	Compex	22.71	1.66
	Cryotherapy	23.43	1.93
	Control	23.46	1.66
	Total	23.15	1.77
4	Compex	22.64	1.60
	Cryotherapy	23.58	2.02
	Control	23.45	1.67
	Total	23.18	1.80
5	Compex	21.45	4.76

Table 4-7 (cont'd)

Cryotherapy	23.05	2.31
Control	23.22	1.71
Total	22.47	3.44

H4: *There will be no difference in peak torque between the three treatment groups.*

This hypothesis was supported as there were no significant differences for the interaction between group and time [Wilks'=.978, $f_{(2,69)}$=.777, p=.464] (see table 4-8). Mean scores for peak torque decreased for the Compex and cryotherapy groups, but increased for the control group. There was no significant difference between groups for peak torque [$f_{(2,69)}$=.096, p=.908] and time [Wilks'=.980, $f_{(1,69)}$=1.39, p=.242] for the hamstring muscle. Table 4-8 includes the means and standard deviations for peak torque values in foot-pounds of force from Biodex testing.

Table 4-8

Peak Torque Biodex Scores (ft. lbs.) for the Compex, Cryotherapy and Control Groups

Peak Torque	Treatment	Mean	Standard Deviation
Pre-Test	Compex	69.14	44.47
	Cryotherapy	56.08	17.20
	Control	62.87	20.16
	Total	62.70	30.08
Post-Test	Compex	56.48	29.86
	Cryotherapy	45.04	29.24
	Control	66.41	33.67
	Total	55.83	31.75

H5: *There will be no difference in time to muscular fatigue between the three treatment groups.*

This hypothesis was supported as there were no significant differences for the interaction between group and time [Wilks'=.991, $f_{(2,68)}$=.305, p=.738] (see table 4-9). There was also no significant difference between groups for percent fatigue of the hamstring muscle [$f_{(2,68)}$=.394, p=.676]. However, there was a significant difference for the main effect of time [$f_{(1,68)}$=4.86,

p=.031]. Participants post test scores were higher than there pre-test scores, indicating subjects were able to perform more consistently on the post test. Table 4-9 includes the means and standard deviations of the percent fatigue results from Biodex testing.

Table 4-9

Biodex Percent Fatigue for the Compex, Cryotherapy and Control Groups

Percent Fatigue	Treatment	Mean	Standard Deviation
Pre-Test	Compex	11.12	15.34
	Cryotherapy	13.61	12.94
	Control	13.48	11.93
	Total	12.72	13.37
Post-Test	Compex	20.17	10.88
	Cryotherapy	14.72	14.96
	Control	13.48	11.93
	Total	16.16	12.88

H6: *There will be no difference in time to peak torque between the three treatment groups.* This hypothesis was supported as there were no significant differences for the interaction between group and time [Wilks'=.964, $f_{(2,69)}$=1.27, p=.288] (see table 4-10). There were also no significant differences between groups for peak torque [$f_{(2,68)}$=2.08, p=.133] and time [Wilks'=.999, $f_{(1,68)}$=.042, p=.837] for the hamstring muscle. Table 4-10 includes the results of time to peak torque from Biodex testing in milliseconds.

Table 4-10

Time to Peak Torque (msec.) for the Compex, Cryotherapy and Control Groups

Time	Group	Mean	Standard Deviation
Pre-Test	Compex	541.13	475.87
Table 4-10 (cont'd)			
	Cryotherapy	746.04	388.07
	Control	715.66	358.1
	Total	665.88	415.84

Table 4-10 (cont'd)

Post-Test	Compex	533.4	456.25
	Cryotherapy	787.15	421.59
	Control	749.79	431.21
	Total	687.97	445.43

4.4 SUMMARY

Statistical testing revealed no single treatment group demonstrated superior recovery compared to the others. Significant main effects for time were seen with pain pressure threshold at six inches, for perceived soreness, six inch girth, and for muscular fatigue. Other trends indicated more consistent testing on the post-test compared to the pre-test on the Biodex. The results from the tested variable represent a macroscopic evaluation of DOMS symptoms, but there are other measurements that could be used in future testing to look at recovery on a smaller level.

CHAPTER 5

DISCUSSION

5.1 INTRODUCTION

This chapter will provide a general overview of the results found in the present study and discuss them in relation to the relevant literature focused on therapeutic modalities from DOMS. First, the findings from the Biodex testing and three treatment groups will be reviewed and discussed. Those results will then be compared to prior studys' findings and methodologies. Third, clinical implications will be discussed and finally, limitations, future research and conclusions will be presented.

5.2 SUMMARY OF RESEARCH FINDINGS

Based on the results of the study, no statistically significant differences were found between the Compex, cryotherapy or control treatment groups for muscular girth, pain pressure threshold and Biodex measures. Muscular girth increased similarly across the three treatment groups. Decreases in pain pressure threshold were also found to be similar across all treatment groups. Participants' perceived soreness was not different between the control group and the two groups that received a therapeutic modality. Results for muscular endurance as measured using the Biodex revealed none of the treatments produced higher values from baseline to post-test. When all individuals were compared equally to each other, significant differences were found for soreness perception and pain pressure threshold for time; however, the cause for those differences is unclear.

5.3 PAIN PRESSURE THRESHOLD

Overall the findings of this study suggest there were no significant differences between groups pre and post DOMS for pain pressure threshold. However, when all participants where

combined into one group, pain pressure at six inches were significant across various time points. These time points were baseline to Day 1, baseline to Day 2 and Day 3 to Day 4. These findings suggest that the Biodex protocol was sufficient enough to induce pain from pressure. Similar to the current study, Allen et al. (1999) concluded that microcurrent electronic nerve stimulation (MENS) was ineffective at relieving increasing pain tolerance due to eccentric biceps contractions compared to a control group when a weight was applied to an orthoplast sphere to produce pain.

The current study's algometer was hand-made, fashioned of an inverted syringe with a spring to create the pain pressure threshold in participants. This instrument was similar to Bakhtiary et al. (2013) who also used a 20 ml syringe containing a spring to elicit pain in their subjects. Mancinelli et al. (2008) used an algometer for pain pressure threshold assessments after vertical jump testing and shuttle runs and obtained measurements that had no statistically significant change for group interaction, a finding comparable with the current study's results. Similar to the current findings, Pumpa et al. (2011) also used an algometer to measure pain pressure threshold after downhill running and reported no significant differences between a control group and a group that received an anti-inflammatory NSAID. Contrasting findings were reported by Udani et al. (2009) who used an algometery to assess pain pressure thresholds five centimeters above the superior pole of the patella after five minutes of as many squats as possible. Measurements taken at 24, 48, 72 and 96 hours showed significant differences in the experimental group (who had ingested a dietary recovery supplement called BounceBack) compared to the control group at 24 hours. These differences may be due to Udani et al. (2009) using a supplement to decrease the effects of DOMS while this study used the Compex system.

5.4 BIODEX

The present study's findings did not reveal any significant interactions between group and time for the Biodex measures of percent fatigue, time to peak torque, or peak torque. The testing protocol used more sophisticated methods than Allen et al. (1999), who used barbells and eccentric biceps curls, but was also able to produce soreness and pain in the targeted muscle group. The lack of effective therapeutic intervention in the current study align with Allen et al. who found MENS (a treatment similar to Compex) to be an ineffective remedy for DOMS. A similar protocol was used by Butterfield et al. (1997) to induce muscle soreness. Specifically, these researchers use a Cybex leg extension machine, and had subjects perform up to 30 sets of 10 repetitions of eccentric knee flexion, with a 15-20 second rest period between sets to induce DOMS. Unlike the current study, the one repetition maximum concentric knee extension exercise was the pre-test and post-test measurement. Butterfield and colleagues found high volt pulsed current, another electrical modality program, showed no more analgesic effects compared to sham treatments, much like the current study found Compex use produced results similar to the control or cryotherapy condition.

Cockburn et al. (2008) used a Cybex isokinetic dynamometer, six sets of ten repetitions of hamstring eccentric and concentric contractions, and induced soreness on both legs. Cockburn et al. found protein and carbohydrate drinks to attenuate muscle soreness compared to drinks with only carbohydrates or protein, which may point to a more effective method of treating DOMS than cryotherapy, electronic stimulation, or no intervention.

5.5 GIRTH

In regard to leg girth, there were no significant interactions between the compex, cryotherapy and control groups. Similarly, Mikesy & Hayden (2005) also used girth measurements after 50 maximal repetitions of elbow flexion at 60°/second on a Kincom

isokinetic dynamometer. These researchers also did not report significant differences between a placebo and control group for arm girth before, immediately after and seven days post protocol. Sellwood et al. (2013) performed girth measurements on the thigh after 50 seated eccentric leg extensions at 120% of the maximum concentric weight. After performing the DOMS protocol, participants used ice water, room temperature water, or contrast bath and found no significant differences between groups. The current study used cryotherapy which was equally effective as the control and Compex conditions at restoring normal muscular function. Finally, Stay et al. (1998) evaluated upper extremity girth after eccentric and concentric dumbbell curls and found no differences between the group that received pulsed ultrasound or sham treatments from baseline out to 96 hours after testing. Therefore, it doesn't appear that leg girth increases or decreases due to therapeutic interventions.

Although there were no differences between groups' pre and post-test, overall all participants reported temporary increases in leg girth six inches above the popliteal fossa over time. Similarly, Micklewright (2009) used girth measurements to assess intramuscular swelling of the upper arm following eccentric elbow extensions and soft tissue release treatment, and reported immediately increases in scores following the DOMS induction protocol which returned to baseline after 48 hours. However, there were no statistically significant differences between the experimental and control groups.

5.6 SORENESS PERCEPTION

No significant group interactions were found for measurements taken from the visual analog scale for muscle soreness perception, however, there was an increase in score from pre-test to post test for all the subjects. The visual analog scale is adaptable to each subject as pain and soreness can present in different ways after DOMS. A study by Bakhtiary et al. (2013) also

captured the subjective dimension of soreness from a muscle damaging activity using a visual analog scale, finding higher means than this study. Bakhtiary et al. (2013) used vibration therapy as the therapeutic technique for DOMS while Butterfield et al. used high volt pulsed current. Ciccone, et al. (1991) also used a visual analog scale for quantifying the subject experience of DOMS. The researchers found that visual analog scales didn't demonstrate significant differences in level of soreness reported in control and experimental groups and across the body with DOMS induced by eccentric preacher biceps curls. Their study compared ultrasound to phonophroesis to sham ultrasound to treat DOMS. There are many methodological differences in the DOMS intervention protocol that may explain the differences in results.

Hilbert, Sforzo and Swensen (2003) utilized a Cybex isokinetic dynamometer with a testing protocol on the hamstrings of eight submaximal repetitions, two maximal repetitions and five maximal repetitions before using massage to attenuate DOMS. Concluding that there was no significant effect for treatment on peak torque production in the hamstrings, their findings concur with the current study.

Mancinelli et al. (2006) used a visual analog scale to assess perceived soreness with massage treatment compared a control condition following shuttle runs and vertical jump testing. A significant reduction of reported DOMS was seen within four days for the treatment group while no significant reduction was found for the control group. Mancinelli and colleagues results are in contrast to the current study whose visual analog scores showed no statistically significant reductions within or between treatment groups (2006).

Following eccentric and concentric elbow extensor contractions, Micklewright (2009) used visual analog scores to examine self-reported tenderness in the upper arm. No subject was found to be a non-responder and it was concluded the visual analog scale was adequate to convey

the subjective dimensions of DOMS. Visual analog scale values were higher after the soft tissue release treatment, and Micklewright suggested that this may be a contraindicated technique for DOMS reduction (2009).

In contrast to the findings of the current study which found no decreases or increases in muscle soreness as indicate by the visual analog scale, Sellwood et al. (2005) found that ice water immersion resulted in higher levels of perceived muscular soreness than room temperature water or control conditions. This finding opposes the idea that cryotherapy is superior to control conditions at relieving the perception of DOMS. This treatment may have the opposite effect as desired, increasing patient soreness perception rather than reducing it.

5.7 CLINICAL IMPLICATIONS

The results of the current study indicate that the Compex demonstrates the same clinical effectiveness at attenuating DOMS as traditional methods of cryotherapy and no treatment. While the latter methods have been used for many years, Compex treatment is a new phenomenon. In the collegiate setting, athlete recruitment can be influenced by the new toys and tricks each school has, and health care is not immune from the desire to always have the newest and most innovative tools. New methods and techniques for enhancing patient care are highly desirable. Increased psychological readiness for exercise is a goal as necessary as physiological recovery because elite athletes and physical therapy patients have to be physically and mentally ready to perform. Traditional methods for alleviating the symptoms of DOMS are taught as curriculum and a normal part of the thought process of the athletic trainer, physician or physical therapist, but more novel techniques like magnetic therapy, vibration therapy and Compex are up to whomever controls the budget.

5.8 LIMITATIONS

There were several limitations to the study. First, as college students, classes in certain majors such as Kinesiology or nursing require physical activity on a regular basis. This may have affected recovery from the DOMS protocol and altered subject's ability to perform to their greatest extent. No athletes were used in the course of the study because of the inability to control their daily physical activity. Students were verbally queried about their physical activity status and not all reported the same training status. Variability between the types of physical activity performed (i.e. weight lifting vs. distance running) creates different inherent characteristics that affect maximal hamstring contractions.

Lifestyle choices may have swayed the results of the study. Alcohol intake was not standard across each subject, and one subject asked if going to three parties and drinking would affect her recovery. The exact effect of alcohol on recovery from damaging muscle exercise is beyond the scope of this study but could change subject test scores. Subjects were not asked to document their deviations from subject instructions (i.e. no exercise, pain medications, etc.) This would have been helpful in assessing subject compliance and help eliminate subject data that would affect the final results of the study. Finally, the small sample size for each group may have contributed to the lack of significant findings.

5.9 FUTURE RESEARCH

Due to the inconsistent findings of various studies investigating Compex use, more research is warranted. Future research could limit the subject population to one sex and utilize only athletes as test subjects. Future research could also be chronologically stratified, checking to see if specific age groups respond more to Compex usage. Future studies could focus on the use of Compex with an older age group. The geriatric population requires therapy and corrective exercise for a variety of injuries and conditions but has limitations a younger population does

not. A Compex unit can be used at home for increased strength and endurance without the possibility of falling, a major injury in older populations. Therapeutic exercises are necessary but an elderly patient cannot do as many as sets and repetitions.

EMS training can take the place of some exercise if the benefits of additional strength can be achieved by external stimulation. Russian stimulation is done concurrently with patient contraction, and that could be done with a Compex program to accentuate recovery. Arresting atrophy and increasing function could be maximized by higher level muscular stimulation from the brain and local stimulation from the Compex.

All measurements were taken externally in the current study, but there were a couple of other methods that were not employed. Electromyography could also serve to examine muscular activation patterns and can be done via surface electrodes or intramuscular needles. Because the Compex unit is intended to assist athletes with a variety of muscular attributes, functional testing paired with dynamometry could provide a better indication of muscular function, both objectively and subjectively. Finally, future research could also concentrate on sport specific activities like shooting in soccer or throwing for baseball or softball.

5.10 CONCLUSIONS

Given the lack of statistical significance for any of the tested variables, the study indicates that Compex, cryotherapy and control conditions are equally effective at attenuating the symptoms of DOMS and restoring muscular function up to five days after muscle damaging exercise. Interactions between groups revealed no significance for muscular girth, pressure pain threshold, perceived soreness, peak torque, time to peak torque or percent fatigue. Significance was found for time with perceived soreness and muscular girth at six inches above the popliteal

fossa, indicating test subjects reported soreness after the testing protocol, which was sufficient to produce a palpable pain pressure measurement above baseline values.

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