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Effect of Therapeutic Treatment on Delayed Onset Muscle Soreness (DOMS)

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EFFECT OF THERAPEUTIC TREATMENT ON DELAYED ONSET MUSCLE SORENESS (DOMS)

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Literature Review Introduction

Delayed onset muscle soreness (DOMS) is a common following exercise and does not occur after every form of exercise, but most often occurs after unaccustomed exercise, and/or exercise that involves eccentric muscle contractions. [1, 2, 8, 12, 26, 34, 35, 36, 39, 42] An eccentric contraction involve lengthening of the muscle while contracting, and causes a more powerful force, [36] yet more damaging effect on the involved muscle versus a concentric muscle contraction. Eccentric contraction is commonly seen in weight lifting, plyometric exercise, and sports that involve powerful bursts of strength and speed. [8, 15, 24, 28, 29, 36, 39]

DOMS is one of the more common injuries after exercise, and has been classified as a grade I muscle strain.[27] Symptoms of DOMS include muscle stiffness, pain, tenderness, decreased range of motion (ROM), and decreased muscle strength. [1, 4, 8, 12, 14, 23, 24, 25, 26, 27, 28, 32, 33, 35, 38, 39, 42] The severity of these symptoms can vary based on the individual and their pain perception. Symptoms can also increase or decrease in severity based on the type and intensity of exercise and previous or current training of an individual. DOMS symptoms typically do not occur immediately after exercise. A peak of symptoms is observed 24 to 48 hours after exercise and has been known to peak up to 72 hours. [1, 8, 14, 15, 23, 24, 26, 27, 28, 29, 32, 34, 35, 36, 39, 42] Typically symptoms may not completely resolve until five to seven days post exercise. [15, 16, 28, 29, 36, 39]

The first observed occurrence of DOMS was in the early 1900s. [17] Hough's (1902) study consisted of using an ergograph, which provided resistance to the middle finger, which would then perform flexion exercises. The main purpose of Hough's study was to observe the fatigue that was experienced by the flexor muscles, and to test that the soreness that untrained muscles experienced was not that of pure fatigue but that there may be another type of soreness. Hough described fatigue as a result of waste product from activity and in turn can hinder generation of energy in the involved muscle(s). Fatigue then is resolved when the body uses blood to help rid the area of the waste products. The main points of observation in his study was soreness presented itself about eight to ten hours after exercise (with greater values of soreness observed when resistance was placed on the involved muscle), peaked on the second day, and lasted for about four days after exercise.

Hough (1902) went on to describe that there are two types of soreness. The first is that of untrained muscles that presents about 12 hours after exercise. The second type of soreness occurred in untrained or trained muscles, and is a result of tetanus (or sustained muscle contraction) and may occur immediately after exercise. The first type of soreness is consistent with what we know as DOMS. Hough did not use the term DOMS during his study, but did report the importance of knowing the difference of soreness and fatigue. His description noted soreness had a gradual onset that differed from fatigue. He continued with this description and noted that soreness caused the muscle to not be able to generate the same amount of force, even with the absence of pain. This led Hough to his theory of what causes this gradual onset soreness to occur. Due to the decreased power output, Hough (1902) stated that some muscle fibers were disrupted and unable to function, and that adhesions formed during repair were being torn which caused pain, especially during movement. Hough said this could mean this soreness is a result of fiber, connective tissue, or nerve damage possibly accompanied by inflammation of the connective tissue.

Today, Hough's theory of what is now called DOMS is still relevant and is still discussed in literature as a possible cause. Yet, there is no one theory that fully explains DOMS. Many researchers have stated that it is most likely a combination of different proposed theories that lend an explanation into this phenomenon. In the next section a description of these theories is meant to provide a better understanding of what may cause DOMS.

Theories of DOMS

Lactic Acid Theory

Lactic acid is a waste product that is produced primarily during anaerobic glycolysis exercise. [3, 8, 22, 35, 39] During activity, the presence of lactic acid quickly changes to lactate, which can inhibit the muscles' ability to contract.[35]

Lactic acid and lactate are known to cause pain during and immediately following exercise. This pain is caused by the waste production by energy produced in the involved muscles, which then stimulates a noxious (pain) stimulus.[8] In order to test this theory, a blood sample is required from the individual participating in the study. As mentioned previously, DOMS typically peaks 24 to 48 hours after exercise. It is now known that lactic acid levels return back to their baseline levels in about an hour after unaccustomed or intense exercise.[3, 5, 8, 12, 34, 39] Therefore, the lactic acid theory of DOMS has been rejected.[3, 8, 12, 34, 39]

Muscle Spasm Theory

Muscles spasms occur in the muscles, and can cause a painful response for the individual. A muscles spasm occurs when a motor unit continues to contract. Tetanus contraction can cause palpable pain as well as pain with further movement and contraction of the involved muscle. This tetanus contraction can stimulate pain on a neural level.[34] A "vicious cycle" was defined in literature to help explain the muscle spasm theory.[8, 34, 39] The vicious cycle is thought to start with the continued activation of resting muscle. Activation of the involved muscle is said to compress blood vessels causing ischemia, and accumulate muscular waste that can causes pain. Pain is continued to be stimulated on a neural level, which continues this cycle of ischemia caused by reflex muscle spasms. Cheung & Maxwell (2003) claim there is a lack of sensitivity of the instruments used to test this theory. Bipolar and unipolar electromyography (EMG) is used to help detect any muscle activity that remains after exercise has ended. There have been inconsistencies with the EMG and muscle soreness relationship, and therefore this theory has been labeled inconclusive. Muscle spasm theory is not a commonly discussed theory to explain the cause of DOMS in the majority of literature.

Enzyme Efflux Theory

In order to understand Enzyme Efflux Theory, it is necessary to review muscle contractions. Muscle contraction is defined as the shortening of a muscle, which is also called concentric contraction. DOMS is primarily a result from eccentric contraction which is contraction of the muscle while it lengthens. The sliding filament theory (figure 1) is defined as myosin cross-bridge forms to attach to an actin filament and the power stroke drags the two filaments past one another.(41) The attachment then breaks off and finds a new site further down the filament until it reaches the z-disks (z-line) or calcium enters the sarcoplasmic reticulum to ready the muscle for further contraction. This whole process begins with adenosine triphosphate (ATP) which is the energy source for muscle contraction.(35, 41)

Calcium is stored in the sarcoplasmic reticulum. It remains their waiting for ATP to start the sequence of a muscle contraction.(41) The enzyme efflux theory proposes that during eccentric exercise, the sarcoplasmic reticulum undergoes damage, and is unable to then store the calcium, which builds up in the involved muscle.(8) This is thought to hinder the process of ATP creation.

Cheung et al. (2003) also states that pain can occur due to the calcium causing a chain reaction that weakens the z-lines involved with contraction and stimulate the pain nerve endings. This theory is not widely tested, and is not commonly found in the literature.

Inflammation Theory

The inflammation theory is more often discussed in literature as a cause for DOMs. To understand this theory, a basic understanding of the healing process following injury is needed. The inflammatory response is the first stage of three in the healing process, and will be the only one of focus in this review. After injury occurs, this stage will begin immediately and will last approximately four days.[(31)] Common symptoms of inflammation are redness, swelling, point tenderness, increased temperature (warm to the touch on affected area), and possible loss of function.[(31)] These symptoms are a result of a cellular response to the injury. Leukocytes are signaled to the injured area to “clean up” waste products that are caused by the injury. Waste products produced by injury are exudate, blood, and/or damaged cells.[(31)] Phagocytic cells follow, and eliminate and dispose of any leftover cellular metabolic waste.[(31)] These three cellular responses are able to occur because of three chemical mediators. First, histamine causes vasodilation and increases cell permeability which allows the fluid to enter the area causing swelling. Second, leukotrienes cause margination (adherence of leukocytes and phagocytic cells to the cell walls). Third, cytokines help signal leukocytes to the injured area, which is then followed by phagocytes.[(31)] The last part of this healing phase is the clotting process, immediately proceeds into the second phase of healing.[(31, 35)]

It is known that eccentric contraction causes damage to muscular structures.[(8, 15, 23, 26, 34, 35, 36, 39. 42)] During the acute inflammatory response there are cellular and chemical events that occur that may lead to the pain associated with DOMS. [8, 31, 39] Adhesions that form during the healing process can be disrupted and could be an explanation to pain of DOMS.[15, 16, 17] Hilbert, Sforzo & Swenson (2003) compared neutrophil margination levels to perceptual pain, and were unable to find a relationship. Soreness was decreased after their treatment of massage was administered, but they were unsuccessful at decreasing margination. One can conclude that while margination in fact occurs during the inflammatory process[15] it may not be responsible for pain sensation.

Pain sensation instead could be a result of specific neural stimulation. There are different types of neurons in the body that are responsible for detecting/ different sensations. These pain neurons are classified as group III and IV and their sensory receptors are called nociceptors.[8, 15, 16, 31, 39] Not many explanations have been brought forward to explain how these neurons might be stimulated, but the swelling that occurs in the inflammatory response phase could be a cause. Osmotic pressure caused by the swelling can stimulate these nerves and make them more sensitive to their triggers such as movement or palpation.[8, 15, 34] Donnelly, McCormick, Maughan, Whiting, & Clarkson (1998) and Sellwood, Brunker, Williams, Nicol, & Hinman (2007) have observed peak perceived soreness coincides with peak measurements of girth and limb volume. Another possible cause is the accumulation of phagocytic cells (macrophages) which can also stimulate pain neurons in the injured area.[1, 8, 31, 34] Removing or decreasing the swelling from the involved area would also mean a decrease in neutrophils and phagocytic cells, which in turn can help decrease pain.[23] Yet there have been some inconsistencies with decreased pain and the efficiency of decreasing swelling, but this can also be dependent on the type of intervention/treatment administered. While this theory more commonly found in literature, it remains inconclusive and purely hypothetical when used by itself.

Connective Tissue and Muscle Damage Theories

These last two theories will be discussed together even though they are separate. Both theories involve the damage to the specific structure that is a result of eccentric exercise. Eccentric exercise is known to be more damaging versus concentric and can therefore cause greater damage that leads to DOMS.[1, 2, 8, 12, 23 26, 34, 35, 36, 39, 42] Also, both theories provide a mechanical explanation to the occurrence of DOMS versus a chemical explanation provided in the inflammation theory.[26] Each of these theories was first speculated as a cause for DOMS by Hough in 1902.

They are separate because connective tissue and muscles are two different structures in the body that serve different purposes and there are different measurements that suggest the presence of their respective damage to the involved muscle structure. Connective tissue is a structure that is responsible for holding other structures of the body together; there are different types of connective tissue, but this review will focus on the tissue involved with DOMS. Muscles are responsible for contracting changing joint angles to produce movement.[41] A layer of connective tissue surrounds every muscle.[41] Both structures can become damaged and these theories can explain why it can cause of DOMS.

The *connective tissue damage theory* is not explained as frequently as its counterpart, but is rarely discussed without it. Two different muscle fiber types comprise the content of the connective tissue that surrounds muscles; these fiber types are type I and type II.[8, 34]. Type I fibers are a "slow twitch" fiber that is utilized primarily in aerobic exercise.[41] Type II fibers or "fast twitch" and are utilized with anaerobic exercise that involves bursts of speed and power.[41] Due to the nature of eccentric exercise and the stress it can place on the fibers, type II fibers may be more susceptible to damage versus type I. Type II fibers can experience an extra strain from eccentric exercise that it is not equipped to handle, and can in turn damage the connective tissue.[8, 34] Fascia is another component of connective tissue that can attach and surround the muscle. It is an inelastic tissue where adhesions may form that can cause pain and prevent normal movement. [11, 13] Some studies have used measurements of urine excretion hydrozyproline and hydrozylysine (amino acids found in collagen) to observe collagen activity because part of connective tissues' structure is the protein, collagen. Collagen activity in this measurement has not been specified to synthesis or break down, but presence in the urine means one or the other.[8] Damage to the muscles occurs separate from the connective tissue and has its own forms of measurements.

The *muscle damage theory* is more commonly explained in literature.[8, 39] It seems to be that damage may occur in the muscle to the components that are described in the sliding filament theory as previously mentioned. Specifically, damage is said to occur along the z-discs (z-lines) which is the attachment points for muscle contraction.[8, 35] Similar to the connective tissue damage theory, type II muscle fibers are weakest because of their narrow z-discs (z-lines), and therefore may assume the most damage. Another vague explanation of this theory is a section of muscles fibers become ineffective because of the unique stress that eccentric contraction places on the fibers. [8, 15, 16, 20, 24, 30, 34, 39] When cross-sections of muscle fibers are shut down, the muscle has a much harder time recruiting fibers to cause a contraction and without as many muscle fibers to recruit for contraction power output can decrease which means the muscle has fatigued.[8, 16, 27, 30, 32, 35, 36] Many studies have used stretch and range of motion (ROM) as a dependent variable to measure DOMS, but overall results remain too inconsistent for those variables to be considered reliable measurements.

Measurements of muscle damage are common in DOMS studies. Presence of muscle damage could help support the use of the muscle damage theory. The gold standard of measurement for muscle damage is creatine kinase (CK).[1, 8, 13, 20, 27, 32, 37] When there is damage to the muscle, specifically along the z-discs (z-lines) CK levels will become elevated, indicating that there is damage in the muscle.[1, 8, 13, 20, 27, 32, 36] However, there have been inconsistencies with peak DOMS and peak CK levels.[6]

An important relationship to address is the one between DOMS and muscle damage caused by exercise. Symptoms of DOMS are not always an accurate indicator of muscle damage.[27, 36] There have been inconsistencies in results of studies with dependent measurements of strength and ROM as well as the measurement of perceived soreness/pain and edema (measured by girth). Studies measuring these variables do have different interventions, which could attribute to inconsistencies, but most studies did not come close to the same results. For example, two separate massage studies had contrasting results. Mancinelli, Davis, Aboulhosn et al. (2006) observed a decrease of soreness along with an increase of performance in a vertical jump test while Zainuddin, Newton, Sacco, & Nosaka (2005) found a decrease in soreness but found no positive change in strength or ROM. Dawson, Gow, Modra, Bishop, & Stewart (2005) used an active recovery intervention and observed an increase in soreness with increased ROM whereas Bailey, Erith, Griffin et al. (2007) used cryotherapy intervention and observed a decrease in soreness along with a decrease in strength. Due to inconsistent results such as these, the relationship between DOMS and muscle damage is questioned. The severity of DOMS is not correlated with the severity of muscle damage and symptoms of each have not consistently coincided.[27, 36]

Regardless of technical differences with each of these theories, their stimulation of pain remains similar to one another. As mentioned previously, nociceptors cause pain when stimulated, and they are located in the connective tissue and stimulated through damage beginning with damage to the muscle fibers.[8, 15, 16, 27, 34] Similar to the pain mechanisms of the inflammation theory, type III and type IV pain receptors are stimulated due to the disruption in the muscular structure.[14, 36] Therefore it can be concluded that the inflammation theory, connective tissue damage theory, and the muscle damage theory all cause stimulation of pain in the affected muscle(s).

In DOMS research, one theory is rejected. The lactic acid theory does not fit into an explanation of DOMS because of its absence when DOMS symptoms arrive, and the fact that it returns to normal levels without intervention. Less popular theories, muscle spasm theory and enzyme efflux theory are not rejected, but do not provide a substantial enough explanation to DOMS to be discussed in literature. The three most common theories are inflammation, connective tissue damage, and muscle damage. All three of these theories provide the most logical explanation for DOMS, but remain hypothetical. One theory alone cannot explain why DOMS occurs, but intertwining the three provides a logical sequence of events.[8, 35] (figure 2). By understanding of these theories, one can begin to understand the various forms of interventions used to help prevent and decrease DOMS. Interventions of DOMS that will be discussed next in this review are cryotherapy, thermotherapy, massage, foam rolling, and non-steroidal anti-inflammatory (NSAID) medication.

Therapeutic Interventions

Many different types of therapeutic interventions have been used to help prevent and decrease the symptoms of DOMS. Some of the most common treatments are cryotherapy, thermotherapy, NSAIDs, massage, foam rolling, ultrasound, stretching, and supplementation. In this review, cryotherapy, thermotherapy, NSAIDs, massage, and foam rolling will be discussed.

Cryotherapy

Prentice described cryotherapy as, "the use of cold in the treatment of acute trauma and subacute injury and for the decrease of discomfort after reconditioning and rehabilitation." Cryotherapy is represented as the gold standard of treatment for soft tissue injury, RICE. The acronym RICE stands for rest, ice, compression, and elevation.[8, 30, 34, 39] There are many different techniques to apply cryotherapy to an individual. Some involve the other aspects of RICE and some do not. Different treatments include ice packs, ice cup massage, and cold water immersion (CWI), also known as cold whirl pool (CWP).[31] Of these treatments listed, the most popular treatment used for the prevention and treatment of DOMS is CWI[6, 17, 22, 36] and has been used in many studies because of the physiological effects that it has on the body.

Physiological effects from CWI are not limited to just this treatment, but occur when any cryotherapy application occurs. When cryotherapy is applied, an individual will feel a sensation of CBAN. CBAN stands for cold, burning, aching, numbness.[31, 36] One of the main reasons cryotherapy is used for acute and subacute injury is its effect of decreasing tissue temperature.[8, 34, 39] Decreasing tissue temperature is hypothesized to help decrease metabolic rate which then decreases heat to help prevent hypoxia and cell necrosis to limit additional injury to the involved tissue; overall this could help decrease the inflammatory response cause by damage to the muscle structure involved.[4, 8, 17, 30, 33, 34, 39] Use of cold is also said to decrease present edema, as well as prevent further formation and also decreases lymphatic and venous drainage.[4, 8, 30, 33, 34] All of these physiological responses result from the damage and inflammation that occurs in the involved muscle structure. As previously mentioned CK is a measure of muscle damage. Cryotherapy is said to be able to decrease CK levels,[30] but possibly not on a significant level.[18]

The physiological reasons previously discussed provide a theory for the use of cryotherapy in treating DOMS, but the main reason it is used for DOMS is to provide an analgesic effect. Reducing soreness/pain is important because it is the most common symptom of DOMS. Soreness/pain reduction is thought to occur due to the decrease in nerve conduction velocity.[4, 8, 16, 20, 30, 35] With applying any type of treatment to a human being, there is always a chance of a psychological affect as well. It is possible with the application of cryotherapy an individual can experience a positive psychological benefit from the treatment as well as physiological.

Cold water immersion (CWI) is the most common cryotherapy for the prevention and treatment of DOMS.[6, 17, 22, 36] There have been many different parameters described for CWI. Typically treatments should last five to fifteen minutes with a temperature of 50 to 60 degrees Fahrenheit.[30] There is not a standard protocol in place for CWI, and as a result different results have been observed from these various studies. In a study performed by Proske & Allen (2005), a very low temperature of 41 degrees Fahrenheit and a treatment time of one minute immersed and one minute out for nine minutes an increase in soreness/pain was observed when compared to a control group. When temperatures were increased for the water, different results were observed for perceived soreness/pain. Higher degrees of 50 with more consistent treatments times of two sets of five minutes provided a decrease in soreness/pain at 24 and 48 hours.[18] No difference was observed with soreness/pain after a protocol of fourteen minutes in 59 degrees.[38] Bailey et al. (2007) and Lateef (2010) observed lower measures of strength and power following CWI but Ingram, Dawson, Goodman, Wallman, & Beilby (2009) and Reilly & Ekblom (2005) observed improvements in their strength and power measurements. Vaile, Halson, Gill, & Dawson (2008) observed similar measurements to baseline of a squat jump test despite having a decrease in perceived soreness/pain. In contrast to Vaile et al. (2008), Ingram et al. (2009) observed decreases in soreness/pain at 24 and 48 hours and the treatment group also provided the best sprint times and leg strength to baseline when compared to their other groups. One last measurement that was inconsistent with CWI was CK. No significant decrease in CK has been consistently observed.[18, 32] Yet Ingram et al. (2009) did observe smaller elevations in CK levels in their CWI treatment group compared to their other groups.

Great inconsistencies continue to occur with cryotherapy intervention on DOMS. Results from many studies in the literature do not provide a solid recommendation for the use of cryotherapy, but it continues to be a popular treatment.[8, 4, 18, 22, 31] One possible explanation for its continued use is there might be a beneficial psychological benefit from the treatment.[22] Another reason it may stay a popular choice for treatment is the immediate numbing affect it has on the body. An analgesic affect occurs immediately following treatment application, but disappears 24 hours afterwards.[38] Inconsistencies can also be attributed to the large differences in treatment parameters.[8, 32, 36] One interesting theory for not using cryotherapy involves the physiological effects of cold. Cold may be detrimental for training because of its vasoconstrictive properties and how it may hinder training progress.[3, 22] On the opposite end of the spectrum lies thermotherapy and will be discussed next.

Thermotherapy

Thermotherapy is the use of heat to treat injury and disease.[30] Typically, thermotherapy is used in a subacute stage of injury as to not exacerbate the inflammatory response which we know promotes healing in the site of injury.[28, 30] Heat has been utilized to treat conditions for thousands of years[28] and is still commonly used today. There are many different types of heat modalities. Most common are dry and moist heat packs, warm whirlpool, chemical wraps, diathermy, paraffin wax, and infrared laser[8, 28, 30, 34] Literature on thermotherapy and DOMS is limited. There may seem to be many indications to apply thermotherapy to DOMS conditions, but one must first understand the physiological responses the body experiences during and after application of heat.

One of the first physiological effects to occur is the rise in tissue temperature.[8, 26, 30, 34, 39] This is an important first even because it then leads into a chain of other physiological effects. When tissue temperature increases with heat, it is first at a superficial layer, and depending on the amount of time heat is applied to the body and the type of modality used, it begins to have a deeper effect into the muscle.[30] As temperature rises, blood flow/circulation is increased to the area.[19, 26, 28, 30, 39] Local metabolic rate and an increase in nutrition at a cellular level occur after increase blood flow.[30] Physiological effects to heat do not only involve changes from increased blood flow, but heat also affects the body on a neural level. Sensory nerves are stimulated by heat which causes an analgesic effect and it decreases pain.[28, 30] This analgesic effect is one of the main indications to use heat. Since heat is known to help decrease pain, it also helps with promoting muscle relaxation to conditions such as muscle spasms.[30, 39] Related to this thought of muscle relaxation, heat is also thought to increase connective tissue extensibility[25, 34] and in turn help improve ROM.[26, 30, 39] While there are many physiological effects form thermotherapy, they are all affected by parameters of the treatment.

Time of treatment is dependent on the treatment itself. There are different recommendations for different modalities. For example, heat packs are recommended to be applied for fifteen to twenty minutes.[30] Regulations also exist for temperature control of moist heat packs, which are stored in a container with water that is about 150 to 160 degrees fahrenheit.[30] Warm whirlpools (WWP) are recommended to remain at a temperature of 98 to 105 degrees fahrenheit for optimal treatment and treatment should be applied for ten to twenty minutes.[30, 31] Long term heating has also been utilized and can last up to several hours depending on the type of heat modality. A heating pad that was used for two hours once a day starting 36 hours after exercise resulted in a slight decrease in perceived soreness/pain.[19] For an even longer period of time a chemical heat wrap was applied for eight hours at the 18 hour mark and 32 hour mark post exercise and a great decrease in soreness/pain was observed.[25] Perhaps it is the case when heat is applied before DOMS is known to peak (around 24 hours) it is more effective at decreasing soreness/pain.[25, 28] While soreness/pain decreases may be observed with the application of heat due to sensations provided on a neural level, the healing process itself is not improved.[19, 26] Another inconclusive result is how heat affects physical function. Jayaraman, Reid, Foley et al. (2004) did not observe any advanced recovery from muscle damage and function with heat, but Mayer, Mooney, Matheson, Erasala, Verna, Udemann et al. (2006) observed less of a decrease of function when applying a heat wrap for a period of eight hours. There have not been many studies conducted on the effect of WWP on DOMS. Unlike heat pack there have not been any decreases in perceived soreness/pain with WWP.[35] In a study conducted by Vaile et al. (2008), WWP helped improve isometric muscle strength when compared to baseline, but did not provide a significant improvement. There was also no decrease in swelling after WWP in this same study, which is to be expected based on the physiological effects of heat.

The analgesic effect of heat occurs more often than not.[19, 26, 30] This immediate affect after application is said to occur through use of the gate control theory, where pain receptors are desensitized and neural signals are sent to the brain to help decrease the sensation of pain.[31] One theory for use of thermotherapy on DOMS is its possibility to help clear out inflammatory mediators and waste by increasing blood flow.[19, 26, 28] More studies need to be conducted on thermotherapy and its physiological effects on DOMS to determine if there is a possibility it can help decrease symptoms. Like thermotherapy, massage has been around for many years, with a new self-massage treatment called foam roll (FR) emerging.[11, 23, 29, 42]

Massage and Foam Roll

Massage is a well-known form of treatment after exercise. It is a very old technique that has been date back before Medieval times.[34] Prentice defines massage as, "the act of rubbing, kneading, or stroking the superficial parts of the body with the hand or with an instrument." Many different types of massage techniques exist[29] and the most common are as followed: Effleurage is the soft gliding over skin with minimal pressure. Petrissage refers to the kneading motion of the muscles with use of the hands. Tapotement involves quick percussion to the body such as cupping, tapping, and slapping. Friction massage involves using small motions to move the tissue under the skin. Myofascial release involves a group of techniques to help release the muscle from a tight fascial layer of tissue around it.

A new form of treatment that has not been as popular as massage FR. FR involves a cylindrical shaped piece of foam that varies in density, and involves the individual using their body weight to apply pressure to the intended area on the body and roll back and forth. It has been labeled as a "self-induced massage"[29] and the individual is able to control the pressure applied and apply treatment to specific parts of the body[11] There has been very little research done on foam rolling and its use to help prevent and treat DOMS. To date there are only three studies that have begun to look at its effects.

Since FR is compared to effleurage and petrissage massage, it is important to understand the effect of massage on a physiological level. The pressure that is applied to the body during massage tends to be in a pattern, and this stimulation from the pressure can help promote relaxation.[15, 29] Stimulation from this pattern of massage can also help increase blood flow and lymphatic flow which in turn can help oxygen delivery to the affected muscle. [8, 24, 27, 29] Increased blood flow and lymphatic flow can affect the inflammatory response as well. In early stages of inflammation, massage can help with the removal of waste products from healing.[15, 37] Another effect of massage is a common trend in all treatments discussed so far, and that is the pain relieving effect. Pain is thought to be relieved by massage through the gate control theory, which the stimulation of the skin and into the muscles by massage sends signals to the brain to decrease soreness/pain sensations.[29] Foam rolling shares these effects, but is not well documented. It is documented to help increase blood flow[27] which in turn should lead to other physiological effects discussed after increased blood flow. Soft tissue restrictions are also primarily treated by foam rolling, which is similar to the myofascial massage techniques.[23, 27]

There is not gold standard of treatment parameters for FR, or massage. There have been inconsistent results in literature for massage and DOMS. The majority of studies witness a decrease in the perception or soreness/pain[8, 15, 24, 27] but some did not have the same results and there was no decrease in soreness/pain.[8, 23] Timing the treatment after exercise is an important variable to consider. As with previous treatments, it is stated that it should be applied before DOMS sets in. Mancinelli et al. (2006) applied petrissage immediately following exercise, and found no relief from DOMS at 24 and 48 hours. This contrasts to studies done by Hilbert et al. (2003) and Zainuddin et al. (2004) that had decreased scores of perceived soreness/pain when massage was applied two hours after exercise. Perhaps it is a difference of massage techniques used, and possible combinations of techniques that affect the results. Petrissage alone and a mix of effleurage and petrissage did not help alleviate DOMS, but a combination of effleurage, tapotement, and petrissage provided relief.[8, 23] CK levels and swelling were two variables that were inconsistent in results as well, but the majority saw decreases in both.[8, 42] There are a couple variables that consistently were not affected by massage. As mentioned previously in this review, neutrophil margination occurs during the inflammatory response phase of healing. Massage was unable to decrease neutrophil levels and margination after treatment was applied.[15, 23] Strength and ROM was also not regained after a massage treatment.[15, 27, 42]

There are only three studies that examine the effects of foam rolling, and only two of these specifically look at DOMS. Overall there have been beneficial results with decreasing pain after foam rolling following exercise.[23, 29] When compared to a control group soreness/pain was decreased, and in one study peak soreness occurred at 24 hours compared to 48 for the control group.[23, 29] Pearcey, Bradbury-Squires, Kawamoto, Drinkwater, Behm, & Button (2015) observed an increase in sprint speed, power, and strength when compared to their control group. This contrasts Macdonald, Button, Drinkwater, & Behm (2014) who observed decreases in strength and concluded that foam rolling does not aid in muscle recovery from muscle damage.

Furthermore Curran, Fiore, & Crisco (2008) examined the difference between foam roll densities and found that a higher density foam roll was more efficient at reaching deeper tissue and muscle layers gradually. This is important to help set treatment parameters for FR. There continues to be limited clinical data for the use and technique of foam rolling and more research needs to be completed.

Non-Steroidal Anti-Inflammatory (NSAIDs)

There are multiple forms of medication that help with the relief of pain from various causes. NSAID medication is a medicine that is typically taken orally, but can be applied topically. It is used to help decrease pain, inflammation, and fever.[(10)] Primary use of NSAIDs about 70 years ago did not begin with anti-inflammatory purposes, but has only been used this was for the past 30 to 35 years.[(21)] NSAIDs are in multiple medications. The most common ibuprofen medications are Advil®, Motrin®, Aleve®, Anaprox®, and Volteren®.[(10)] Most NSAID medications are available over the counter (OTC), but stronger ones have to be prescribed by a physician. For fever and pain, a lower dose is typically administered, versus a higher dose to help alleviate inflammation. For inflammatory condition, a dose of 600 to 800 mg every six to eight hours is ideal.[(10)]

One of the main physiological effects NSAIDs have on the body is how it inhibits prostaglandin synthesis.[(8, 10, 35)] Prostaglandins are responsible with lining the stomach with mucous.[(8)] NSAIDs also thin the blood, and is contraindicated when an individual is already taking blood thinner medications. One last physiological effect of NSAIDs is its analgesic effect after administration.[(21, 33)] There have been many mixed results in studies that use ibuprofen to help prevent and treat DOMS.

It is known that DOMS can be a result of the inflammatory response and increase of muscle edema after injury, and therefore the thought behind NSAIDs seems to fit the indications.[8] Overall researchers have observed a decrease in perceived soreness/pain with the administration of an NSAID, specifically ibuprofen.[8, 21, 33] Yet it is important when the ibuprofen is taken to how much decrease in soreness/pain will be experienced. When the medicine is taken prophylactically versus therapeutically, there may be a greater decrease in soreness/pain.[8, 21] Soreness/pain decreases can be observed at 24 and 48 hours after exercise with the use of ibuprofen,[8, 21, 33] but most studies administered multiple doses of ibuprofen over a span of two to three days. Ibuprofen did not help with the recovery of ROM and strength of muscles overall.[8, 34]. This may be because NSAID medications could actually hinder the healing process that is brought on by the inflammatory response. If inflammation is decreased too early in healing, this could stunt the process.[8, 33] This could be why CK levels remained elevated even after the administration of ibuprofen[8, 21, 33] An individual can decrease their pain by a reduction in edema and pressure in the muscle structure, but may impede the healing process by doing so.[8, 21, 33]

Conclusion

DOMS is a common occurrence following eccentric exercise that presents with symptoms such as muscle stiffness, pain, and tenderness decreased range of motion (ROM), and decreased muscle strength. There is not one theory to explain DOMS, but many attempt to. A few of the theories that are not commonly discussed are the lactic acid theory, the muscle spasm theory, and the enzyme efflux theory. The three important theories are the inflammation theory, connective tissue damage theory, and the muscle damage theory. Separate these theories do not provide a comprehensive explanation of DOMS, but together they can provide better insight into the mechanism of DOMS. Multiple treatments also exist for DOMS, some of the most common being cryotherapy, thermotherapy, massage, foam roll, and NSAIDs. No one treatment completely helps resolve DOMS symptoms, but perceived soreness/pain can be decreased the majority of the time. More research needs to be conducted to provide gold standards of treatment for each method. Until consistent results are observed, theories and treatments will continue to be hypothetical.

Abstract

Context: Delayed onset muscle soreness (DOMS) is common after unfamiliar, repeated eccentric contractions, or intense exercise. Symptoms of DOMS can range from moderate to severe pain and point tenderness. Many therapeutic interventions are used to decrease the symptoms of DOMS, but currently there is no gold standard.

Objective: The aim of this study was to explore the most efficient treatment to decrease DOMS.

Participants: Twenty-seven participants (5 male, 22 female) between the ages of 18 to 25 (19.81 + 1.79) were recruited.

Methods*:* Values of perceived soreness were recorded with the use of a visual analog scale ranging from 0 to 100 (0=none, 25=mild, 50=moderate, 75=severe, 100=worst). Participants were randomly placed into four treatment groups (cold whirlpool (CWP)=5, warm whirlpool (WWP)=5, non-steroidal anti-inflammatories (NSAIDs)=5, foam roll (FR)=6) and one control group (CON=6). Participants completed a 30 minute stepping protocol with a predetermined high intensity cadence to induce DOMS.

Results: A repeated measures analysis of variance (RMANOVA) was used to analyze data. No significant differences were observed for raw score decrease or percentage of decrease of soreness values. However differences between the groups were noted. WWP had the lowest overall average raw score value (24.8) and CWP had the highest average (28.76). FR had the lowest average raw score at 72 hours (16.667) and NSAIDs had the highest average (30) at 72 hours. WWP was the first group to have the highest percentage decrease (11%) between 24 and 48 hours, whereas FR saw the greatest percentage decrease overall (25.8%) between 48 and 72 hours. CON had the greatest initial increase (23%) between zero and 24 hours, and NSAIDs had the least amount of decrease (15%) between 48 and 72 hours.

Conclusion: Relief of DOMS can benefit active individuals. WWP and FR were the two best treatments to help decrease symptoms associated with DOMS by 72 hours. More research about parameters of these therapeutic interventions can help identify better therapeutic interventions for DOMS.

Introduction

Delayed onset muscle soreness (DOMS) is one of the most common injury experienced after unaccustomed and/or eccentric exercise. Symptoms that occur with DOMS are moderate to severe pain, muscle stiffness, decreased range of motion (ROM), and decreased muscle strength, typically peak 24 to 48 hours following DOMS inducing exercise, and can persist up to five to seven days.[1, 8, 14, 15, 23, 26, 27, 32, 34, 35] DOMS can be a debilitating experience, and can negatively affect an individual's activities of daily living and exercise.

The cause of DOMS has been narrowed down to three main theories: inflammation response theory, connective tissue damage theory, and the muscle damage theory. Alone these theories do not provide a sufficient explanation of DOMS, but together they help provide a more concise picture (figure 2). Like the multiple theories, there are also multiple therapeutic interventions that are utilized to help decrease DOMS. This study focused on the use of cryotherapy in the form of a cold whirlpool (CWP), thermotherapy in the form of a warm whirlpool (WWP), non-steroidal anti-inflammatories (NSAIDs), and foam rolling (FR). Each of these treatments was used for their therapeutic properties that connect to decreasing the symptoms caused by each theory.

CWP can help decrease inflammation and decrease pain.[4, 6,8, 22, 31, 39] WWP can help increase blood flow, ROM, and decrease pain.[8, 19, 30, 31, 39] NSAIDs can be prescribed but are more commonly used over the counter in the form of ibuprofen to decrease inflammation and relieve pain.[8, 13, 21, 33] Last is FR, which is the use of a cylindrical shape of foam that helps an individual administer a form of self-massage and soft tissue mobilization to help increase ROM, decrease edema, and desensitize pain receptors.[11, 23, 29]

One of the most common therapeutic interventions used to treat DOMS is cryotherapy. While very popular, there seems to be a traditional factor of use behind it as there is inconsistent evidence that CWP actually helps decrease symptoms of DOMS.[8, 4, 3, 18, 20, 22, 31, 34, 39] Most studies agree that CWP is beneficial for an immediate analgesic effect,[8, 4, 18, 20, 22, 31, 39] but there is no consistent evidence that soreness will decrease at the 24/48 hour peak mark. WWP may be used to decrease DOMS because it may help accelerate the healing process by increasing blood flow and removing metabolic waste from the affected area, but it has been observed that the administration of heat did not help improve the healing process.[18, 19, 26] Currently, there is not much literature on the use of WWP to decrease DOMS.[18, 25, 28, 30, 35] NSAIDs are very common for people to use because of the accessibility and easy administration. There is an overall consensus that NSAIDs can help decrease soreness and pain associated with DOMS, but this is after multiple doses.[8, 21, 33] Only three studies have examined the effects of foam rolling after exercise, and only two of them have researched DOMS.[11, 23, 27] The least researched intervention for DOMS is FR. Overall decreases in soreness and pain have been observed[23, 27] and it is possible that FR can cause peak soreness to occur earlier at 24 hours versus 48.[23, 27]

Decreasing the symptoms of DOMS is important to any active individual. The symptoms associated with DOMS impede any exercise and training and negatively affect their activities of daily living. Typically DOMS studies include participants that are sedentary, however this study's participants were required to have a certain level of physical activity (as explain in methods). This study aims to answer two research questions:

1. What therapeutic intervention (CWP, WWP, NSAIDS, or FR) will be most efficient at decreasing DOMS over four measurements of zero, 24, 48, and 72 hours based on raw score and percentage change?
2. What therapeutic intervention will have the lowest average perceived soreness by 72 hours?

To determine efficiency, the primary investigator will analyze what treatment works most quickly and what treatment causes the largest decrease over four measurements at zero, 24, 48, and 72 hours based on percentage improvement and a raw data score.

METHODS

Participants

Twenty-seven volunteers participated in this study. These participants were recruited by flyers in the student recreation center and exercise science classes. Male (n=5) and female (n=22) participants were all healthy with no current lower body injury or illness at the time of participation. Participants were required to be 18 to 25 years (mean=19.8 $\pm$ 1.7) of age to be eligible to participate. Participants were also required to sign an informed consent document which asked them to not exercise 24 hours prior to participation as well as 72 hours post participation and not to provide any self- treatment to alleviate any DOMS they may experience in the 72 hours post participation. After signing the informed consent participants filled out an exercise questionnaire to determine activity level. Inclusion criteria required participants to be lightly to moderately active (table 1). The final form for participation was a medical history questionnaire to determine that the subject was healthy and had no contraindications to any of the treatments. This study was approved by the Human Subjects Review Board at Bowling Green State University.

Exercise

Exercise consisted of a 30 minute stepping protocol.[7, 40] Warm-up included biking for five minutes followed by a demonstration of how to step. Five practice steps and a switch were given to familiarize the participants with the protocol. The steps used were basic stackable cardio steps. Step height was determined by the tibial tuberosity.[7, 40] Stepping occurred in the forward direction with stepping down backwards. A metronome was used to keep a beat of 50 steps per minutes.[7, 40] Each time the metronome beeped, the participant's lead leg was either stepping onto the step or onto the ground. Participants were able to choose what leg they wanted to lead with at the beginning. Every five minutes participants were asked to switch their lead leg. [7, 40] Each leg led a total of three times each with a total of six switches in the whole protocol. For safety precautions, participants were told to stop for one beat with both feet on the ground and then switch to their other leg.

Measurements

DOMS was recorded on five occasions with the use of a perceived soreness scale that measured 0 to 100.[9] Zero equals "no soreness", 25 equals "mild soreness", 50 equals "moderate soreness", 75 equals "severe soreness" and 100 equals "worst soreness." This scale was used in order to better quantify the participants' measure of DOMS because it can be subjective to each individual. Values were recorded at pre-exercise, immediately post exercise (0 hour), 24 hours, 48 hours, and 72 hours. During this time of measurement, participants were asked to refrain from exercise and any form of self-treatment (anything that would help relieve and DOMS they may experience). Raw score values (table 2, figure 3) of perceived soreness and percentage change values (table 3, figure 4) were recorded.

Treatment

There were a total of four treatment groups and one control group. Treatment groups included cold whirlpool, foam roll, ibuprofen, and warm whirlpool. Participants were placed into groups at random. No participants had contraindications for any treatment. Treatment group placement was not known to the participant until post-exercise.

Both the cold whirlpool and warm whirlpool were both ten minutes long. Participants were instructed to lower themselves into the pool up to their anterior superior iliac spine (ASIS). The cold whirlpool remained at 50 degrees Fahrenheit and the warm remained at 105 degrees Fahrenheit.[8, 31, 38] Jets were turned on to let the water circumvent around the participant. Four structures of the lower body were treated in the foam roll group (gastrocnemius/soleus, quadriceps, hamstrings, and iliotibial band). Each structure completed two times 60 seconds of rolling. Participants were instructed to begin at the most proximal portion of the structure and then use short and smooth rolls until they reach the most distal portion; once the distal portion is reached they then rolled back to the proximal portion in one big smooth motion and repeat until the 60 seconds were completed.[23, 29] For ibuprofen, participants were administered 400mg once. All treatments were initiated within five minutes of exercise completion.

Statistical Analysis

A repeated measures analysis of variance (RMANOVA) was used. Two separate analyses were completed, one for the percent change of soreness values and the raw score of soreness values. A between-subjects and within-subjects effects was run to determine significance of perceived soreness values between treatment groups and changes over time. Mauchly's test of Sphericity was assumed for the percent change and Greenhouse-Geisser was utilized for the raw score to determine significant interactions. Significance was set a priori as $p < .05$.

Results

Significant differences were observed for time between measurements ($p < .05$). A significant increase in the percentage change of soreness value (table 4) occurred between the zero hour measurement and 24 hours. Raw score values (table 5) provided significant differences between the zero hour and 24 hour measurements, between 24 and 72 hours, and between 48 and 72 hours. No significant difference was observed between the raw score values of 24 and 72 hours. This signifies there was no clear peak of DOMS as values were similar on each day. These results establish that DOMS was successfully induced in this study.

No significant results were observed for raw score (table 6) change or percentage of change of soreness values (table 7), but differences between the groups were identifiable. WWP had the lowest overall average raw score value (24.8) and CWP group had the highest average (28.76). FR had the lowest average raw score at 72 hours (16.667) and NSAIDs had the highest average (30) at 72 hours. WWP was the first group to have the highest percentage decrease (11%) between 24 and 48 hours, whereas FR saw the greatest percentage decrease overall (25.8%) between 48 and 72 hours. CON had the greatest initial increase (23%) between zero and 24 hours, and NSAIDs had the least amount of decrease (15%) between 48 and 72 hours.

Discussion

The objective of this study was to determine which therapeutic intervention (CWP, WWP, IBU, or FR) would be most efficient at decreasing DOMS. Efficiency of the treatment was based on the amount of decrease of the raw score and percentage change value over four measurements of zero, 24, 48, and 72 hours, and the overall average raw score by 72 hours. Significant differences were observed over time, confirming DOMS occurred. The main significant differences occurred from the zero hour measurement and 24 hours measurement, but there was no significance between the 24 hour and 48 hour measurements. This could mean that there is no clear peak of DOMS in the participants, and that none of the treatments had a significant effect of causing an earlier peak to lead to an earlier recovery. This is consistent with the literature that says DOMS usually peaks 24 to 48 hours following exercise.(1, 8, 14, 15, 23, 24, 26, 27, 28, 29, 32, 34, 35, 36, 39, 42)

There were no significant differences between treatment groups, but it is important to note that there were differences that occurred between could benefit active individuals. Activities of daily living can be debilitated by DOMS, and also affect further exercise due to its symptoms, so any relief can be an advantage. No single treatment presented as the best option to help alleviate DOMS, but WWP and FR both had decreases in soreness. WWP had the lowest overall average raw score value while FR had the lowest raw score value at 72 hours. WWP functions more on the principle of the inflammation response theory and based on the physiological effects of thermotherapy (increased blood flow), this could mean there is an increase of healing agents to the area of muscle that was affected by the exercise and also greater clearance of metabolic waste left from damage caused to the muscle.(8, 18, 19, 25, 26, 30, 39) Heat also provides an analgesic effect by use of the gate control pain theory that blocks pain fibers from being stimulated.(31) There is not much literature to support the results gained in this study for WWP, and compared to the use of heat packs for a longer period of time and more often WWP does not produce decreases in soreness or pain.(19, 26, 30, 35) Jayaraman et al. (2004) observed a trend in slightly decreased perception of soreness a couple days following exercise after application of topical heat, which does follow the trend of our results with application of WWP. Similar to WWP, there is limited literature that investigates the benefits of FR on DOMS.

Out of all the treatment groups, FR had the lowest average raw score at 72 hours which means that on average, these participants experienced the least amount of DOMS symptoms compared to the other four groups. FR had a steady incline to a peak at 48 hours, followed by the highest percentage decrease out of all groups between 48 and 72 hours (25.8%). This large decrease in percentage is important because FR had the highest average raw score at the pre-exercise measure (10.83). There are very few studies that examine the effect of FR on DOMS but most results have been consistent with this study.[23, 29] Macdonald et al. (2014) and Pearcey et al. (2015) both observed FR following exercise helped decrease DOMS. Pearcey et al. (20150 used different parameters in their study, and had participants perform the treatment on three occasions; one immediately after exercise, 24 hours after, and 48 hours after. This study's FR parameters were modeled after Macdonald's et al (20140, but all three were very close in time (16 to 20 minutes).A high density foam roller as used in this study can be more effective at treating deeper tissues and muscles.[11] The treatment method behind FR addresses multiple theories of DOMS. FR has been documented to help increase blood flow which in turn can help increase healing agents to the affected area and remove more metabolic waste from the injured tissue.[15, 27, 37] While this can help decrease soreness and pain, the main purpose of FR is to help treat soft tissue restrictions in connective tissue and muscles.[23, 27] A FR provides a self-myofascial release, which can help break-up adhesions that may form along the connective tissue and the muscle which can cause pain and restriction in movement.[11, 23, 27, 29] With this self-myofascial release, it can also stimulate the muscles to help block stimulation of pain neurons.[29]

FR is a new form of treatment, unlike CWP which is a popular treatment used to help decrease of DOMS.[8, 6, 18, 22, 36, 39]

CWP is a common tool used to help decrease DOMS, but has little evidence to support its use.[8, 6, 18, 22, 36, 39] In this study CWP had the highest average raw score (28.76) and added to the results seen in literature that cryotherapy may not the best for DOMS despite its benefits to acute injury.[8, 31, 36, 38] Cryotherapy is theorized to help decrease inflammation, and it provides an immediate analgesic effect,[4, 8, 18, 22, 31, 38, 39] but results show it may not help the recovery of damaged tissue. It can be said that there is not much recovery of the damaged tissue because there is no significant effect on the decrease of creatine kinase (CK) levels after the application of CWP[18, 36] and the lack of performance improvement.[8, 4, 22] Vaile et al. (2008) had results that were not similar to others and they observed no decreases in perceived soreness or pain, but observed an increase of dynamic power in the form of a squat jump. This contrasts other studies performed; Ingram et al. (2009) observed the lowest soreness values after CWP and Lateef (2010) observed an overall decrease in power after CWP. This study contributes to the inconsistency of results found in literature. CWP did not only have the highest average raw value score, but it also had the largest percentage increase between 24 and 48 hours (9.6%). Based on the results of this study CWP is not a recommended form of treatment for DOMS. Yet CWP is not the only treatment that proved to be ineffective because NSAIDs had unproductive results as well.

NSAIDs had the highest raw score at 72 hours(30) and it had the smallest percentage decrease between 48 and 72 hours (15.%). Only the CON group had higher percentage increases in the first two days of the study compared to NSAIDs. Our results were inconsistent with results commonly found in the literature.[8, 21, 33] One of the biggest differences to those studies with beneficial results is the dosage and timing of the medication. Lanier (2003) observed decreases in soreness and pain as well as several studies mentioned in a review by Cheung et al. (2003). Timing was important, and prophylactic administration may be the best option to help decrease DOMS by decreasing the inflammatory response, and further help decrease soreness by administering a few times a day (as instructed) for multiple days.[8, 21, 33] There is no dispute that NSAIDs successfully help decrease soreness and pain, but to do so it must be taken consistently.[8, 21] Doses higher than 400 mg may be necessary to target the inflammation and pain. Creating the right parameters and correct dosage for medication is one of the limitations this study encountered.

Parameters for all treatments in this study vary from literature and this was a limitation. There is no gold standard for treatment parameters which can provide different results for treatment of DOMS. Another limitation was our small sample population, which left outliers in some treatment groups and exaggerated the standard deviations of some results. Psychological factors of participants may also have affected results if they entered the study with knowledge or opinions of the therapeutic interventions.

Conclusion

DOMS can negatively affect individuals with activities of daily living and exercise because of soreness and pain. WWP and FR are two uncommon therapeutic interventions that could help decrease DOMS most efficiently. CWP was not efficient at decreasing DOMS and NSAIDs' parameters were not sufficient to decrease DOMS. Further research needs to be done to set a standard of parameters for each treatment to help find a gold standard of treatment for DOMS.

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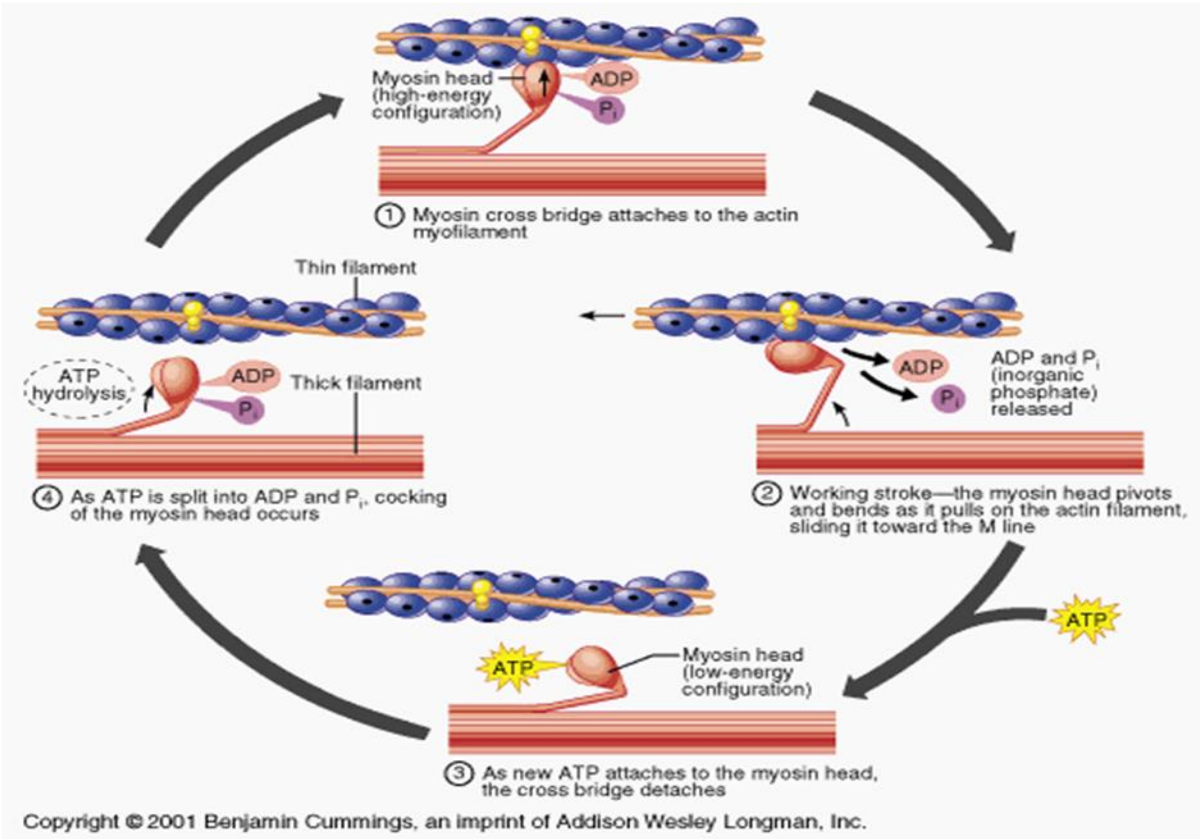
Figure 1 *Sliding Filament Theory*



http://legacy.owensboro.kctcs.edu/gcaplan/anat/notes/api%20notes%20j%20%20muscle%20contraction.htm

Figure 2. *Sequence of events of DOM*[8,39]

1)Eccentric exercise causes high tensile forces on the muscle that causes damage.

↓

2)ATP production is interrupted due to accumulation of calcium at the injured fiber(s).

↓

3)Substances from the muscle damage signal monocytes to the area that turn into macrophages. Neutrophils begin to go to the injury site. This peaks at about 48 hours.

↓

4)Macrophages produce prostaglandins. Type III and IV nerve endings are stimulated which cause the sensation of pain.

↓

5)Accumulation of waste from the phagocytes result in edema and pressure which also stimulate the sensation of pain.

Figure 3 *Raw Score Average Values Over 72 Hours*

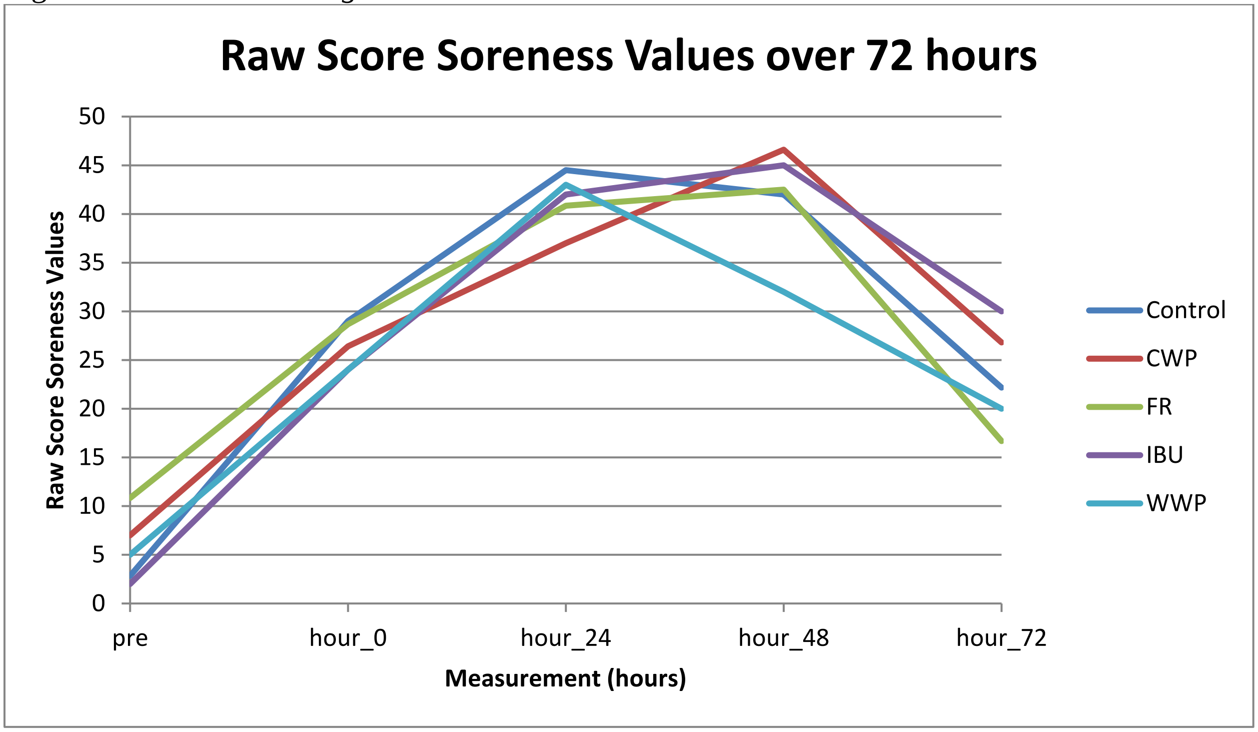


Figure 4*Percentage Change of Soreness Values Over 72 Hours*

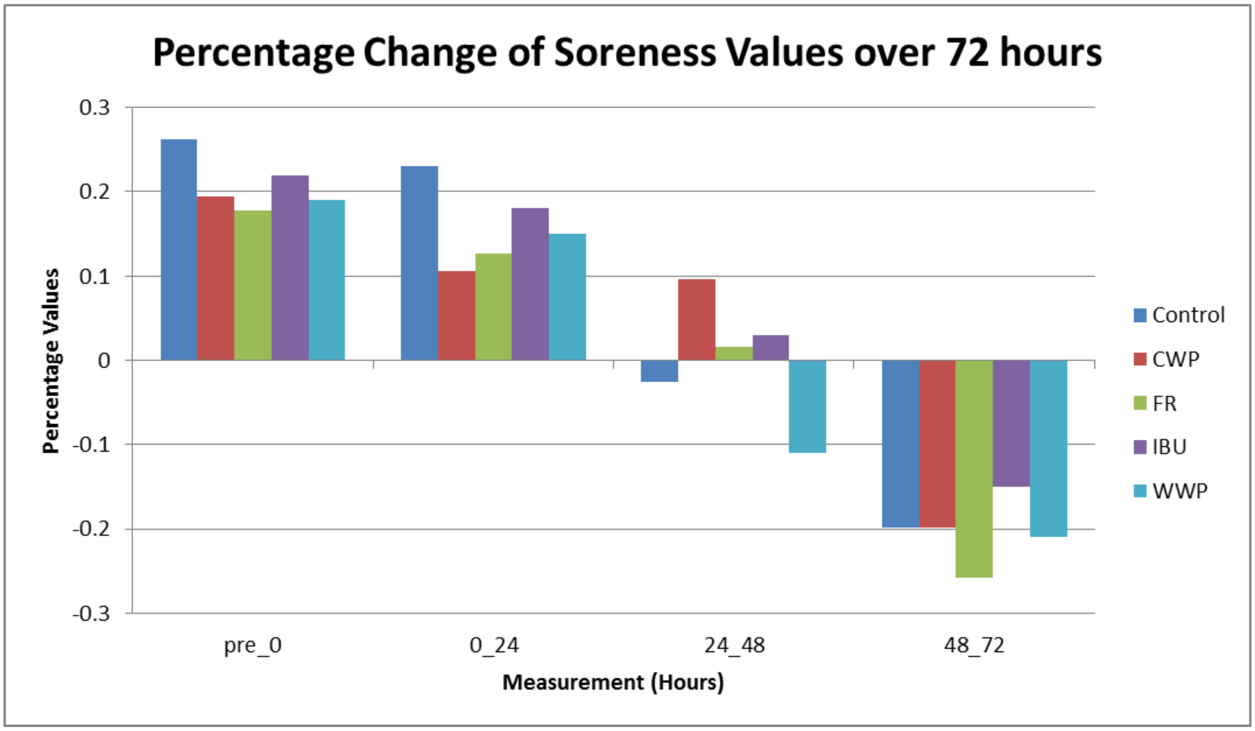


Table 1 *Activity Inclusion Criteria*

Activity Level	**Light**	**Moderate**
Days Per Week	2-3 days	3-5 days
Aerobic Activity	>90 minutes	>150 minutes <300 minutes
Strength Activity	1-2 days per week	2 days per week

Royal, P.S., Troiano, R.P., Johnson, M.A., Kohl, H.W., & Fulton, J.E. (2008). 2008 Physical activity guidelines for Americans. Retrieved from http://www.health.gov/paguidelines.

Table 2 *Raw Score Descriptive Statistics by Time Measurement and Groups*

Time Measurement	**Group**	**Mean**	**Standard Deviation**
Pre	CON	2.8333	4.91596
	CWP	7.0000	8.36660
	FR	10.8333	8.61201
	IBU	2.0000	2.73861
	WWP	5.0000	5.00000
	TOTAL	**5.6296**	**6.76045**
0 hour	CON	29.0000	12.88410
	CWP	26.4000	17.16974
	FR	28.6667	13.14027
	IBU	24.0000	9.61769
	WWP	24.0000	15.57241
	TOTAL	**26.5926**	**12.92064**
24 hours	CON	44.5000	15.60449
	CWP	37.0000	19.23538
	FR	40.8333	12.81275
	IBU	42.0000	22.80351
	WWP	43.0000	13.50926
	TOTAL	**41.5556**	**15.80977**
48 hours	CON	42.0000	16.67333
	CWP	46.6000	18.98157
	FR	42.5000	23.82226
	IBU	45.0000	23.71708
	WWP	32.0000	21.38925
	TOTAL	**41.6667**	**19.99808**
72 hours	CON	22.1667	6.49359
	CWP	26.8000	23.00435
	FR	16.6667	11.25463
	IBU	30.0000	18.37117
	WWP	20.0000	23.71708
	TOTAL	**22.8519**	**16.60330**

Table 3 *Percentage Change Descriptive Statistics by Time Measurements and Groups*

Time Measurement	Group	Mean	Standard Deviation
Pre to 0 Hours	CON	.2617	.14905
	CWP	.1940	.10455
	FR	.1783	.09065
	IBU	.2200	.10954
	WWP	.1900	.18507
	TOTAL	**.2096**	**.12507**
0 hours to 24 hours	CON	.2300	.11314
	CWP	.1060	.10213
	FR	.1217	.15303
	IBU	.1800	.16047
	WWP	.1500	.16583
	TOTAL	**.1589**	**.13743**
24 hours to 48 hours	CON	-.0250	.15732
	CWP	.0960	.13722
	FR	.0167	.14720
	IBU	.0300	.11511
	WWP	-.1100	.24341
	TOTAL	**.0011**	**.16570**
48 hours to 72 hours	CON	-.1983	.13644
	CWP	-.1980	.18674
	FR	-.2583	.17151
	IBU	-.1500	.06124
	WWP	-.2100	.16733
	TOTAL	**-.2048**	**.14405**

Table 4 *Percent Value Changes Over Time*

Time (hours)	Time Comparison	Mean Difference	Std. Error	Significance
Pre to 0	0-24	.051	.041	1.000
	24-48	.207	.046	.001
	48-72	.412	.036	.000
0-24	Pre-0	-.051	.041	1.000
	24-48	.156	.039	.004
	48-72	.360	.043	.000
24-48	Pre-0	-.207	.046	.001
	0-24	-.156	.039	.004
	48-72	.204	.052	.004
48-72	Pre-0	-.412	.036	.000
	0-24	-.360	.043	.000
	24-48	-.204	.052	.004

Table 5 *Raw Score Value Changes Over Time*

Measurement Time (hours)	**Time (hours)**	**Mean Difference**	**Std. Error**	**Significance**
Pre	0	-20.880	2.542	.000
	24	-35.933	3.286	.000
	48	-36.087	4.125	.000
	72	-17.593	3.266	.000
0	Pre	20.880	2.542	.000
	24	-15.053	3.443	.002
	48	-15.207	4.801	.045
	72	3.287	3.881	1.000
24	Pre	35.933	3.286	.000
	0	15.053	3.443	.002
	48	-.153	3.184	1.000
	72	18.340	3.032	.000
48	Pre	36.087	4.125	.000
	0	15.207	4.801	.045
	24	.153	3.184	1.000
	72	18.493	2.630	.000
72	Pre	17.593	3.266	.000
	0	-3.287	3.881	1.000
	24	-18.340	3.032	.000
	48	-18.493	2.630	.000

Table 6 *Raw Score Values Between Subjects*

Group	**Group**	**Mean Difference**	**Std. Error**	**Significance**
CON	CWP	-.660	6.701	1.000
	FR	.200	6.390	1.000
	IBU	-.500	6.701	1.000
	WWP	3.300	6.701	1.000
CWP	CON	.660	6.701	1.000
	FR	.860	6.701	1.000
	IBU	.160	6.999	1.000
	WWP	3.960	6.999	1.000
FR	CON	-.200	6.390	1.000
	CWP	-.860	6.701	1.000
	IBU	-.700	6.701	1.000
	WWP	3.100	6.701	1.000
IBU	CON	.500	6.701	1.000
	CWP	-.160	6.999	1.000
	FR	.700	6.701	1.000
	WWP	3.800	6.999	1.000
WWP	CON	-3.300	6.701	1.000
	CWP	-3.960	6.999	1.000
	FR	-3.100	6.701	1.000
	IBU	-3.800	6.999	1.000

Table7 *Percent Change Values Between Subjects*

Group	Group	Mean Difference	Std. Error	Significance
CON	CWP	.018	.034	1.000
	FR	.052	.033	1.000
	IBU	-.003	.034	1.000
	WWP	.062	.034	.823
CWP	CON	-.018	.034	1.000
	FR	.035	.034	1.000
	IBU	-.020	.036	1.000
	WWP	.045	.036	1.000
FR	CON	-.052	.033	1.000
	CWP	-.035	.034	1.000
	IBU	-.055	.034	1.000
	WWP	.010	.034	1.000
IBU	CON	.003	.034	1.000
	CWP	.020	.036	1.000
	FR	.055	.034	1.000
	WWP	.065	.036	.816
WWP	CON	-.062	.034	.823
	CWP	-.045	.036	1.000
	FR	-.010	.034	1.000
	IBU	-.065	.036	.816