EFFECTIVENESS OF FOAM ROLLING IN COMBINATION WITH A STATIC STRETCHING PROTOCOL OF THE HAMSTRINGS

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TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Stretching is common among athletes and recreationally active people for its claims to increase flexibility, range of motion(ROM), [1-10] and reduce injury risk.[11] Although flexibility is generally recommended and well studied, claims to its effectiveness and importance remain controversial. Decreases in flexibility of soft tissue may lead to faulty movement patterns and potential injury. To achieve optimal flexibility, many stretching techniques are utilized.

The most common stretch technique is static stretching. Static stretching involves taking a muscle to a point of tension and holding the position for a period of time. A less common but increasingly popular stretching technique is self-myofascial release (SMR). The SMR technique involves the use of objects such as tennis balls , medicine balls, massage sticks, or foam rollers to be rolled across a muscle group.[12] Self-myofascial release is popular because it can be done by the athlete when active release or deep tissue massage is not available.

Self-myofascial release claims to improve mobility and ROM, reduce adhesions and scar tissue, and improve overall movement.[12] These claims are achieved through finding and addressing myofascial adhesions using various SMR tools. Previous investigations on SMR are lacking. In one study it was reported that hamstring flexibility was not affected by foam rolling over an 8 week period.[13] This study however did not compare foam rollers to a regular stretching protocol.

Foam rollers are commonly used as an adjunct to a stretching program or in replacement of regular stretching. Given this, it is assumed that the combination of SMR and stretching will improve ROM. The purpose of this study therefore is to examine the effects of foam rolling to a regular static stretching protocol on hamstring flexibility.

RESEARCH HYPOTHESIS

1. A foam rolling protocol of 3 two minute repetitions performed immediately before a static stretching protocol of 3 one minute static stretches will have a greater ROM than the foam rolling or static stretching protocols.

2. Static stretching only and static stretching with foam rolling will have a greater increase in flexibility than the control

3. There will be no difference in flexibility between the foam rolling only and controls.

DEFINITION OF TERMS

1. Recreationally Active - Participation in a moderate to low intensity physical activity at least 1 hour per week and no more than 5 hours per week.

2. End Range of Motion - Determined by the primary investigators sensation of a firm endpoint. The subject's sensation of discomfort will also be used in conjunction with a firm end point to determine end ROM.

3. Discomfort - A sensation of resistance and stretch felt in the back of the thigh. The sensation will be at the sub-painful level, and of an intensity that can be tolerated by the subject.

4. Chronically Tight Hamstrings - A hip flexion ROM angle of less than 90° as measured by a bubble inclinometer.

5. Active-Static Stretching - A static stretch that also involves a muscle contraction initiated by the individual. The muscle contraction moves the limb to the point of stretch and the muscle contraction is sustained to maintain the stretching sensation.

6. Passive-Static Stretching - A static stretch that requires no muscle contraction. The limb to be stretched is moved to the point of stretch by an outside force other than a muscle contraction. This could be propping the limb up against a wall, having someone move the limb, or using an instrument to move the limb.

7. Dominate Leg - Leg the subject would use to kick a ball. If the subject reports that they use both legs equally to kick a ball the subject will be asked to close their eyes. With the primary investigator standing behind them a small push will be given to disrupt the subjects balance. The foot the subject moves forward first to re-establish their balance will be deemed their dominate leg.

8. SMR - Self myofascial release will be accomplished through the use of a 6 in x 36 in Cando™ open cell firm foam roller.

ASSUMPTIONS

1. Subjects will honestly answer questions on the pre-participation health history questionnaire.

2. Subjects will refrain from participation in any outside stretching or flexibility program, or any other recreational activity that may influence flexibility.

3. Subjects will maintain their current level of activity by not increasing or starting a new exercise program.

4. Subjects will respond truthfully when being stretched letting the investigator know when a uncomfortable sensation is felt.

5. Subjects will place as much pressure as possible between their hamstring and the foam roller when completing the foam rolling technique.

DELIMITATIONS

1. Passive hip ROM must be less than 90° with complete knee extension.

2. Subjects must be free from upper and lower extremity injury 6 months prior to data collection.

3. Subjects must not be pregnant.

4. Subjects must not be taking pain medications such as Tylenol or other NSAID's.

5. Subjects must not have any conditions that may alter circulation.

6. Subjects must not have any neurological conditions that result in sensory or motor impairment.

7. Subjects must not be currently involved in an outside flexibility program.

LIMITATIONS

1. Subjects and investigator are aware of which protocol they are receiving.

2. Pressure between the foam roller and hamstring may vary between subjects.

CHAPTER II

REVIEW OF LITERATURE

There are numerous studies addressing the different methods used to increase flexibility. These studies address different methods of stretching, massage, and myofascial release while also exploring the mechanisms behind increased flexibility. Stretching studies are common, but studies examining the effects of self myofascial release are limited. Even more limited, are studies combining the 2 methods (stretching and self myofascial release). This literature review will include information related to the various methods used to increase flexibility. It will also cite incorporate evidence relevant to flexibility including: skeletal muscle physiology, hamstring muscle movement and injuries, mechanisms behind increased flexibility, duration and frequencies of stretching, connective tissue makeup and trauma, and myofascial release techniques, including foam rolling.

Proprioceptive Neuromuscular Facilitation

Proprioceptive neuromuscular facilitation is an effective way to increase flexibility.[14] The technique has been reported to increase muscle strength,[15] promote muscle balance,[16] and improve stability around a joint.[16] The technique incorporates alternating muscle contractions along with passive stretching.[16] The 3 most common PNF techniques with regards to flexibility are contract-relax, hold-relax, and slow-reversal-hold-relax.[17] The muscle contraction performed by the subject is held for 3, 6, or 10 seconds[18] and is either isotonic or isometric. The examiner is responsible for applying a passive stretch which is held for 15-30 seconds along with resistance to the muscle contraction. The muscle contraction and passive stretch is alternated and repeated 4 to 5 times.[18]

Ballistic/Dynamic Stretching

Ballistic stretching has been reported to be an effective method to increase flexibility.[16] This method requires that a muscle be forcefully taken to a point of stretch.[18] Once the stretching end point is reached, a repetitive bouncing motion is used via the bodies momentum to carry the muscle and body beyond the available ROM.[18] Ballistic stretching is often argued to cause more harm than good, because fast, high velocity movements may predispose an individual to muscle strain.[19] To combat this argument, a slow and safe increase in speed and velocity of ballistic stretches should be employed.[16]

Dynamic stretching like ballistic stretching uses the bodies momentum and force produced to take the joint through a full ROM.[20] Dynamic stretches are defined as low intensity exercises that mimic or resemble the type of sport action to follow.[20] Examples of dynamic stretches include medicine ball rotation, walking lunges, and body weight squats.[20] These exercises target more than one muscle and work to increase blood flow to large muscle groups, and are popular in a variety of sports.

Static Stretching

Static stretching is the most common type of stretch used among physically active people and often classified in 3 different categories; active, passive, and active-assisted.[21-22] Each classification involves moving a muscle to a point of tension, holding 20 to 30 seconds, and repeating the action 3 times.[20] By using this technique a low load or force and long duration is applied ultimately increasing flexibility.[23] Unlike ballistic stretching, static stretching is done with minimal to no velocity and under maximum control[16] (which is preferred over ballistic stretching.) Static stretching is reported to be an effective method for increasing ROM.[1-3, 6-10] It can be done before and after activity with claims of injury reduction and prevention of post exercise soreness.[11, 16] Requiring less effort than PNF or ballistic, less time and space, and the ability to perform by one's self are advantages of static stretching.

Static stretching has been investigated while using hot and cold therapy. In one study hip ROM was examined after applying heat and cold during a passive stretch.[24] The stretching protocol lasted a total of 20 minutes with heat or cold applied to the posterior thigh. Following application hip ROM increased in both conditions with greater gains seen with cold. The authors speculate the increased ROM with cold may be due to the depression of the stretch reflex.[24] They also report that cold may have a numbing effect which could negate the mild feeling of discomfort felt at the end range of most stretches.[24] These investigations examining the effect of hot and cold therapy in combination with stretching are important but no investigator has yet to examine stretching and foam rolling. Foam rolling like cold could be another method used to help increase ROM. Addressing myofascial restrictions prior to stretching may enhance the stretching effect.

Muscle Physiology

Flexibility is defined as the ROM available in a joint or group of joints.[16] Muscles, joints, fascia, tendons, and ligaments all influence flexibility. The muscle plays a key role in flexibility and in order to understand flexibility a basic understanding of muscle anatomy and function is key. The ultimate goal of muscle is to produce movement of a joint. In order to achieve this, muscles must contract. Contraction occurs through a series of events that involve actin and myosin.[16] These actin and myosin work together to create a contraction of the muscle. Myosin filaments have structures called cross bridges that attach to binding sites on actin filaments.[16] When calcium is present a cross bridge attachment occurs where actin slides the filaments across each other, releasing and repeating the action until the desired muscle length is met.[16] When muscle is lengthened during a stretch, there are different events and processes that take place.

The most important units that come into play when a muscle is stretched are the muscle spindle and golgi tendon organs (GTO). The actin and myosin filaments mentioned above are classified as extrafusal fibers, meaning they are involved with the cross linking and contraction of muscle. Intrafusal muscle fibers are sensory receptors that are active during lengthening and shortening of muscle and include the GTO and muscle spindle.[16] The GTO is located at the muscle tendon junction and is responsible for sensing tension generated by muscle contraction or stretch.[16] Golgi tendon organs respond with autogenic inhibition, a reduced force of the muscle being contracted or stretched. This provides a safety mechanism to prevent muscle or tendon damage. This reduction is muscle force temporarily allows for greater tension (i.e. stretching) to develop in the muscle. The GTO may be activated through the use of SMR tools. For example the person using a foam roller generates enough pressure and tension between the roller and his/her muscle activating the GTO thus relaxing the muscle.

Muscle spindles are the primary stretch receptor in muscle.[16] They are located in all skeletal muscle of the body but are found in greater numbers in muscles that control fine, delicate motion such as those of the hands.[16] Muscle spindles lie parallel to the muscle fibers allowing them to stretch when muscle is stretched and shorten when muscle is contracted. Muscles spindles are sensitive to both stretch and contraction reacting to the length and velocity of the stimulus being applied. Muscle spindles are classified as slow-adapting receptors meaning they omit a constant sustained discharge when stimulation is present.[16]

The muscle spindles function can be demonstrated with the stretch reflex.[16] This reflex is explained by the classic example of the patellar or knee jerk reflex.[16] When the patella tendon is tapped, the muscle and muscle spindle are stretched causing tension on each. A signal is sent to the spinal cord, where it is processed and sent back to the muscle causing it to contract relieving tension on both the spindle and muscle.[16] The contraction shortens the muscle and muscle spindle to the appropriate length. When a stretch is applied and the spindles are held at a constant length they begin to adapt by reducing the amount of signals being sent to the muscle, thus decreasing the resistance to stretch. This is the logic for holding a stretch as more stretch can be applied once muscle spindles adapt.[25]

Hamstring Muscle Action and Injury

The semitendinosus, semimembranosus, and biceps femoris, and portions of the adductor magnus collectively make up the hamstring muscles of the posterior thigh.[16, 19] These muscles actively work to flex the knee and extend the hip while also assisting with rotational movements and stability to the knee.[16, 19] Hamstring injuries are a common occurrence among people who are recreationally active. Hamstring strains can occur at either the proximal attachment site on the ischial tuberosity, the distal insertion site, or in the muscle belly.[19] The mechanisms of hamstring injury include: disproportionate quadriceps to hamstring ratio, direct trauma, improper muscle firing sequences, inability of the hamstring muscle to keep up with growing bone, and fatigue.[19] Sports requiring fast acceleration such as football, track and field, and basketball see an increased incidence of hamstring injuries.[19]

Stretching the hamstring has been recommended prior to activity in order to reduce the chance of muscle injury. However, there is no conclusive evidence that stretching actually works to prevent injury.[26] In recent reviews[26-27] it has been reported that stretching prior to activity has no effect on injury reduction. While some studies report a change in injury risks from stretching, it cannot be concluded that stretching alone caused any changes. In another study it was reported that stretching did not produce a significant reduction in all-injury risks[11] reported but had a small effect on soreness. These results must be interpreted with caution, as many limitation were present (i.e. compliance, follow-up, and self reports).[11]

In another study it was reported that the effects of stretching following an injury are hard to perform because of the sample size needed, time requirements, and other factors that need to be controlled for (i.e. previous injury) which can be difficult to control.[26] On the other hand, it was concluded that stretching over the long term may have an effect on injury reduction. Given these differences, it appears that there are conflicting results on the benefits of stretching.

Stretching Duration and Frequency

Although stretching prior to activity is reported to have no decrease in injury risk, athletes, coaches, clinicians and recreationally active people still accept various stretching regimes.[7] Static stretching is the most popular and easiest stretching method preformed. However, there is disagreement on the length of time a static stretch should be held. One study[28] examined the length of time a muscle stretch should be sustained to obtain maximally flexibility. Where a 15 second stretch increased ROM 3.78°, 30 seconds increased ROM 12.50°, and 60 seconds increased ROM 10.86.°[28] From this it appears that that 15 seconds of static stretching is enough to promote slight gains in flexibility.[28] The results also lead to the idea that holding a static stretch for longer than 30 seconds does not equate to greater gains in flexibility. These results agree with another study[10] where 30 seconds of hamstring stretching was as effective in increasing flexibility as 90 or 120 seconds of stretching. As a result, 30 seconds seems to be the optimum time and is thus used in other clinical trials investigating the effects of static stretching on flexibility.[1-9, 29-31]

Mechanisms for Increased Flexibility

Increases in joint ROM may be important for performing most sport specific activities and psychologically important to the athlete and sport participant. Common thought is that gains in flexibility are due to mechanical changes in muscle.[25] These mechanical changes include viscoelastic deformation, plastic deformation, increased sarcomere length, and neuromuscular relaxation.[25] However, recent reports[25, 32] indicate that increases in flexibility may actually be due to an increase in subject stretch tolerance. With that said, gains in flexibility must be interpreted with caution as actual changes in mechanical extensibility are not likely taking place. The increase in flexibility about a joint can be attributed to changes in the viscoelastic properties of muscle and the increased stretch tolerance of the subject.[33] Viscoelasticy is the viscous and elastic properties in tissue.[16] With regards to muscle, it acts both viscously, meaning tissues deform based on the rate and time of tensile force (i.e. stretching) and elastically (tissue returns to its normal resting length after a force is removed).[16, 25] Since most measurements that are taken clinically occur immediately after a stretch, the increase in ROM reflects this viscoelastic deformation.

Magnusson et al.,[34] demonstrated that increased tissue extensibility in flexible subjects was due to enhanced tolerance to an externally applied stretching load. Therefore subjects were able to attain a greater maximum joint angle with corresponding peak tension.[34] Thus large changes equate to greater movement of the knee, suggesting greater flexibility.

In another study[33] 30 minutes of daily stretching for 6 weeks produced no changes in tissue extensibility. Rather, the increase in ROM was attributed to the subjects ability to tolerate stretch.[33] This was done by examining a standardized and non-standardized amount of torque when stretching the hamstring muscle. It was reported that flexibility was enhanced with the non-standardized torque with no increase in pain suggesting an increase in stretch tolerance.

A recent review by Weppler and Magnusson[25] indicate that single stretching sessions and short-term stretching programs (3 to 8-weeks) show modifications in stretch sensation which account for increases in flexibility. The authors refute that increases are due to mechanical adaptation in skeletal muscle and report that viscoelastic deformation is observable but the effects are minimal and very short lived suggesting modification of stretch sensation to be the factor affecting flexibility.[25]

Table 1. Summary of Static Stretching and Flexibility Research Involving Various Interventions

Authors/Year	Stretch Type	Duration	Freq.	DV	Sub.	Results
Ross[1] 2007	Static	30s x 5	15 days (1 x day)	Hamstring flexibility Single hop distance test (AKE)	13	↑ hamstring flexibility & single hop distance
Davis et al.[2] 2005	Static, PNF, Self Stretch	Static 30s x 1 Self 30s x 1 reps PNF 10s contrac. 30s hold	12 days (3 days/wk)	Hamstring Flexibility (PKE)	19	All 3 techniques showed ↑ w/ static stretching
de Weijer et al.[3] 2003	Static	30s x 3	1 session	Hamstring flexibility (AKE)	56	One session of static stretch w/ or w/o warm up ↑ flexibility which was maintained over 24 h
O'Sullivan et al.[4] 2009	Static & Dynamic	30s x 3	2 sessions (dynamic & static)	Hamstring flexibility (PKE)	36	5 min warm up ↑ flexibility. Static stretching further ↑ flexibility while dynamic did not. Flexibility ↓ after 15 min
DePino GM et al.[5] 2000	Static	30s x 4	1 session	Hamstring flexibility (AKE)	30	6 AKE's before stretching ↑ knee joint ROM. Static stretching ↑ hip ROM for only 3 min, ROM returned to baseline by 6 min
Funk DC et al.[32] 2003	Static & PNF	Static 15s (5 min total) PNF 30s (5 min total)	1 session	Hamstring flexibility (AKE)	40	PNF stretching ↑ flexibility after exercise more than static. Claims it is more effective after exercise as muscles are less stiff
Brodowicz GR et al.[24] 1996	Static	3 min stretches (20 min total)	1 session	Hamstring Flexibility	24	Stretching w/ ice showed ↑ improvements in flexibility. May be due to reduction in stretch reflex
Kanazawa H et al.[35] 2010	Static	10 min	1 session	Gastrocnemius Flexibility	20	More stretching took place at aponeurosis than MTJ in injured subjects. Not true in healthy subjects. Authors suggest ↑ extensibility of deep apponeurosis
Bandy WD et al.[6] 1997	Static	1 min x 3 30s x 3 1 min x 1 30s x 1	5 days a wk (6 wks)	Hamstring flexibility (PKE)	100	No difference between groups. ↑ duration or frequency does not ↑ flexibility. One 30s stretch 5 days a week for 6 weeks increased hamstring flexibility

Table 1. Continued

Zakas A et al. 2006	Static	15s x 4 (60s total) 15s x32 (8min total)	1 session	Quadriceps Flexibility	15	Shorter duration stretching protocol (60 s) had no effect on peak torque of the quadriceps compared to the ↓ in peak torque seen in the 8min stretching protocol. Shorter durations have no effect on performance.
Marek SM et al.[29] 2005	Static & PNF	4 x 30s	1 session	Quadriceps Flexibility (AROM & PROM)	19	Static & PNF stretching ↓ PT & MP at both 60^{o} & 300^{o}s. Static & PNF both ↑ AROM & PROM. There was also ↓ in muscle activation after both stretching protocols.
Yuktasir B et al.[36] 2009	Static & PNF	4 x 30s	4 day a wk (6 wks)	Hamstring flexibility(PKE) & Jump performance	28	PNF & static stretching ↑ flexibility over the 6 wks. Neither PNF nor static had an effect on performance. Suggesting there is no long term effect from stretching on performance
Jamtvedt G et al.[11] 2009	Static	30s x 1 (7 muscles)	12 wks. Before/after physical activity	Injury risk & muscle soreness	2,377	Stretching before & after exercise showed no ↓ in injury & showed a small ↓ in soreness
Ayala F et al.[22] 2010	*Active-static & Passive static	15, 30, & 45s	3 days a wk (12 wks)	Hamstring flexibility (PROM)	173	All groups showed ↑ in flexibility. ACSM guidelines of 3x per week w/ 180s of total stretching worked.
Ayala F et al.[37] 2010	Active stretch	15, 30, & 45s	3 days a wk (12 wks)	Hamstring flexibility (PROM)	150	All showed ↑ in flexibility. 12 x 15s stretch was more efficient in ↑ flexibility.
Kokkonen J et al.[38] 2010	Static	15s x 3	2 days a wk (8 wks)	Strength Gains (Hamstring)	32	Flexibility programs during off lifting days (2x/wk) experienced ↑ strength gains
Ylinen JJ et al.[39] 2010	Active, Manual, & Machine (Linden Ltd.) ROM testing	30s x 6	7 days a wk (4 wks)	Hamstring Flexibility	12	Instrument/machine method of testing hamstring flexibility was superior to the ASLR or MSLR. When possible ISLR test should be used. The MSLR test was more reliable then ASLR
Russell PJ et al.[7] 2010	Static	30s x 1	3 days a wk (4 wks)	Hamstring flexibility (AKE)	47	All 3 showed ↑ AKE. The AKE-N test showed ↓ ROM
Rancour J et al.[31] 2009	Static	30s x 4	7 days a wk (4 wks)	Hamstring Flexibility (PROM)	35	Cessation of stretching after 4 wk program gradually ↓ ROM. At 8 wks. Intermittent stretching (2-3 days) a wk was enough to maintain a slight ↑ ROM gains.

Table 1. Continued

Bandy WD et al.[28] 1994	Static	15, 30, 60s x 1	5 days a wk (6 wks)	Hamstring flexibility (PKE)	57	Durations of 30s & 60s showed ↑ gains in ROM as compared to 15s stretch over 6 wks. 30s ↑ ROM more than 60s.
Decoster LC et al.[8] 2004	Static	30s x 3	3 days a wk (3 wks)	Hamstring flexibility (AKE)	29	Standing & supine stretches showed same ↑ in ROM. Supine stretch may be recommended at home because of easier positioning & less worry about pelvic position.
Meroni R et al.[40] 2010	Static & Active	Static (30s x 3) Active (30s x 4) 2 times per day	4 day a wk (6 wks)	Hamstring flexibility (AKE)	33	Active stretching was more efficient & had ↑ in ROM. After 4wks cessation active stretching retained ↑ flexibility than static
Cipriani D et al.[9] 2003	Static	10s x 6 30s x 3 (Repeated 2x)	6 wks (daily)	Hamstring flexibility (PROM)	23	Both durations showed ↑ in ROM. Stretching gains seem to be more dependent on duration as compared to single stretch duration
Taylor KL et al.[41] 2008	Static & Dynamic Warm-up	30s x 2 30s x 1	Single Session	Vertical Jump & 20m sprint	13	Dynamic stretch is more beneficial than static stretch for pre-event warm up. A sport specific skill performed after a session on static stretching ↓ the deleterious effects of static stretching
Ford GS et al.[10] 2005	Static	30, 60, 90, 120s x 1	7 days a wk (5 wks)	Hamstring flexibility (PROM)	35	All showed ↑ in ROM. 30s showed as much ↑ as the 90s & 120s. Also showed greater ↑ than the 15s duration. Suggest there is no need for longer durations
Winchester JB et al.[42] 2008	Static	30s x 1-6	1 session before 1RM test	1RM Knee Flexion	18	As the number of 30s reps ↑, strength ↓. Single 30s stretch was enough to ↓ strength
Fasen JM et al.[21] 2009	Passive, Active, Active-Assisted NM component & passive SLR	30s x 3	5 days a wk (8 wks)	Hamstring flexibility (PKE)	100	Static passive SLR showed the greatest ↑ in ROM. Involved using a wall & propping the heel on the wall to achieve a hamstring stretch
Shrier I [43] 1999	Review	Review	Review	Review	Lit. Rev.	Stretching before exercise will not ↓ injury risk in the LE Stretching causes a ↓in force & power if done before an activity, possible predisposing a muscle to injury

Connective Tissue

Stretching is not the only method used to increase flexibility. Myofascial release is a technique that is widely used by clinicians practicing manual therapy to break up scar tissue as well as promote tissue extensibility.[44] Myofascial release is a hands on approach to releasing connective tissue adhesions, most notably found in fascia.[45] Connective tissue is analogous to fascia, which is all fibrous connective structures not otherwise specifically named that vary in thickness, structure, density, and function.[16, 45]

Connective tissue is composed of collagen, elastin, and ground substance.[45] It is the ground substance that makes up the bulk of the extracellular matrix which is composed of proteins and lipids.[45] Proteoglycans, glycoaminoglycans, and structural glycoproteins make up these lipids and proteins. They have a high water binding and ion exchange capacity allowing them to serve as conductive material for intracellular communication.[45]

Connective tissue also serves as a supporting and space filling role in mediating nerve and vascular functions,[46] nutritional flow,[45] and lymph drainage.[47] Connective tissue, like skin can be labeled as an organ because it also works to control chemical and electrical processes via an open system. This open system of connective tissue allows energy and stimulus to be spread throughout the entire system allowing for the transmission and processing of information.[47-48]

Flexibility and movement are another function of connective tissue (fascia) along with the roles stated above. If connective tissue is overlooked and adhesions are not addressed not only will faulty movement patterns develop but the bodies nutritional, lymph, and vascular systems could be compromised. With so many functions it becomes important that connective tissue is addressed when looking at performance and overall well being.

Connective tissue (fascia) provides a framework which binds muscle together to ensure proper alignment of fibers, blood vessels, and nerves.[16] It allows for the transmission of forces safely across the whole tissue, provides the necessary lubrication for muscles and their fibers to move and change shape, energy storage, cushioning, transport, and protection. Connective tissue (fascia) are classified into 3 different layers.[16] The superficial fascia lies directly below the skin allowing it to glide and move freely in all directions.[16] The deep fascia lies underneath the superficial fascia covering and fusing muscles, bones, nerves, blood vessels, and organs of the body.[16] The deep fascia is also responsible for compartmentalizing the muscle into 3 distinct bands called the epimysium (covering the entire muscle), perimysium (covering bundles of muscle fibers called fasciculi), and the endomysium (covering each individual muscle fiber).[16, 23] The third layer of fascia is the subserous fascia and is located in the innermost cavities of the body covering the lungs, heart, abdominal cavity, and organs.[16]

Connective Tissue Trauma

As with tissue, fascia responds to trauma. Trauma can be cumulative in nature as seen with many overuse injuries, or can result from acute trauma such as contusions or sprains. As a protective mechanism, fascia tighten forming restrictions which become a source of tension for the rest of the body.[45] Specifically, elastin a major component of fascia loses its pliability, ground substance solidifies, and collagen develops cross links becoming fibrous and dense.[45] When collagen production exceed collagen breakdown, more cross links are established making tissue more resistant to stretch.[16] In one study it was suggested that mobilization techniques and exercise may help collagen breakdown keeping cross links and tissue resistance to stretch to a minimum.[49-50]

Abnormalities that occur within the fascia can place tension on bony structures pulling them out of alignment which in turn, leads to compressions of joint surfaces, pain, or muscular dysfunction.[45] It is noted that blood vessels and nerves may become entrapped in fascial restrictions causing neurological and ischemic (lack of oxygen) conditions.[45] Given that fascia are so intimately connected to muscles, restrictions can lead to muscle shortening. This shortening, in turn, leads to reduced strength and muscle imbalances.[45] It is easy to see that any restriction in the fascia could cause problems and addressing these restrictions would be beneficial to the active or general population.

Myofascial Release Technique

There are a variety of methods used to address fascial restrictions the most common being general massage and stretching techniques. Restrictions can be relieved using the forces of tension, compression, shearing, bending, stress, and strain.[51] Recently a new technique called myofascial release technique (MRT) has been used to address fascial adhesion or muscle spasms.[44] The technique requires a clinician to locate an area of restriction and using their hands, apply a force (usually of low-load, long duration) to the fascia for 90-120 seconds or until a release in the fascia is felt.[16, 45] The MRT has received some attention in the literature as to its effectiveness in reducing pain, increasing tissue extensibility, and decreasing muscles spasm.[44] It is suggested that this occurs as a result of breaking the pain-spasm cycle by releasing muscle spasms and decreasing adhesions, thus restoring normal homeostasis to connective tissue.[44]

Thixotropic property of fascia was another possible mechanism for increasing extensibility.[44] Thixotropic or thixotropy is the time-dependent reduction in a muscles resistance to stretch following movement[52] or the decrease in apparent viscosity under shear stress, followed by a gradual recovery when stress is removed.[53] The reduction of viscosity in ground substance and ultimately the resistance of fascia through myofascial release is a plausible mechanism for the increase in muscle extensibility.[54]

Myofascial restrictions can be eliminated with massage, MRT, and the Active Release Technique®. These techniques, however require a skilled clinician and can be costly and time consuming.[12] Therefore, a technique known as self myofascial release (SMR) is a beneficial alternative. Self myofascial release techniques are administered by the subject themselves and involve the subject using their own body weight to apply tension to a group of muscles. This tension is the stimulus needed to activate the GTO which causes autogenic inhibition thus relaxing the muscle.[12] The SMR technique can be applied using a variety of tool and objects. These include; medicine balls, tennis balls, foam rollers, and myofascial sticks.[12] Foam rollers have become popular in fitness clinics and athletic training rooms for their easy use, versatility, and proposed results.[12] Foam rollers are proposed to: improve mobility and ROM, reduce scar tissue and adhesions, decrease muscle tone and overactive muscles, improve quality of movement, and replace hands-on sessions of ART® or deep tissue massage.[12] Despite the popularity and numerous benefits SMR and foam rolling offer, limited research has been conducted on their effectiveness in addressing its claims.

Foam Rolling

Foam rolling is done with a foam cylinder that can vary in size, shape, and density. Different lengths are available making foam rollers more travel friendly and easier to maneuver on different parts of the body. Density relates to how hard of soft the foam roller is. Foam rollers can be of a high or low density and of the open or closed cell type. Open cell foam rollers are usually more giving (softer) and more comfortable to use. Closed cell rollers are usually denser and provide a firm surface to roll on. People who are just starting out or have significant myofascial restrictions may find these rollers uncomfortable to use and are better suited for a softer open cell roller. Foam rollers are best used for large muscle groups.[12] Each muscle group has a designated position and protocol with different starting and ending points.[12] Generally each rolling protocol calls for 30 to 60 seconds of rolling on the specified muscle with the action repeated on the opposite limb. Some protocols also call for the roller to be stopped and held on any tender or painful areas along the muscle, in an attempt to release a muscle spasm or knot.[23] People who have poor tissue quality and are new to foam rolling generally need to spend more time on the roller in order to achieve best results.[12] Foam rolling sessions can be done 1 to 2 times a day and may be used before a workout as a warm-up tool, or after as a recovery option.[12]

An article by Miller and Rockey[13] looked at the effectiveness of foam rollers on increasing hamstring flexibility requiring foam rolling 3 days a week for 8 weeks. It was reported that there were increases reported with treatment and control groups. However pre-and post measures were not consistently taken and control subjects also showed an increase in flexibility. With this data it was concluded that foam rollers were ineffective for increasing hamstring flexibility over an 8 week period.[13]

CHAPTER III

METHODS

Subjects

Forty-six subjects were recruited to participate in this investigation. Six subjects were excluded from participating because they failed to meet inclusion criteria leaving 40 subjects (male: n = 14, age = 21.29 ± 2.58 yrs, ht = 176.62 ± 5.28 cm, mass = 73.96 ± 16.9 kg; female: n = 26, age = 21.08 ± 2.91 yrs, ht = 167.05 ± 6.19 cm, mass = 73.62 ± 11.52 kg) who completed all requirements. Subject inclusion criteria included: no previous history of knee, hip, or spine injury, currently not participating in any lower extremity flexibility program, free from any current injury or diseases that could affect hamstring flexibility, free from any circulation problems, chronically tight hamstrings, and overall recreationally active and healthy. Recreationally active was defined as engaging in physical activity 1 to 5 hours per week.[29] Subjects who were involved in a current exercise program were asked to refrain from increasing exercise intensity or volume throughout the duration of the study. All subjects were screened for hamstring flexibility prior to the study. Chronically tight hamstring were defined as having a hip ROM less than 90^{o} as measured by a passive straight-leg raise (PSLR).

Statistical Design

A 2 x 4 x 6 repeated measures design on all factors guided data collection. The independent variables were time (pre and post), group (static stretching (SS), foam rolling and static stretching (FR/SS), foam rolling (FR), and control) and day (1, 2, 3, 4, 5, 6). The dependent variable was hip flexion ROM.

Screening Procedure

Subjects reported to the Applied Musculoskeletal and Human Physiology Research Laboratory Room 192 in the Colvin Recreation Center wearing a T-shirt and shorts. Subjects read and signed an IRB consent form describing the purpose, risks, and benefits involved in participation of the study. Subjects lied supine on an examination table where their non-dominate leg was strapped to the table across the thigh and anterior iliac spine to restrain the tendency for pelvic tilt[7] (Figure. 1). The dominate leg was determined by questioning the subject as to which leg they kick a ball. This leg was deemed the test leg and was stretched through the duration of the study. A bubble inclinometer was held in place on the anterior thigh (Figure. 1) while the test leg was passively raised into hip flexion (Figure. 1). The examiner used two finger widths distance above the superior pole of the patella to ensure consistent placement of the bubble inclinometer The end point of the PSLR was determined by using one or both of the following criteria: (a) the examiner's perception of a firm resistance, and/or (b) when subjects indicated discomfort or tightness Once either one or both of these criteria were met the value from the bubble inclinometer was read and recorded. Subjects who had hip ROM less than 90° were included in the study.

Figure 1. Subjects anterior iliac spine and non-dominate leg secured with bubble inclinometer placement on the anterior thigh.

Procedures

Subjects were randomly assigned to one of four groups by picking a number from a bowl: 1) static stretching only (SS), 2) foam rolling and static stretching (FR/SS), 3) foam rolling only (FR), and 4) control. Subjects in the FR/SS and FR group were allowed to familiarize themselves with the foam roller. The foam rolling protocol was shown to each subject with specific instructions. Subjects were then asked to demonstrate the foam rolling technique to ensure proper form.

Each subject had baseline ROM measures before engaging in their designated protocol. Subjects in the SS group were stretched on a standard examination table with their non-dominate leg secured to the table (Figure. 2) Each stretch was 1 minute in duration with a 30 second rest between repetitions. The stretch was repeated 3 times for a total of 3 minutes. The subjects were required to return to the Applied Musculoskeletal & Human Physiology Research Laboratory in the Colvin Recreation Center for 6 visits separated by 48 hours.

Figure 2. Subject being passively stretched.

Subjects in the FR/SS group were stretched in the same manner as the SS group. Before being stretched subjects in this group were required to roll on a 6 x 36in Cando ™ open cell firm foam roller. The subjects began by sitting on the foam roller with their legs extended keeping their ankles in a relaxed position orientated toward the ceiling. The subjects began the foam rolling movement at the ischial tuberosity (Figure. 3) and completed the movement at the popliteal fossa (Figure. 4). Subjects supported their body weight with their arms extended as the foam roller was moved to and from the appropriate landmarks. Subjects were instructed to allow as much pressure between the hamstring muscle and the foam roller as possible. The foam roller was moved at an approximate cadence of 1 second down (ischial tuberosity to popliteal fossa) and 1 second up (popliteal fossa to ischial tuberosity).The foam rolling protocol was timed and observed by the examiner with verbal feedback given (as needed). Subjects maintained full knee extension and proper ankle orientation during the entire foam rolling movement. The foam rolling protocol included 3 one minute repetitions with a 30 second break between to allow for recovery of the arms from supporting body weight. After completing the foam rolling and stretching protocols subjects returned to the examination table and ROM measurements were again taken.

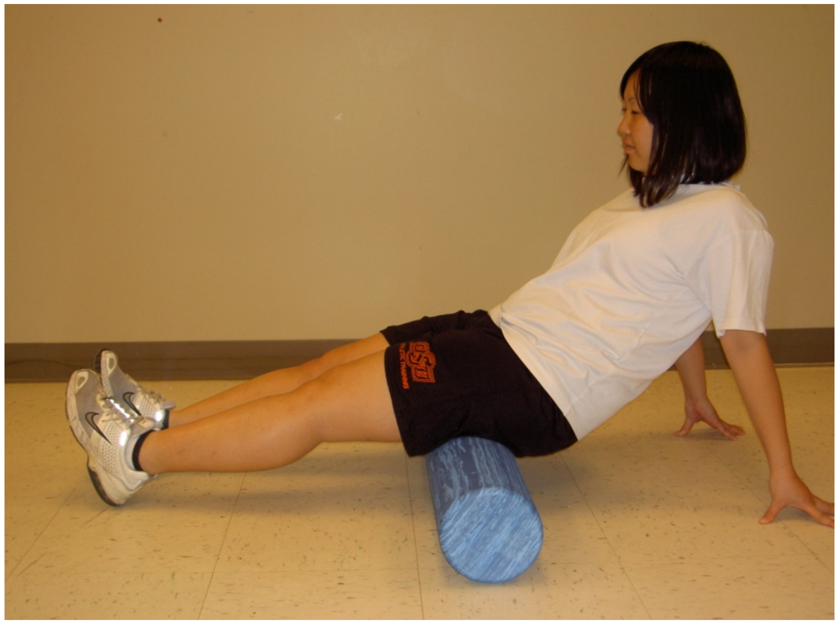

Figure 3. Starting position at the ischial tuberosity.

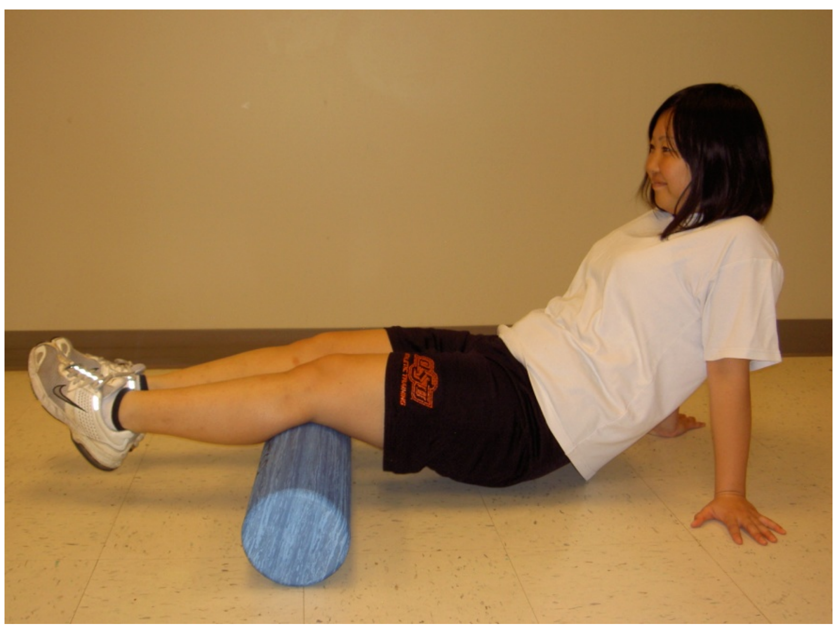

Figure 4. Ending position at the posterior knee

Subjects assigned to the FR group were required to perform only the foam rolling protocol. After the foam rolling protocol was completed, subjects returned to the examination table where ROM measures were again taken.

Subjects in the control group were asked to report at previously scheduled times over the 2 weeks. Subjects had an initial ROM measurement taken and then lied supine on the examination table for 15 minutes. At the end of 15 minutes ROM measurements were taken again.

Statistical Analysis

We computed means and standard deviations for each group (static stretching (SS), static stretching and foam rolling (SS/FR), foam rolling (FR), and control) across time.

Differences in hip flexion ROM were determined with a 3-way (time x group x day) repeated measures ANOVA with random effects for subject. Tukey-kramer multiple comparison post-hoc testing and two-factor interaction testing were used to identify statistical differences. Results were considered statistically significant at an alpha level of $P < .05$. Number Crunchers statistical software (NCSS 2001, Kaysville, UT) was used to analyze all data.

CHAPTER IV

RESULTS

Data are summarized in Table 2. There was a significant interaction between group and time ($F_{3,16}$ =7.20; P< .003; 1 – β = .96). Regardless of group, subjects hip ROM increased over time (Tukey-Kramer, P < .05). Baseline hip ROM for subjects receiving stretch only was less than subjects that received the foam and stretch (Tukey-Kramer, P < .05). Subjects in the foam and stretch group increased hip ROM more than those in the stretch only, foam only, and control groups (Tukey-Kramer, P < .05). Subjects in the stretch only, foam only, and foam and stretch groups increased hip ROM more than the control (Tukey-Kramer, P < .05).

Table 2. Average ROM for stretch type across time (n=10 sub/group; Mean ± SD)

Time	Stretch[A]	Foam/Stretch[A]	Foam[A]	Control
Pre	70.68 ± 11.27[B]	77.88 ± 15.85 [B]	77.80 ± 12.11	72.90 ± 12.11
Post	78.09 ± 11.86[C,D]	86.85 ± 16.58 [C,D]	82.19 ± 12.37 [C,D]	73.45 ± 11.98 [C,D]

[A]Post > Pre; P < .05
[B]Foam Stretch, Pre > Stretch, Pre; P < .05
[C]Foam Stretch, Post > Stretch, Post; Foam, Post; Control, Post; P < .05
[D]Stretch, Post; Foam Stretch, Post; Foam, Post; > Control, Post; P < .05

CHAPTER V

CONCLUSION

Our objective was to determine if a foam rolling protocol performed before static stretching would influence hip flexion ROM. We hypothesized that since static stretching has been reported to improve hip ROM[1-4, 6-10, 29] the addition of a foam rolling protocol with its claimed benefits of improving flexibility[12] would increase hip flexion ROM more than static stretching or foam rolling alone.

Often clinicians incorporate a therapeutic intervention prior to warm up activities.[12] We decided to use the foam roller before a static stretching protocol to act as a warm up for the hamstring muscles. With the increased hip flexion ROM observed in the foam and stretch group, it is likely that the combination of the foam roller and stretching acted as we thought it would and supports others who have examined therapeutic interventions prior a static stretching protocol.[3-4]

Although we did not measure temperature or blood flow, the 6 minutes of foam rolling may have increased intramuscular tissue temperature and blood flow thus increasing the viscoelastic properties of muscle.[55] Another possible explanation is due to the thixotropic property reported in muscle and fascia.[54] Thixotropy allows muscles and fascia to have less viscosity when exposed to some stress making the tissues less stretch resistant.

With regards to using the foam roller, our data supports other investigators who also reported an increase in ROM.[13] Subjects in our study foam rolled for 3 two minute repetitions totaling 6 minutes in contrast to 3 one minute repetitions in the previous study.[13] Regardless, it appears that subjects increase hip flexion ROM while using the foam roller.[13]

Our control group data contradicts a previous study.[13] Our control groups hip flexion ROM did not change over time, indicating that subjects who maintained their current level of activity do not alter hip ROM. Control subjects in the previous study, however, increased over an 8 week period.[13] Like our subjects, individuals in the previous study were asked to continue with normal activity while avoiding increased activity beyond their normal regimen.[13] However we used a passive straight leg raise test in our study compared to an active knee extension test others used. Caution must therefore be taken when evaluating control group data between studies that measure hip ROM.

An interesting observation was the increased baseline hip ROM in the foam and stretch group as compared to the stretch only group. Subjects in the foam and stretch group began the study with greater ROM values than seen during the screening session (Tables 2 and 3). Since subjects were randomly assigned to a group, this difference is likely due to when subjects were screened for the study. Screening occurred at various times prior to data collection thus any potential inconsistency may be responsible.

Clinically, the results of this study can be used to support the use of a foam roller in combination with a 2 week static stretching protocol. Our results showed an increase in hip flexion ROM across all treatment groups with the greatest gains in the foam and stretch group. If time allows and maximal gains in hip ROM are desired, foam rolling the hamstrings prior to static stretching would be appropriate in non-injured patients who have less than 90° of hamstring ROM.

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APPPENDICES

APPENDIX A

Subject	Age	Ht (cm)	Mass (kg)	Group
1	24	180.34	69.09	2
2	24	177.8	80.91	3
3	29	177.8	73.64	1
4	21	162.56	73.64	1
5	19	165.1	108.18	1
6	20	182.88	102.73	2
7	27	172.72	81.36	1
8	21	165.1	59.55	4
9	21	172.72	62.73	2
10	20	175.26	91.36	1
11	19	165.1	73.64	1
12*	18	162.56	74.09	1
13	19	154.94	74.55	3
14	19	175.26	49.55	3
15	26	167.64	79.09	3
16	19	177.8	68.64	3
17	20	157.48	79.55	3
18	20	177.8	52.27	1
19	18	175.26	99.09	2
20	20	162.56	84.55	4
21	23	175.26	64.09	3
22	20	175.26	72.27	2
23	19	170.18	75.45	1
24	19	165.1	69.55	4
25	19	170.18	50.91	2
26	19	160.02	73.64	2
27	19	162.56	51.82	4
28	21	165.1	68.18	4
29	25	160.02	66.36	4
30	19	170.18	70.00	2
31	23	170.18	77.73	2
32	19	172.72	71.36	1
33	18	175.26	68.18	2
34	21	175.26	82.27	4
35	22	160.02	59.55	3
36	20	165.1	62.27	3
37	26	173.99	80.45	1
38	19	177.8	72.27	4
39	19	187.96	98.64	4
40	23	165.1	62.27	3
41	26	172.72	75.45	4
Mean ± SD	21.05 ± 2.8	170.21 ± 7.44	73.44 ± 13.38	

*Subject was excluded from study and data analysis

Group- (1= Stretch, 2= Foam and Stretch, 3= Foam 4= Control)

APPENDIX B

Table 2. Average ROM for each stretch type across time (n=10 sub/group; Mean ± SD)

Time	Stretch[A]	Foam/Stretch[A]	Foam[A]	Control
Pre	70.68 ± 11.27 [B]	77.88 ± 15.85[B]	77.80 ± 12.11	72.90 ± 12.11
Post	78.09 ± 11.86[C,D]	86.85 ± 16.58 [C,D]	82.19 ± 12.37 [C,D]	73.45 ± 11.98 [C,D]

[A]Post > Pre; *P* < .05
[B]Foam Stretch, Pre > Stretch, Pre; *P* < .05
[C]Foam Stretch, Post > Stretch, Post; Foam, Post; Control, Post; *P* < .05
[D]Stretch, Post; Foam Stretch, Post; Foam, Post; > Control, Post; *P* < .05

Table 3. Baseline ROM measures for each group (Mean ± SD; n = 10 sub/group)

Group (Number)	Baseline
Stretch (1)	70.40 ± 10.72
Foam & Stretch (2)	69.63 ± 10.77
Foam (3)	75.33 ± 9.34
Control (4)	71.93 ± 8.91

Table 4. Average ROM for each stretch type over each day (n=10 sub/group; Mean ± SD)

Time	Stretch	Foam/Stretch	Foam	Control
Day 1				
Pre	66.60 ± 11.37	69.44 ± 11.17	78.06 ± 6.97	70.28 ± 8.45
Post	74.32 ± 11.51	80.77 ± 14.53	81.02 ± 8.15	71.60 ± 9.50
Day 2				
Pre	70.08 ± 11.55	74.88 ± 14.33	76.65 ± 10.03	72.07 ± 13.34
Post	76.74 ± 12.09	82.29 ± 15.13	79.90 ±10.95	72.00 ± 12.99
Day 3				
Pre	68.21 ± 11.37	77.84 ± 15.95	77.44 ± 10.54	73.29 ± 11.01
Post	77.09 ± 12.48	84.98 ± 15.89	82.85 ± 11.45	73.73 ± 11.19
Day 4				
Pre	72.26 ± 10.77	78.87 ± 15.50	79.75 ± 11.20	73.24 ± 13.03
Post	77.30 ± 11.66	88.35 ± 17.08	83.93 ± 12.18	73.28 ± 12.99
Day 5				
Pre	72.19 ± 10.50	82.67 ± 16.16	77.40 ± 13.15	75.23 ± 13.57
Post	79.91 ± 9.81	92.77 ± 16.23	82.71 ± 14.04	75.82 ± 13.39
Day 6				
Pre	74.75 ± 10.16	83.56 ± 17.02	77.47 ± 14.63	74.16 ± 12.00
Post	83.18 ± 11.65	91.93 ± 16.82	82.71 ± 15.74	74.26 ± 10.94

Table 5. Repeated measures ANOVA source terms

Term	DF	Term Fixed	Denominator Term	Exp Mean Square
A: Group	3	Yes	C(AB)	S+dsC+bcdsA
B: Day	5	Yes	C(AB)	S+dsC+acdsB
AB	15	Yes	C(AB)	S+dsC+cdsAB
C(AB): Sub	16	No	S(ABCD)	S+dsC
D: Time	1	Yes	CD(AB)	S+sCD+abcsD
AD	3	Yes	CD(AB)	S+sCD+bcsAD
BD	5	Yes	CD(AB)	S+sCD+acsBD
ABD	15	Yes	CD(AB)	S+sCD+csABD
CD(AB)	16	No	S(ABCD)	S+sCD
S(ABCD)	400	No		S

Table 6. Repeated measures ANOVA for each group across time over 6 days

Source	DF	SS	MS	F	Prob	Power
A: Group	3	4984.41	1661.47	0.43	0.74	0.12
B: Day	5	2683.32	536.66	0.14	0.98	0.07
AB	15	1221.07	81.40	0.02	1.00	0.05
C(AB): Sub	16	61975.67	3873.48	127.07	0.001	
D: Time	1	2884.47	2884.47	54.08	0.001	1.00
AD	3	1152.37	384.12	7.20	0.003	0.95
BD	5	22.44	4.49	0.08	0.99	0.06
ABD	15	100.33	6.69	0.13	1.00	0.08
CD(AB)	16	853.44	53.34	1.75	0.04	
S	400	12193.56	30.48			
Total (Adjust	479	88071.06				
Total	480					

Table 7. Tukey Kramer multiple comparison test for ROM for each group

Group	Count	Mean	Different From Groups
Stretch	120	76.18	
Foam & Stretch	120	82.64	
Foam	120	78.79	
Control	120	73.99	

Table 8. Tukey-Kramer multiple comparison test for ROM for each days

Group	Count	Mean	Different from Groups
Day 1	80	74.15	
Day 2	80	76.13	
Day 3	80	77.30	
Day 4	80	78.40	
Day 5	80	80.74	
Day 6	80	80.67	

Table 9. Tukey-Kramer multiple comparison test for ROM for time

Group	Count	Mean	Different From Groups
Pre	240	75.45	Post
Post	240	80.35	Pre

Table 10. Tukey-Kramer multiple comparison test for ROM for group and days

Group	Count	Mean	Different From Groups
Stretch,1	20	73.55	
Stretch, 2	20	75.85	
Stretch, 3	20	74.50	
Stretch, 4	20	75.38	
Stretch, 5	20	78.25	
Stretch, 6	20	79.53	
Foam & Stretch, 1	20	74.62	
Foam & Stretch, 2	20	79.03	
Foam & Stretch, 3	20	81.87	
Foam & Stretch, 4	20	83.92	
Foam & Stretch. 5	20	87.97	
Foam & Stretch, 6	20	88.43	
Foam, 1	20	76.72	
Foam, 2	20	76.80	
Foam, 3	20	78.95	
Foam, 4	20	80.37	
Foam, 5	20	80.18	
Foam, 6	20	79.73	
Control, 1	20	71.72	
Control, 2	20	72.83	
Control, 3	20	73.88	
Control, 4	20	73.95	
Control, 5	20	76.55	
Control, 6	20	74.98	

Table 11. Tukey-Kramer multiple-comparison test for ROM for group and time

Group	Count	Mean	Different from Groups
Stretch, Pre	60	73.19	FS,Pre; S,Post; FS,Post; F,Post
Stretch, Post	60	79.17	S,Pre; C,Pre; FS,Post; C,Post
FS, Pre	60	78.15	S,Pre; FS,Post
FS, Post	60	87.13	S,Pre; FS,Pre; F,Pre; C,Pre; S,Post; F,Pc C,Post
Foam, Pre	60	76.67	FS,Post
Foam, Post	60	80.92	S,Pre; C,Pre; FS,Post; C,Post
Control, Pre	60	73.78	S,Post; FS,Post; F,Post
Control, Post	60	74.19	S,Post; FS,Post; F,Post

Abbreviation Key

S = Stretch only group

FS = Foam & Stretch group

F = Foam only group

C = Control

ROM = Range of Motion

APPENDIX C

Approved Consent Form

Okla. State Univ.
IRB
Approved 1/24/11
Expires 1/23/12
IRB # ED-10-158

CONSENT TO PARTICIPATE IN A RESEARCH STUDY
OKLAHOMA STATE UNIVERSITY

Projects Title: The effects of foam rolling combined with static stretching on hamstring flexibility.

Investigators: Andrew Mohr, ATC; Graduate Assistant Athletic Trainer, Health and Human Performance; Oklahoma State University; Stillwater, OK; 402-669-3568. Blaine Long, Ph.D., ATC, *Colvin Recreation Center, Health and Human Performance, Oklahoma State University*

Purpose: This study is being conducted at Oklahoma State University. The purpose is to examine the effects of the foam rolling technique combined with stretching. The foam rolling technique claims to increase flexibility in active populations to ultimately reduce injuries, improve muscle imbalances, and sport performance.

Procedures: If you decide to participate in this study you will complete a health history questionnaire form in order to determine if you qualify. Since foam rolling claims to increase flexibility, you will only be included if you have less than 90 degrees of hip flexion; suggesting tight hamstring muscles. You will be asked to come to the Applied Musculoskeletal & Human *Physiology Research Laboratory in the Colvin Recreation Center (Room. 192) on 6 different* occasions over a 2-week period. Each visit will last no more than 20 minutes. On the first visit, you will be randomly assigned to 1 of 4 groups. Static hamstring stretching, static stretching and foam rolling, foam rolling only, and a control (nothing). After your random assignment to a group you will be asked to lie on a padded table where a mark will be placed on the front of your leg. Your opposite leg will be secured with a belt to prevent any unwanted movement. A baseline hamstring flexibility measurement will be taken by flexing your hip.

Following baseline measures, you will remain lying on the padded table. If your assigned group calls for stretching you will receive three, 1 minute hamstring stretches with 30 seconds rest. The leg not being stretched will be secured to prevent unwanted movement. If you are in the stretch/foam roller group you will perform the foam rolling technique first then be stretched in the same manner as mentioned above. The foam roller will be placed under your upper leg while your body weight is supported with your arms. The foam rolling action will require you to move the foam roller from your upper leg to the back of your knees (rolling the hamstring muscle along the way) and then returning the roller to the starting position. You will move the foam roller from the start to the end position for a total of 2 minutes with 30 seconds rest between sets. This will be repeated 3 times. If you are in the foam rolling group you will be asked to perform the foam rolling technique only. If you are in the control group you will report for the same time intervals as the other groups. You will lie on a table for 15 minutes and receive no treatment After you have completed your assigned protocol flexibility measurements will be taken. The testing will occur on 6 days with each session lasting approximately 20 minutes or less.

Risks of Participation: There will be minimal risk involved with participation in this study. You may experience slight discomfort or pressure from rolling on the foam that will dissipate after the rolling is complete You may also feel a slight burning or pulling sensation in your hamstring with the stretching. There is a chance you may be sore the next day from the stretching or foam rolling protocol.

Benefits or Participation: You may gain an appreciation and understanding of how research is conducted. Data collected from this study could provide useful evidence on different methods to increase flexibility that may be beneficial for future patients. In addition, you may see an increase in flexibility which may improve overall wellbeing.

Confidentiality: The investigator will make all attempts to keep personal information confidential. Subjects will be identified by a subject number and all signed consent forms along with study data will be kept on a secure password protected hard drive. Any paper documents will be kept in a research binder in a locked file. This information will be saved as long as it is scientifically useful; typically, such information is kept for five years after publication of the results. Results from this study may be presented at professional meetings or in publications. You will not be identified individually; we will be looking at the group as a whole. It is possible that the consent process and data collection will be observed by research oversight staff responsible for the safeguarding the rights and wellbeing of people who participate in research.

Contacts: You may contact any of the researchers at the following addresses and phone numbers, should you desire to discuss your participation in the study and/or request information about the results of the study: Andrew R. Mohr, ATC, Oklahoma State University, Stillwater, OK 74078, (402)669-3568; amohr@okstate.edu or Dr. Blaine Long, ATC, Colvin Recreation Center, Dept. of Education Oklahoma State University, Stillwater, OK 74078, (405)744-3670; blaine.long@okstate.edu. If you have questions about your rights as a research volunteer, you may contact Dr. Shelia Kennison, IRB Chair, 219 Cordell North, Stillwater, OK 74078, 405-744-3377 or irb@okstate.edu.

Participant Rights: Your participation in this research is voluntary. There is no penalty for refusal to participate, and that you are free to withdraw your consent and participation in this project at any time, without penalty. Participation in this research is voluntary and there is no compensation available for participation. In case of injury or illness resulting from this study, emergency medical treatment will be available (state how and where). No funds have been set aside by Oklahoma State University to compensate you in the event of illness or injury. In the event of illness or injury the subject will be referred to the Oklahoma State University Student Health Center.

CONSENT DOCUMENTATION:

I have been fully informed about the procedures listed here. I am aware of what I will be asked to do and the benefits of my participation. I also understand the following statements:

I affirm that I am 18 years of age or older.

I have read and fully understand this consent form. I sign it freely and voluntarily. A copy of this form will be given to me. I hereby give permission for my participation in the study.

____________________________________ __________
Signature of Participant Date

I certify that I have personally explained this document before requesting that the participant sign it.

____________________________________ __________
Signature of Researcher Date

APPENDIX D

Subject Information &Health History Questionnaire

Please answer all questions to the best of your knowledge. Please place a check in the appropriate box. All information from the questionnaire will be kept confidential.

Subject ID number ___________

Please indicate the most appropriate answer to the following questions

	YES	NO
1. Have you injured or had surgery on either leg in the past 6 months?		
2. Are you currently active in a stretching program?		
3. Have you had a history of chronic hamstring injuries?		
4. Do you have any conditions affecting circulation?		
5. Do you know or have any conditions that contribute to decreased sensation in the lower extremity?		
6. Do you know of or have any medical conditions that might aggravate you during this study?		
7. Have you had or currently have any injury to the shoulder, arm, or wrist that would prevent you from supporting your body weight?		
8. If no injury are you currently able to support your body weight using your hands (ex. body supported in a push up position)		

On average how many days a week do you spend engaged in physical activity? _____________

Should you become ill and/or incapable of finishing the study, alert the investigator (s) immediately.

APPENDIX E

Recommendations for Future Research

- Determine if foam rolling has an effect on acute muscular power or strength.
- Determine the dose response for foam rolling. Comparing 1 minute vs. 2 minute vs. 3 minute repetitions.
- Determine if increasing the study length (> 2 weeks) would show increased results.
- Determine if foam rolling affects the quadriceps or other muscle groups the same as the hamstring.
- Determine if foam rolling has an influence on injury reduction rate with prolonged use.

VITA

Andrew Robert Mohr

Candidate for the Degree of

Master of Science

Thesis: EFFECTIVENESS OF FOAM ROLLING IN COMBINATION WITH A STATIC STRETCHING PROTOCOL OF THE HAMSTRINGS

Major Field: Applied Exercise Science

Biographical:

Education:

Bachelor of Science — Southeast Missouri State University
Major: Bachelor of Science
Area of Emphasis: Athletic Training

Completed the requirements for the Master of Science in Applied Exercise Science at Oklahoma State University, Stillwater, Oklahoma in May, 2011..

Experience:

Southeast Missouri State University: Undergraduate Athletic Training Student

Oklahoma State University: Graduate Assistant Athletic Trainer
-Women's Cross Country/Track and Field

Professional Memberships:

National Athletic Trainers Association (Membership #: 2000001099)
Licensed Athletic Trainer Oklahoma (Licensure #: 588)

Name: Andrew Robert Mohr | Date of Degree: May, 2011
Institution: Oklahoma State University | Location: Stillwater, Oklahoma

Title of Study: EFFECTIVENESS OF FOAM ROLLING IN COMBINATION WITH A STATIC STRETCHING PROTOCOL OF THE HAMSTRINGS

Pages in Study: 48 | Candidate for the Degree of Master of Science

Major Field: Applied Exercise Science

Scope and Method of Study: The purpose of this study was to examine the effects of a foam rolling protocol in combination with a static stretching protocol. For this human subjects approved study, 46 healthy subjects were recruited with no history of lower or upper extremity injury in the 6 months prior to study participation. Forty subjects (male: n = 14, age = 21.29 ± 2.58 yrs, ht = 176.62 ± 5.28 cm, mass = 73.96 ± 16.9 kg; female: n = 26, age = 21.08 ± 2.91 yrs, ht = 167.05 ± 6.19 cm, mass = 73.62 ± 11.52 kg) completed all requirements of the study. Subjects were randomly assigned to 1 of 4 groups. Subjects received baseline hip range of motion (ROM) measurements before performing either a; stretching only, foam rolling and stretching, foam rolling only, or control protocol. Immediately after completion post hip ROM values were obtained. Subjects visited the lab 6 times over a two week period.

Findings and Conclusions: Regardless of group hip ROM increased over time ($P < .003$). Those subjects receiving the foam and stretch treatment had the greatest increase in hip ROM ($P < .05$). Those subjects receiving the stretch only, foam and stretch, and foam only had greater hip ROM values than controls ($P < .05$). Pre hip ROM measurements for subjects in the foam and stretch were greater than those in the stretch only group ($P < .05$).

ADVISER’S APPROVAL: Blaine C. Long Ph.D., ATC, LAT