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The Effects of Thermal Ultrasound on Active and Passive Ankle Dorsiflexion Range of Motion Inside and Outside the Stretching Window

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THE EFFECTS OF THERMAL ULTRASOUND ON ACTIVE AND PASSIVE ANKLE DORSIFLEXION RANGE OF MOTION INSIDE AND OUTSIDE THE STRETCHING WINDOW

By

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A Thesis

Submitted to the Department
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in partial fulfillment of the requirements
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To the Dean of the School of Human Performance and Leisure Sciences:

I am submitting herewith a thesis written by Marti Greer entitled “The Effects of Thermal Ultrasound on Active and Passive Ankle Dorsiflexion Range of Motion Inside and Outside the Stretching Window.” I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Movement Science and specialization in Athletic Training.

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Dr. Sue Shapiro, Thesis Committee Chair

We, members of the thesis committee,
have examined this thesis and
recommend its acceptance:

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Accepted:

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Chair of Department of Sport and Exercise Sciences

Accepted:

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Dean of School of Human Performance and Leisure Sciences

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I never thought I would ever get to this point, but through a lot of hard work and constant guidance the road has finally come to an end. The following people have had a great impact on my life and success throughout this entire process:

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Abstract

Therapeutic ultrasound is a modality commonly used to treat numerous musculoskeletal conditions, specifically those regarding range of motion. The purpose of this study was to determine whether thermal ultrasound on the Achilles tendon effects active and passive ankle dorsiflexion range of motion inside and outside the stretching window.

Thirty-two Barry University students volunteered for the study. Inclusion criteria consisted of all participants being free of any right lower extremity injury in the last six months, as well as reporting no contraindications to a therapeutic ultrasound treatment. Participants were randomly allocated to two groups; group A, which received a therapeutic thermal ultrasound treatment or group B, which received a placebo ultrasound treatment. Three pre-test and post-test active and passive ankle dorsiflexion range of motion measurements were performed on each participant. There were also three repeated measurements of active and passive ankle dorsiflexion range of motion following an 8 minute temperature decay time.

A repeated measure multiple analysis of variance (MANOVA) was used to determine statistical significance ($p < 0.05$) between groups over time. This compared the multivariate mean of each of the three pre-test, post-test, and post 8 minute delay measurements for passive and active ankle dorsiflexion range of motion. Post-hoc tests were then run to determine if differences existed between dependent variables. The results showed there was a significant multivariate interaction within both the treatment and control groups over time for both active and passive ankle dorsiflexion range of motion. There was also a significant increase in passive ankle dorsiflexion range of motion over active range of motion. However, there was no statistical significance found between the two treatment groups over time. Although limited statistical significance was found within this study, results may have helped to show a clinical importance with the use of a therapeutic thermal ultrasound treatment in regards to ankle dorsiflexion range of motion.

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CHAPTER ONE
INTRODUCTION

Statement of Problem

Therapeutic ultrasound is commonly used to treat athletic injuries to stimulate tissue repair, increase blood flow, and increase tissue extensibility.[1,2] Previous research[3,4] has demonstrated that ultrasound is commonly applied in the therapeutic management of numerous clinical conditions based on its documented thermal effects. Specific temperature increases are required to produce beneficial physiologic effects in tissue. It has been generally accepted that tissue temperature must be elevated at least 3 to 4°C from baseline values to achieve thermal benefits.[1,5]

Numerous thermal modalities, such as hot packs, warm whirlpools, and paraffin baths, have been introduced in the field of athletic training. However, the depth of penetration of these modalities is superficial; ranging from only 1 to 2 centimeters.[2] Therapeutic ultrasound has traditionally been classified as a deep heating modality and is primarily used for this purpose. According to prior research,[6-8] therapeutic ultrasound has repeatedly been shown to increase tissue temperature at depths ranging from to 2 to 5 centimeters.

When discussing temperature changes in tissues, careful attention must be paid to the specific ultrasound settings being used.[6,8] To obtain such temperature increases, a variety of technical ultrasound parameters can be adjusted, such as ultrasound frequency, intensity, duty cycle, size of transducer head, and treatment time. Although the literature in this area is growing, research has not yet clearly determined the combination of ultrasound parameters necessary to elevate tissue temperature consistently.

Range of motion is a commonly used measure of flexibility, which may be increased with changes in the viscoelastic properties of muscles and tendons.[9] Park and Chou[9] believe that heating changes the viscoelastic properties of muscle and tendon, which reduces the incidence of injury. It is also believed that limited ankle dorsiflexion range of motion is predictive of acute and overuse injuries. Poor flexibility has been demonstrated to increase the risk of ankle injuries by two and one half times.[9] Recent studies[9,10] have contended that increasing ankle dorsiflexion range of motion, specifically through extensibility of the Achilles tendon, may reduce the risk of tendon injury.

Therapeutic ultrasound is a modality commonly used in the athletic and rehabilitation setting to treat numerous musculoskeletal conditions, specifically those regarding range of motion. The keys to maximizing treatment outcomes with therapeutic ultrasound in musculoskeletal conditions are: determining the stage of healing, determining the treatment goal, and choosing parameters that will accomplish the desired treatment outcome. Theoretically, the application of therapeutic thermal ultrasound should increase range of motion. However, research is controversial on whether extensibility is affected enough to significantly increase range of motion.

The time period of vigorous heating when tissues undergo the greatest extensibility and elongation is referred to as the stretching window.[11] According to numerous authors,[11-13] the stretching window last approximately 2 to 4 minutes after the termination of a continuous therapeutic ultrasound treatment; however, current research[11,14] reports otherwise. Due to the variance of the exact stretching window, this study aims to measure ankle dorsiflexion range of motion immediately and 8 minutes following the termination of a therapeutic ultrasound treatment.

Purpose of Study

The purpose of this study was to determine whether thermal ultrasound on the Achilles tendon effects active and passive ankle dorsiflexion range of motion inside and outside the stretching window.

Research Questions

1. Will a thermal ultrasound treatment increase the active range of motion of ankle dorsiflexion within the stretching window?
2. Will a thermal ultrasound treatment increase the passive range of motion of ankle dorsiflexion within the stretching window?
3. Will there be a greater increase in passive range of motion over active range of motion with ankle dorsiflexion before and after the application of a thermal ultrasound treatment?
4. Will there be a maintained increase in active ankle dorsiflexion range of motion when remeasured outside the stretching window?
5. Will there be a maintained increase in passive ankle dorsiflexion range of motion when remeasured outside the stretching window?

Variables

Independent: Participant groups (ultrasound treatment group, control group); Time (pre-test, post-test, 8 minute post-test)

Dependent: Active ankle dorsiflexion range of motion; Passive ankle dorsiflexion range of motion

Research Hypotheses

1. There will be a significant increase in active ankle dorsiflexion range of motion when measured immediately after the application of a therapeutic thermal ultrasound treatment, when compared to a control group.
2. There will be a significant increase in passive ankle dorsiflexion range of motion when measured immediately after the application of a therapeutic thermal ultrasound treatment, when compared to a control group.
3. There will be a significantly greater increase in passive range of motion over active range of motion with ankle dorsiflexion before and after the application of a therapeutic thermal ultrasound treatment, when compared to a control group.
4. The significant increase in active ankle dorsiflexion range of motion will not be maintained when remeasured outside the stretching window.
5. The significant increase in passive ankle dorsiflexion range of motion will not be maintained when remeasured outside the stretching window.

Null Hypothesis

There will be no significant differences between groups over time in active and passive ankle dorsiflexion range of motion after a therapeutic thermal ultrasound treatment.

Definition of Terms

Active range of motion: The arc of motion attained by a subject during unassisted voluntary joint motion.[15]

Dorsiflexion: Movement in the sagital plane brining the foot up and slightly laterally.[15]

Goniometer: A large protractor with measurements in degrees most commonly used to measure joint position and motion in the clinical setting.[15]

Metronome: Any device that produces a regulated pulse, usually used to establish a steady tempo, measured in beats per minute.[15]

Passive range of motion: The arc of motion attained by an examiner without assistance from the subject.[15]

Range of motion: The arc of motion that occurs at a joint or a series of joints.[15]

Stretching Window: The time period of vigorous heating when tissues will undergo their greatest extensibility and elongation.[2]

Therapeutic ultrasound: An acoustic modality that is used for a number of different purposes including diagnosis, destruction of tissue, and as a therapeutic agent.[2]

Assumptions

1. It was assumed that the goniometer is valid and reliable in assessing the range of motion of ankle dorsiflexion.
2. It was assumed that any uncontrolled external factors, such as beam nonuniformity ratio, transducer soundhead speed, and applied pressure of the soundhead did not affect the therapeutic ultrasound treatment outcome.
3. Since participation in the study was completely voluntary, it was assumed that there was no influence over participation in this study.

Limitations

1. This study was limited to one therapeutic ultrasound treatment session per

participant due to the time constraints of the academic year and the research study.

2. Participants were limited to current healthy students from Barry University who reported no contraindications to therapeutic ultrasound.

Delimitations

1. It was decided that only participants from one collegiate institution would be studied for the purpose of availability of the participants.
2. It was decided that only thermal ultrasound would be used instead of other thermal modalities. Other methods of thermal application may alter the purpose of this study.
3. This study only examined range of motion with ankle dorsiflexion versus other motions or joints throughout the human body.

Significance of the Study

Enhanced range of motion in athletes can greatly reduce the risk of injury during athletic competition. According to Mahieu et al[16] increased stiffness of a tendon has been shown to be a predisposing factor for exercise-related injuries. The application of therapeutic thermal ultrasound can decrease this stiffness and enhance range of motion to aid in the prevention of athletic injuries.

An important goal in any treatment or rehabilitation protocol is attaining the full range of motion at a joint. Therapeutic ultrasound is a modality that is often used to aid in reaching this goal. After injury or immobilization, there may be several limiting factors such as joint contractures, scar tissue, and adhesions that make reaching this goal difficult.[11]

These findings may be important in considering the use of therapeutic ultrasound to treat athletes before practice or competition. By temporarily increasing flexibility in the athletic population, there may be a reduction in the occurrence of injury and an improvement in performance for a given event. Also, understanding the exact role of collagenous elastic properties could help in optimizing training and rehabilitation guidelines for certified athletic trainers.[16] This study may provide evidence that the use of therapeutic thermal ultrasound can improve the range of motion of ankle dorsiflexion from pre-test and post-test treatment measurements.

CHAPTER TWO
LITERATURE REVIEW

Introduction

The purpose of this study was to determine whether thermal ultrasound on the Achilles tendon effects active and passive ankle dorsiflexion range of motion inside and outside the stretching window. It compared the mean of three pre-treatment, post-treatment, and 8 minute post-treatment range of motion measurements of ankle dorsiflexion in regard to a single therapeutic ultrasound treatment. Many studies[9,10,12,17,18] conclude that therapeutic ultrasound can be used to increase range of motion due to its thermal effects. Due to the high incidence of ankle injuries in athletic competition this thermal effect can be used to increase extensibility and possibly reduce the incidence of injury.

The time period of vigorous heating when tissues undergo the greatest extensibility and elongation is referred to as the stretching window.[11] According to numerous authors[11-13] the stretching window last approximately 2 to 4 minutes after the termination of a continuous therapeutic ultrasound treatment; however, current research[11,14] reports otherwise. Due to the variance of the exact stretching window, this study aims to measure ankle dorsiflexion range of motion immediately and 8 minutes after the termination of a therapeutic ultrasound treatment.

Therapeutic Ultrasound

Ultrasound is defined as inaudible, acoustic vibrations of high frequency that may produce either thermal or nonthermal physiologic effects.[2] Typical frequencies used with ultrasound range from 0.8 to 3.0 MHz in combination with variable intensities of 0.25 to 3.0 W/cm^2.[19,20] Ultrasound energy is converted into heat proportional to the intensity of the ultrasound. If this heat is not dissipated by physiological means, a localized increase in temperature will occur and thermal therapeutic effects may arise.[19] If the dissipation of heat equals the generation of it, the effects are said to be nonthermal.[19]

In sports medicine, ultrasound is one of the most widely used therapeutic modalities.[2] It has been used for therapeutic purposes in the rehabilitation of various injuries. The primary focuses in using therapeutic ultrasound are stimulating tissue repair, increasing blood flow, increasing tissue extensibility, and pain relief.[1,2,20] Investigators[11] have indicated that specific temperature increases in tissues are required to achieve beneficial effects. It has been suggested that mild heating, an increase of 1°C over baseline muscle temperature of 37°C accelerates the metabolic rate in tissue up to 13%[3,6,7,11,19] and is used for treating mild inflammation.[3,6,7,11] Moderate heating, an increase of 2°C to 3°C is used in the reduction of muscle spasms, pain control, chronic inflammation and promotion of blood flow.[3,6,7,11,19,17] An increase of 4°C or more is classified as vigorous heating, and has been suggested to alter the viscoelastic properties of collagenous tissue and inhibit sympathetic activity.[3,6,7,11,17,19,20] To obtain such temperature increases within tissues, a variety of technical ultrasound parameters can be varied, such as ultrasound frequency, intensity, duty cycle, and treatment time.

Frequency of Therapeutic Ultrasound

When discussing temperature changes in tissues, producing a therapeutic increase in tissue temperature requires careful attention to the specific ultrasound settings being used.[6,8] One of the primary settings in the application of therapeutic ultrasound is frequency. Frequency is the number of wave cycles completed each second and typically ranges between 0.75 and 3.0 MHz on a standard therapeutic ultrasound machine.[2,7,19,20] Frequency is solely selected based on the depth of the tissue to be treated; therefore, in order to determine the appropriate frequency, the depth of the target tissue must be predetermined.[6]

Ultrasound energy generated at 1 MHz is transmitted through the more superficial tissues and absorbed primarily in the deeper tissues at depths ranging from 2 to 5 cm.[2,10] A 1 MHz frequency is most useful in treating deeper tissue structures, such as the soleus or piriformis muscles.[2,6,7,17,19,21,25] At a 3 MHz setting the ultrasound energy is absorbed in more superficial tissues, with depth of penetration ranging between 1 and 2 cm.[2,6,7,10,11,17,21,25] This makes 3 MHz ultrasound ideal for treating superficial conditions such as Achilles tendinitis and epicondylitis of the elbow. Based on numerous studies[6,17,19,22] the heating rate of 1 MHz ultrasound should be three times slower than that for 3 MHz. This is because 1 MHz ultrasound frequency is absorbed three times more slowly than 3 MHz ultrasound frequency. For example, Draper et al[17] found that 3 MHz ultrasound applied at 1.5 W/cm^2 heated at a rate of 0.9°C/min, whereas 1 MHz ultrasound heated at a rate of 0.3°C/min. These findings support prior research that explains that the ultrasound crystal is deforming three times faster; thus the energy is being absorbed three times faster.[6,19,17]

Therapeutic ultrasound can only have an effect on the target tissue if the energy delivered reaches and is absorbed by the tissue. Ultrasound frequency is primarily responsible for the depth of penetration; however, other factors such as attenuation contributes to the amount of ultrasound energy delivered. Attenuation is a decrease in energy intensity as the ultrasound wave is transmitted through various tissues.[2] The rate of absorption, and therefore the rate of attenuation, increases as the frequency of the ultrasound increases.[2]

Intensity of Therapeutic Ultrasound

According to Demmink et al[7] thermal parameters, such as intensity, thermal conductivity of tissue, and treatment time play a role in tissue heating. Intensity is a measure of the rate at which energy is being delivered per unit area.[2] A standard ultrasound unit provides variable intensities of 0.25 to 3.0 W/cm^2.[19,20] The intensity chosen for a therapeutic ultrasound treatment should depend on the specific treatment goal. In general, the higher the intensity chosen, the faster the rate of heating. There are no definitive rules that govern the selection of ultrasound intensities during treatment, yet using too much may likely damage tissues and exacerbate the condition.[2] According to Prentice,[2] a recommendation for ultrasound is that using the lowest available intensity at the highest available frequency will transmit the ultrasound energy to a specific tissue to achieve the desired therapeutic effect.

Beam nonuniformity ratio (BNR) indicates the amount of variability of intensity within the ultrasound beam.[2] The ultrasound beam is nonuniform in nature and the higher the BNR, the greater the nonuniformity of the beam and potential for hot spots. Standard ultrasound units usually have a BNR of 5:1 or 6:1, creating peak intensities 5 to 6 times greater than that set by the clinician.[7] This means that at a therapeutic intensity of 1.5 W/cm^2, an ultrasound machine with a BNR of 6:1 would produce a peak intensity of

9 W/cm^2. These high peak intensities are what often cause pain or discomfort associated with ultrasound application.

Duty Cycle

Therapeutic ultrasound is capable of producing thermal and nonthermal physiological changes within the body. The duty cycle, which is the ratio between the pulse duration and the pulse interval, is responsible for this thermal change.[2] A continuous output causes primarily thermal effects, whereas a pulsed output produces primarily nonthermal effects. The decision to use thermal or nonthermal ultrasound depends on the stage of healing and the desired treatment goals.

Duration of Treatment

According to several authors[2,17] the appropriate duration of an ultrasound treatment should be determined by the intensity, frequency, size of the area to be treated, and the desired temperature increase. Ultrasound treatments are too often given at a standard duration of five minutes due to the presetting protocols within most ultrasound units. In general clinical practice, the higher the intensity set, the faster the rate of heating. With a 3 MHz frequency setting, the rate of heating is expected to be 3 to 4 times faster than with a 1 MHz frequency setting.[17] Table 2-1 displays the rate of human muscle temperature increase per minute, per W/cm^2, at various intensities and frequencies.[2] By using this table it can be estimated how long it takes muscle to reach a chosen temperature during 1 MHz or 3 MHz continuous ultrasound.

Table 2-1: Ultrasound Rate of Heating per Minute in Human Muscle[2]

Intensity (W/cm^2)	**1 MHz**	**3 MHz**
0.5	0.04°C	0.3°C
1.0	0.2°C	0.6°C
1.5	0.3°C	0.9°C
2.0	0.4°C	1.4°C

Biophysical Effects of Ultrasound

Traditionally, biophysical effects of ultrasound are separated into thermal and nonthermal effects, as shown on Table 2-2. Thermal ultrasound produces a continuous wave exposure and nonthermal produces a pulsed wave exposure. Various authors[3,4] have suggested that continuous ultrasound is more likely to produce greater thermal effects on tissues when compared to pulsed ultrasound, as pulsing the ultrasound beam decreases the average intensity and thus reduces tissue heating. According to Baker et al[23] it is assumed that nonthermal effects will always be accompanied by some heating because the interaction between ultrasound and tissue is simultaneously thermal and mechanical. Conversely, acoustic fields that give rise to heating are always accompanied by nonthermal effects.[23] Pulsing the ultrasound beam reduces the temperature rise proportionately to the pulsing ratio; however it does not eliminate heating completely.

Table 2-2: Basic Therapeutic Ultrasound Applications[2]

Effect	**Temperature Increase**	**Indication**
Nonthermal	None 37.5° baseline	Acute injury, edema, healing
Mild Thermal	1 Degree C 38.5°	Subacute injury, Hematoma
Moderate Thermal	2 Degrees C 39.5°	Chronic inflammation, pain, trigger points
Vigorous Heating	4 Degrees C 41.5°	Stretch Collagen

Nonthermal effects of ultrasound are changes within the tissues resulting from the mechanical effect of ultrasonic energy.[24] Nonthermal effects are usually those associated with cavitation and acoustic microstreaming. The term cavitation is defined as the formation of gas-filled bubbles that expand and compress due to ultrasonically induced pressure changes in tissue fluids.[2,23] Acoustic microstreaming is described as the unidirectional movement of fluids around the boundaries of cell membranes resulting from the mechanical pressure wave in an ultrasonic field.[2,23]

It has been documented that nonthermal effects of therapeutic ultrasound are as important as thermal effects.[2] Nonthermal ultrasound is used when acute injuries are being treated or in cases when increasing the tissue temperature is undesirable. Nonthermal effects have been identified in soft tissue repair via the stimulation of fibroblastic activity, which produces an increase in blood flow in ischemic tissues.[2] As indicated by Starkey[24] pulsed ultrasound is often delivered with a 20 percent duty cycle and an output intensity of 0.5 W/cm^2, which may trigger a series of physiological events that stimulate the healing process. Application in this mode is reported to stimulate phagocytosis, increase the quantity of free radicals, alter cell membrane permeability, and accelerate fibrinolysis.[24]

Thermal effects are changes within the tissues as a direct result in the elevation of tissue temperature.[2,24] Thermal effects are those due to heating and are accepted as including increased metabolic activity, blood flow, and collagen extensibility as well as producing an analgesic effect on nerves.[2,23,24] It has been suggested that for these thermal effects to occur, the tissues must be elevated to at least 40°C for a minimum of five minutes.[2] However, it has been shown that temperature increases above 45°C may be potentially damaging to tissue, yet patients usually experience pain prior to these extreme temperature increases.[2]

Transducer Soundhead

An ultrasound transducer for therapeutic application usually consists of an air-backed piezoelectric element covered with a metallic layer.[20] The metallic layer has a thickness equal to the ultrasound wavelength that provides both mechanical protection and coupling.[20] A water based gel is used to couple the transducer to the body and to ensure good contact. Therapeutic ultrasound machines emitting without coupling are able to heat up the transducer surface within a few minutes to temperatures that if applied to a patient, could cause skin irritations or local skin burns.[20]

During the application of therapeutic ultrasound, it is easy to inadvertently increase the speed of the transducer soundhead. When this happens, the tissue being treated does not have enough time to absorb the energy, often resulting in an inadequate treatment or tissue damage. Moving the soundhead consistently during treatment leads to a more evenly distribution of energy within the treatment area. A frequency recommended rate for the movement of the transducer soundhead is 4 cm/second, covering a treatment area that is approximately 2 to 3 times the size of the effective radiating area of the transducer soundhead.[2,24,25] Overlapping circular motions or longitudinal stroking patterns are the most commonly used techniques for the soundhead movement.[2]

Effective radiating area (ERA) is a measure of the portion of an ultrasound transducer surface that is producing soundwaves.[26] The Food and Drug Administration standard for ERA measurements includes all transducer areas that are producing ≥ 5% of the maximum ultrasound intensity.[27] Draper and Ricard[11] state that when treating an area 2 times the ERA of the soundhead, it takes approximately 4 minutes to raise muscle temperature 4°C during 3 MHz continuous ultrasound at 2 W/cm^2.

During the administration of ultrasound, it is possible that the amount of pressure at the transducer soundhead may affect the physiological response and treatment outcome. Prentice[2] demonstrated that applying an excessive amount of pressure could elevate skin temperature, decrease acoustic transmission, damage the soundhead crystal, or make the athlete uncomfortable. Noble et al[3] reported that the movement of the transducer soundhead causes a massage-mediated thermal effect, which increases local skin temperature. To avoid these factors to the most degree, Prentice[2] recommends that a firm consistent pressure be applied to the soundhead during a therapeutic ultrasound treatment. Several devices such as a metronome or an AutoSound^{TM} therapeutic ultrasound unit can also be used to control and eliminate some of these extraneous factors.

A metronome is any device that produces a regulated pulse, whether audible, visual, or touch, and is used to establish a steady tempo in beats per minute.[15] A metronome can be used to regulate the movement speed of the transducer soundhead, which eliminates the human error of moving the transducer soundhead at various speeds during the application of a therapeutic ultrasound treatment.

An AutoSound^{TM} ultrasound unit is a therapeutic ultrasound machine that performs transducer movement by activating and deactivating four transducer cells, creating a hands-free ultrasound treatment. The AutoSound^{TM} can be used in time constraining situations as well as to ensure an equal and consistent delivery of acoustic energy; however, no objective comparisons between traditional ultrasound and the AutoSound^{TM} exist to date.

Indications and Contraindications for Therapeutic Ultrasound

When applied to biologic tissue therapeutic ultrasound may induce clinical responses in cells, tissues, and organs through both thermal and nonthermal biophysical effects.[2] Previous research[3,4] has demonstrated that therapeutic ultrasound is commonly applied in the management of numerous clinical conditions. Several indications for the use of therapeutic ultrasound are included in Table 2-3.[2] Therapeutic ultrasound is indicated for numerous conditions; however, there are also a number of treatment precautions to the use of therapeutic ultrasound. The contraindications for the use of therapeutic ultrasound are listed in Table 2-3.[2]

Table 2-3: Indications and Contraindications for Using Therapeutic Ultrasound[2]

Indications	***Contraindications***
Acute and post-acute conditions (ultrasound with nonthermal effects)	Acute and post-acute conditions (ultrasound with thermal effects)
Soft tissue healing and repair	Areas of decreased temperature sensation
Scar tissue	Areas of decreased circulation
Joint contracture	Vascular insufficiency
Chronic inflammation	Thrombophlebitis
Increase extensibility of collagen	Eyes
Reduction of muscle spasm	Reproductive organs
Pain modulation	Pelvis immediately following menses
Increase blood flow	Pregnancy
Soft tissue repair	Pacemaker
Increase in protein synthesis	Malignancy
Tissue regeneration	Epiphyseal areas in young children
Bone healing	Total joint replacements
Repair of nonunion fractures	Infection
Myositis osificans	
Plantar warts	
Myofascial trigger points	

Achilles Tendon Injuries

Most biologic tissues such as tendons and ligaments are classified as viscoelastic materials. Since tendons and ligaments often experience stretch and extension in a wide range of strain rates in the body, knowing the viscoelastic properties becomes important in assessing their mechanical integrity to prevent injuries as well as to maintain the normal physical motion of the body.[28] Thermal properties of ultrasound have been shown to increase elasticity and decrease the viscosity of collagen fibers allowing for greater residual length gains, while reducing the risk of damage through the applied stretching force.[25]

Achilles tendon injuries are among the most common ailments seen by orthopedic surgeons, affecting millions of active individuals in the United States today.[9] The Achilles tendon is prone to injury from the load placed on it compared to other tendons in the body. The Achilles tendon possess a relatively small cross sectional area yet experiences high levels of mechanical loading during normal physical activities, making the tendon susceptible to acute and chronic injuries.[29] Recent studies have contended that increasing the ankle dorsiflexion range of motion, specifically motion of the Achilles tendon, may reduce the risk of tendon injury.[9,10] According to several authors,[12,16] 3 MHz frequency is more appropriate than 1 MHz for heating the musculotendinous junction of the Achilles tendon. This is true because 3 MHz ultrasound is better absorbed at a more superficial level.

Stretching Window

The time period of vigorous heating when tissues undergo the greatest extensibility and elongation is referred to as the stretching window.[11] According to numerous authors,[11-13] the stretching window last approximately 2 to 4 minutes after the termination of a continuous therapeutic ultrasound treatment. This is crucial in the clinical setting, since the cooler the tissue becomes, the more resistant it is to stretching.

Based on previous research,[12-13,17] it is estimated that thermal ultrasound can increase temperature as much as 3°C to 6°C in muscle and 5°C to 8°C in tendon. Because these temperatures are maintained for only a few minutes,[11-13] it is believed that range of motion measurement must be taken immediately after an ultrasound treatment to get the maximum increase in connective tissue extensibility.

Not all connective tissues are alike, and the possibility exists that their heating and cooling rates may vary. It is believed that tendon, since it is a denser substance, will heat faster than muscle.[11] Since it is also less vascular than muscle, the possibility exists that tendon may cool at a slower rate than muscle, however the temperature decay in tendon has not yet been tested in humans.

Draper and Ricard[11] reported that after a 5°C temperature increase of the gastrocnemius muscle, the stretching window lasts, on average, 3.3 minutes after the termination of the ultrasound treatment. However, if the temperature were only raised 4°C, the stretching window would be open less than 2 minutes.[11] Rose et al[14] hypothesized that the stretching window might be different following a 1 MHz ultrasound treatment when compared to a 3 MHz ultrasound treatment. This is thought because a 1 MHz frequency focuses on deeper tissue than the 3 MHz frequency. The deeper tissue should retain heat longer since the overlying structures insulate and serve as a barrier to escaping heat.[14] According to Rose et al,[14] the temperature decay with a 3 MHz ultrasound frequency was 1°C in 1 minute, 20 seconds, compared to a 1°C drop in 2 minutes, 34 seconds using a 1 MHz ultrasound frequency. However, Draper and Ricard[11] reported that after a 3 MHz continuous ultrasound treatment it took 18 ± 3.5 minutes for the temperature to go from peak to original baseline temperature.

Range of Motion

Range of motion is a commonly used measure of flexibility, which may be increased with changes in the viscoelastic properties of muscles and tendons.[9] Park and Chou[9] demonstrated that limited ankle dorsiflexion range of motion was found to be predictive of acute and chronic injuries. Poor flexibility has been demonstrated to increase the risk of ankle injuries by two and half times.[9] Recent studies[9,10] have shown that heating does change the viscoelastic properties of muscle and tendon, which may ultimately increase range of motion, thus reducing the incidence of injury.[9]

After injury or immobilization, connective tissue progressively shortens, often causing joint contractures and adhesions that restrict joint range of motion.[12] When injury occurs the main goal in rehabilitation is to restore the normal joint range of motion. This can be accomplished by increasing tissue temperature to increase extensibility, which will ultimately increase range of motion.

Therapeutic ultrasound is a modality commonly used in the athletic and rehabilitation setting to treat numerous musculoskeletal conditions, specifically those regarding range of motion. An important goal in any treatment or rehabilitation protocol is to attain full range of motion. There may be several limiting factors such as joint contractures, scar tissue, and adhesions that make reaching this goal difficult.[11] Therapeutic ultrasound is a modality that is often used to aid in reaching this goal.

Therapeutic ultrasound performed with thermal effects is a common practice thought to lengthen connective tissue and improve range of motion.[12,17,18] When ultrasound is used to vigorously heat tissues (≥ 4°C), the tissues become more pliable.[11,12] The higher the temperature, the more likely the decrease in the viscous properties of collagen, which allows for optimal lengthening and flexibility of connective tissue.[12] Recent research[11,13,17] shows that continuous ultrasound can increase temperatures in human muscle and tendon to therapeutic levels. Wessling et al[30] found that ultrasound applied to the muscle belly before stretching promoted significantly greater immediate gains in ankle dorsiflexion than stretching alone. However, their changes were quite small (1° to 2.5°) by clinical standards.[30] Draper et al[12] found that thermal ultrasound increased ankle dorsiflexion range of motion about 3° (an 11% increase) over nine treatments sessions.

Therapeutic ultrasound machines come from a variety of manufacturers and include a vast number of technical parameters that must be adjusted for treatment. Two studies[22,31] recently indicated that all therapeutic ultrasound machines do not produce consistent or similar heating effects. Since manufacturers do not publish heating guidelines for ultrasound units, clinicians are left to generalize treatment parameters for specific conditions. According to Hayes et al[6] the ultrasound treatment parameters of 3 MHz continuous ultrasound at an intensity of 1.5 W/cm^2 produced vigorous heating (≥ 4°C) in 4.13 ± 1.69 minutes. Reed and Ashikaga[18] reported that thermal ultrasound significantly increased ligament extensibility on human knees. The authors concluded that clinical ultrasound parameters of 1 MHz continuous ultrasound at 1.5 W/cm^2 for 8 minutes increased the extensibility of the lateral and medial collateral ligaments.[18] A study performed on human muscle by Draper et al[32] has shown that following a 10 minute treatment of 1 MHz continuous ultrasound at an intensity of 1.5 W/cm^2 increased the temperature of the gastrocnemius muscle by 5°C. Although these technical parameters range through a variety of settings, a standard therapeutic ultrasound setting for this particular study has been predetermined according to the prior research.

Goniometer

The goniometric measurement of ankle joint range of motion is used in everyday clinical practice. As an evaluative measure, goniometry is used to assess change in status over time that occurs in conjunction with various treatment interventions.[33] The results are usually compared with previous measurements or with those on the opposing side.

For goniometric measures to be interpreted and used in clinical practice, it is important for the clinician to understand the reliability and responsiveness of these measures. Reliability is defined as the reproducibility or consistency of a measure.[33] Intrarater reliability describes the consistency of repeated measurement taken by the same clinician.[33] If intrarater reliability is demonstrated, then one can have confidence in the accuracy of the measurement compared with other measurements by the same clinician under similar conditions. For clinical research studies it is important to show reliability in all aspects of the procedure, which is where intrarater reliability becomes extremely important.

For proper evaluations of a joint to occur, the accurate measurement of range of motion is required. The precise assessment of joint range of motion, particularly joints with short, complex adjacent segments and poor landmarks for alignment, such as the ankle joint, can be difficult to measure.[34] Even when trained examiners are used, joint range of motion measurements have been shown to have poor intrarater reliability.[34] The repeatability of these measures depends on a number of factors, including the experience of the examiner, the technique used in the assessment, the participants studied, and the device used.[34]

According to prior research,[10,35] the standard technique for measuring ankle joint dorsiflexion is as follows: with the hip and knee joint both flexed at a 90° angle, the foot is placed in the neutral position while markings are made over the head of the fibula, the lateral malleolus, and along the fifth metatarsal. Weaver et al[34] defines zero degrees of dorsiflexion or “neutral” as the ankle position where the talocrural joint is at a 90° angle. The short-sit position is also proven best because gastrocnemius muscle tightness may limit ankle joint dorsiflexion when the knee is in an extended positon.[36] The stationary arm of the goniometer is aligned with the mark on the head of the fibula, the axis is positioned 0.5 cm below the lateral malleolus, and the moving arm is aligned with the markings along the fifth metatarsal. Prior research,[10,35] indicates that this goniometric measurement technique was found to be valid and reliable.

During range of motion assessments it is important to be consistent and as accurate as possible in all aspects of the procedure. Investigators[34,37] found that uncontrolled motion at the subtalar joint can produce apparent plantarflexion or dorsiflexion of the talocrural joint. They also reported that incomplete relaxation of the muscles during examination can give the erroneous impression of an endpoint, and result in the inaccurate recording of maximum ankle joint positon.[34]

Summary

Therapeutic ultrasound is a modality that is often used in the athletic and rehabilitation setting to treat numerous musculoskeletal injuries;[2-4] with its thermal effects often being used to increase tissue extensibility.[1,2,9,25] It is believed that increasing the thermal capacity of muscle and tendon changes the viscoelastic properties of these tissues, which ultimately reduces the incidence of injury.[9] It is also believed that limited ankle dorsiflexion range of motion is predictive of acute and overuse injuries. Therefore, recent studies[9,10] have contended that increasing ankle dorsiflexion range of motion, specifically through extensibility of the Achilles tendon, may reduce the risk of tendon injury.

According to numerous authors,[11-13] the stretching window last approximately 2 to 4 minutes after the termination of a continuous therapeutic ultrasound treatment. This is crucial in the clinical setting, since the cooler the tissue becomes, the more resistant it becomes to stretch. Because these temperatures are maintained for only a few minutes,[11-13] it is believed that range of motion measurement must be taken immediately after an ultrasound treatment to get the maximum increase in connective tissue extensibility.

Due to several gaps in prior research, this study aims to measure the range of motion of ankle dorsiflexion inside and outside the stretching window. It hopes to prove that heating the Achilles tendon via a thermal ultrasound treatment will significantly increase ankle dorsiflexion range of motion, as well as determine if the increase in motion is maintained outside the standard stretching window.

CHAPTER THREE

METHODS

Participants

Thirty-two participants were recruited on a volunteer basis for participation in the study. The participants consisted of current male and female students at Barry University. The Institutional Review Board at Barry University approved the recruitment and experimental procedures for this study (Appendix A). For recruitment purposes, flyers containing general information about the study and contact information of the researcher were placed around the Barry University campus (Appendix B). Once contacted, the researcher met with each participant to discuss the research study and the process of volunteering. Each participant was ensured that their identification would be kept private and the data collected would not be used for any other purpose besides in this particular study. After the participants agreed to volunteer a pre-participation screening questionnaire was administered (Appendix C). All participants had to be free of any right lower extremity injury in the last six months in order to participate in the study. Additionally, each participant had to report no contraindications to a therapeutic ultrasound treatment; otherwise they were excluded from participation. Once participation was granted, all participants read and signed an informed consent form (Appendix D) before the study was begun.

The participants were randomly allocated to either group A (n=16) or group B (n=16). Group A was the treatment group, which received a therapeutic thermal ultrasound treatment. Group B was the control group, which received a placebo ultrasound treatment. Three pre-test and post-test active and passive ankle dorsiflexion range of motion measurements were performed on each participant. There were also three repeated measurements of active and passive ankle dorsiflexion range of motion following an 8 minute temperature decay time. The results were then analyzed and compared once the data was fully collected.

Pre-Participation Screening

All participants filled out a pre-participation screening questionnaire that included age, gender, and previous medical history to ensure there were no contraindications to a therapeutic ultrasound treatment. If the participant reported any previous injury in the last six months to the right leg or contraindications to a therapeutic ultrasound they were excluded from participation due to limitations of the research study. Each participant accepted to the study scheduled a date and time with the researcher to perform the testing session.

Materials and Instruments

All measures of ankle dorsiflexion range of motion were performed with one 12 ½ in clear plastic universal goniometer (Jamar, Duluth, GA) with 1° increments. Each measurement was performed and recorded by the same investigator in order to provide good interrelater reliability. Each measurement was then repeated three times and the mean was used for statistical analysis.

All therapeutic ultrasound treatments were administered using the same Rich-Mar® Theratouch 7.7 ultrasound unit (Rich-Mar Corp, Inola, OK) that was last calibrated September 2007. The ultrasound unit can be operated at frequencies of 1 and 3 MHz and has both a 2 and 5 cm^2 transducer head size. The transducer head houses a lead zirconate titanate crystal. The manufacturer reports an average beam-nonuniformity ratio of 5:1 or less and an effective radiating area of 4.5 cm^2. To ensure accuracy in this study, the same investigator performed all ultrasound treatment sessions using the same ultrasound unit.

A quartz metronome (Franz, New Haven, CT) was set at 4 cm/sec, which was used to regulate the movement speed of the transducer soundhead during the application of the ultrasound treatments.

For all participants, a standardized amount (3 mL) of room temperature Aquasonic® 100 ultrasound transmission gel (Parker Laboratories, Fairfield, NJ) was used as the coupling agent for the ultrasound treatments.

Procedures

The study used a thermal therapeutic ultrasound treatment as an indicator of increasing ankle dorsiflexion range of motion. Three pre-test and post-test active and passive ankle dorsiflexion ranges of motion measurements were taken to determine any change in motion. Three repeated measurements of active and passive ankle dorsiflexion range of motion were also taken following an 8 minute cool down time. Each of the 32 participants was randomly assigned to one of two groups; a treatment group (A) and a control group (B).

Participants were instructed to wear gym shorts to allow for comfort and easy access to bony landmarks. Participants were instructed to short-sit on the edge of a standard padded treatment table with the hip and knee joints both at a 90 degree angle. Markings were then placed over the head of the fibula, 0.5 cm below the lateral malleolus, and along the fifth metatarsal of the right foot. The goniometer was then properly positioned according to the identified markings (Fig. 3-1). The stationary arm of the goniometer was aligned with the mark on the head of the fibula. The axis of the goniometer was positioned 0.5 cm below the lateral malleolus and the moving arm was aligned with the markings along the fifth metatarsal. The participant was then instructed to actively dorsiflex their right ankle to a maximal degree while the range was measured. While the participant was dorsiflexing the right ankle joint, the researcher was stabilizing the goniometer while measuring the participant's degree of active ankle dorsiflexion. This was then repeated three times and the results were recorded on the data collection sheet (Appendix E).

Following the active range of motion measurements, three passive ankle dorsiflexion range of motion measurements were taken. The participant continued to short-sit on the treatment table while the goniometer was accurately positioned according to the prior markings on the right leg. The participant was instructed to relax as much as possible while the investigator passively moved the right ankle into maximal ankle dorsiflexion. While moving the right ankle into passive dorsiflexion the research investigator simultaneously stabilized and moved the goniometer while measuring the participant's maximal degree of passive ankle dorsiflexion. This was then repeated three times and the results were recorded on the data collection sheet.

Following the pre-test range of motion measurements the participant was instructed to lie prone on a padded treatment table. A pillow was placed under the right distal shin to allow the ankle to rest in a neutral position. The treatment site began at the musculoskeletal junction of the right triceps surae, extending 9 cm above the calcaneal insertion point. The treatment area was approximately two times the size of the effective radiating area of the transducer head. To ensure that the treatment size was equal for all subjects, a 9 cm x 5 cm template was cut and placed onto the skin overlying the ultrasound treatment site at the triceps surae musculotendinous unit (Fig. 3-2). A standardized amount (3 mL) of room temperature Aquasonic® 100 ultrasound transmission gel (Parker Laboratories, Fairfield, NJ) was placed directly on the skin within the template to serve as the coupling agent for the ultrasound treatment.

The goal of the ultrasound treatment was to vigorously heat the tissue of the Achilles tendon so that a maximal ankle dorsiflexion range of motion could be achieved. To accomplish this therapeutic ultrasound was administered to the treatment group (A), using the following treatment parameters: frequency = 3MHz, intensity = 1.5 W/cm^2, continuous duty cycle, treatment area = twice the size of the transducer head faceplate. The ultrasound treatment was performed for 8 minutes, unless the participant reported any discomfort during the treatment session, in which the treatment was discontinued immediately. For the control group (B), the transducer head was moved over the treatment area but the ultrasound unit was not turned on, and no acoustic energy was delivered to the tissue. The ultrasound transducer was moved using a longitudinal stroking motion within the template at a rate of 4 cm/s as previously established.[6,8,14] A quartz metronome (Franz, New Haven, CT) was used to regulate the movement speed of the ultrasound transducer soundhead. Upon completion of the ultrasound treatment, the tissue was cleansed of the ultrasound gel.

Immediately after each ultrasound treatment session the participant short-sat on the side of the treatment table while three trials of each active and passive ankle dorsiflexion range of motion were remeasured within the stretching window. The investigator aligned the goniometer with the landmark markings previously established for the pre-test measurement. The participant was then instructed to actively dorsiflex the right ankle to a maximal degree while the range was measured. The investigator stabilized the goniometer while measuring the participant’s degree of active ankle dorsiflexion. This was then repeated three times and the results were recorded on the data collection sheet. Next, three passive ankle dorsiflexion range of motion measurements were taken. The participant continued to short-sit on the treatment table while the goniometer was accurately positioned according to the markings on the right leg. The participant was instructed to relax as much as possible while the investigator passively moved the right ankle into maximal ankle dorsiflexion. While moving the right ankle into passive dorsiflexion the investigator was simultaneously stabilizing and moving the goniometer while measuring the participant’s maximal degree of passive motion. This was then repeated three times and the results were recorded on the data collection sheet.

Following the post-treatment ultrasound measurements each participant was instructed to sit comfortably on the same treatment table for 8 minutes, avoiding movement of the right lower leg. After the 8 minute delay time following the ultrasound treatment, each participant resumed the short-sit position on the side of the treatment table while three trials of both active and passive ankle dorsiflexion range of motion were remeasured. The investigator aligned the goniometer with the landmark markings previously established. The participant was then instructed to actively dorsiflex the right ankle to a maximal degree while the range was measured. The investigator stabilized the goniometer while measuring the participant’s degree of active ankle dorsiflexion. This was then repeated three times and the results were recorded on the data collection sheet.

Next, three passive ankle dorsiflexion range of motion measurements were taken. The participant continued to short-sit on the treatment table while the goniometer was accurately positioned according to the markings on the right leg. The participant was instructed to relax as much as possible while the investigator passively moved the right ankle into maximal ankle dorsiflexion. While moving the right ankle into passive dorsiflexion the investigator simultaneously stabilized and moved the goniometer while measuring the participant's maximal degree of passive motion. This was then repeated three times and the results were recorded on the data collection sheet.

Study Design Analysis

A repeated measure multiple analysis of variance (MANOVA) was be used to determine statistical significance ($p < 0.05$) between treatment groups. This compared the multivariate mean of each of the three pre-test, post-test, and post 8 minute delay measurements for passive and active ankle dorsiflexion range of motion. Post-hoc tests were then run to determine if differences existed between dependent variables.

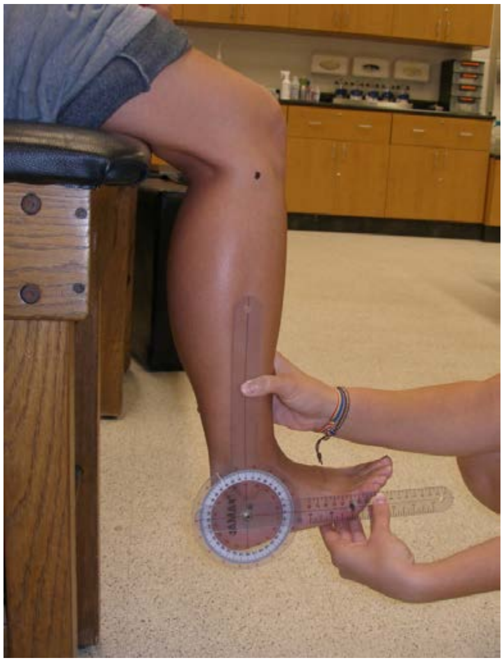


Fig. 3-1: Goniometer Placement

Fig. 3-2: Ultrasound Application

CHAPTER 4
RESULTS

The purpose of this study was to determine whether thermal ultrasound on the Achilles tendon effects active and passive ankle dorsiflexion range of motion inside and outside the stretching window. Twenty-four females and eight males (N=32), with a mean age of 21.13 years, qualified and agreed to participate in the study. All participants met the criteria of: (a) a current Barry University student, (b) no lower extremity injury in the last six months to the right leg, and (c) reported no contraindications to a therapeutic thermal ultrasound treatment. All participants took part in the study on a volunteer basis and could elect to cease participation at any time.

Participants were randomly assigned to one of two groups: treatment group (A) and control group (B). Sixteen participants were in the treatment group and sixteen were in the control group. Participants in both groups performed three pre-test, post-test, and post 8 minute active and passive ankle dorsiflexion range of motion measurements, which were analyzed and compared.

A repeated measure multiple analysis of variance (MANOVA) was used to determine statistical significance ($p < 0.05$) between groups over time. This compared the multivariate mean of each of the three pre-test, post-test, and post 8 minute delay measurements for passive and active ankle dorsiflexion range of motion, which is illustrated in Table 4-1. Post-hoc tests were then run to determine if any differences existed between the dependent variables; active and passive ankle dorsiflexion range of motion.

Table 4-1: Mean Active and Passive Ankle Dorsiflexion Range of Motion over Time

Treatment Group		Mean (Degrees)	Std. Deviation	N
Pre AROM	A	11.58°	2.67	16
	B	13.54°	5.19	16
	Total	12.56°	4.18	32
Post AROM	A	14.08°	3.00	16
	B	13.85°	5.11	16
	Total	13.97°	4.12	32
Post 8 AROM	A	12.77°	3.23	16
	B	13.59°	5.02	16
	Total	13.18°	4.17	32
Pre PROM	A	16.63°	2.93	16
	B	17.88°	5.01	16
	Total	17.25°	4.08	32
Post PROM	A	18.75°	3.18	16
	B	17.69°	4.90	16
	Total	18.22°	4.10	32
Post 8 PROM	A	16.94°	2.88	16
	B	17.36°	5.30	16
	Total	17.15°	4.20	32

Note: AROM = Active Range of Motion, PROM = Passive Range of Motion
Group A = Treatment Group, Group B = Control Group

The repeated measures MANOVA found a significant multivariate interaction between treatment groups and measurement times for both active and passive ankle dorsiflexion range of motion; $F(4,27) = 16.61$, $p < 0.001$. Therefore, the null hypothesis which states, there will be no significant difference between groups over time in active and passive ankle dorsiflexion range of motion after a therapeutic thermal ultrasound treatment was rejected.

When looking at range of motion alone, regardless of the treatment group, there was some significance shown in active and passive ankle dorsiflexion range of motion over time. Active range of motion showed a significant difference between pre-test and post-test range of motion measurements, post-test and post 8 minute test measurements, and pre-test and post 8 minute test measurements, regardless of the treatment group. Passive range of motion showed a significant difference between pre-test and post-test range of motion measurements and post-test and post 8 minute test measurements, regardless of the treatment group. However, there was no significant difference found between pre-test and post 8 minute test measurements with passive range of motion, regardless of the treatment group. When comparing the range of motion changes in regards to the treatment (A) and control (B) groups there was no significant differences found in the range of motion changes. Figure 4-1 shows the changes in active range of motion between the treatment (A) and control (B) groups over time. While figure 4-2 shows the changes in passive range of motion between the treatment (A) and control (B) groups over time.

Fig. 4-1: Active Range of Motion between Treatment Groups over Time

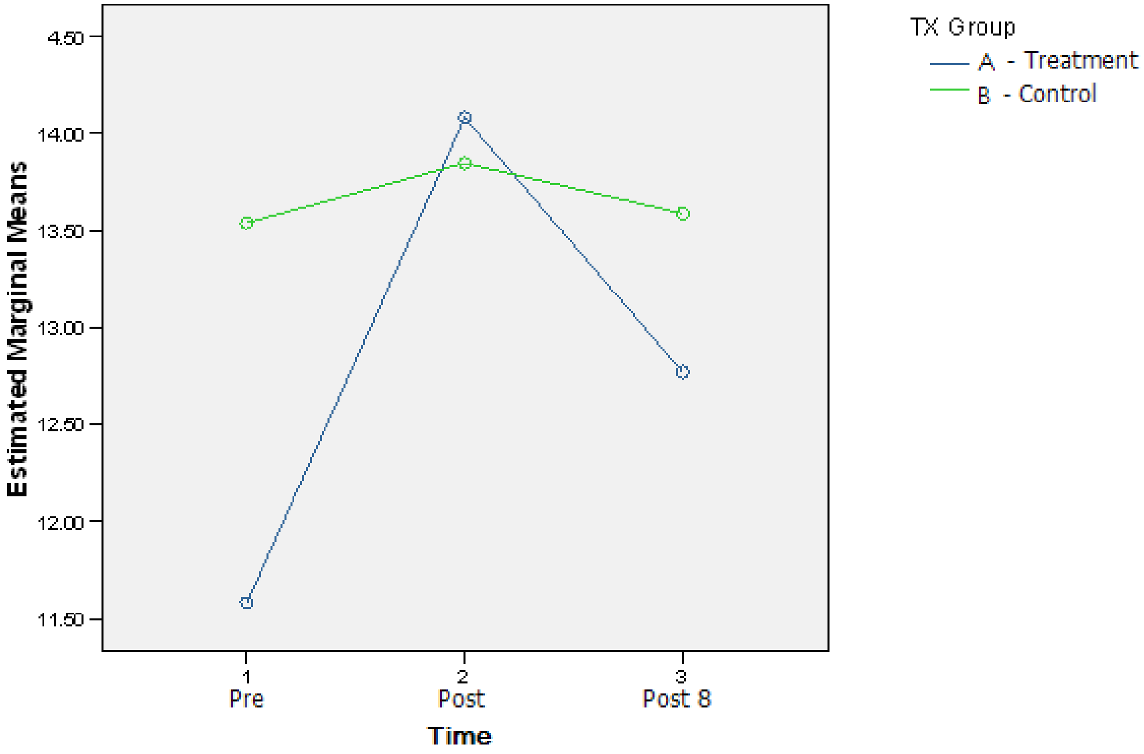
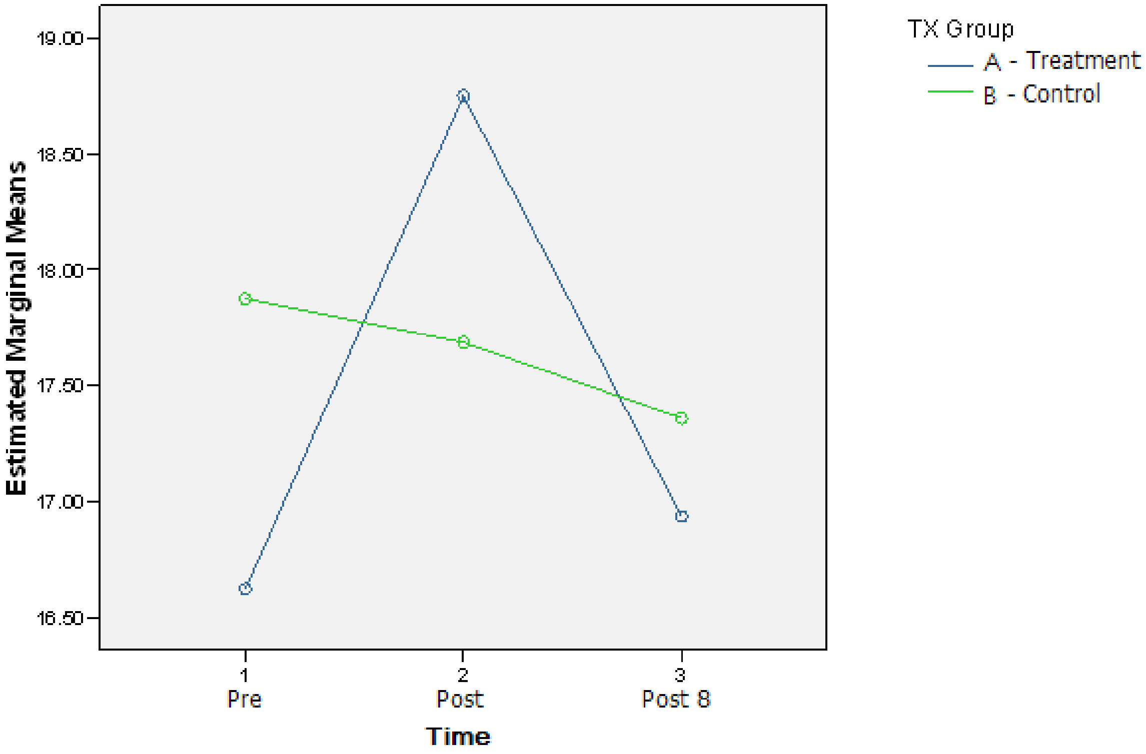


Fig. 4-2: Passive Range of Motion between Treatment Groups over Time



Figures 4-1 and 4-2 graph the changes in active and passive ankle dorsiflexion range of motion between treatment groups over the different measurement times. Group A had an average of 11.58 ± 2.67 and 16.63 ± 2.93 degrees for pre-test active and passive ankle dorsiflexion range of motion, respectively; whereas group B averaged 13.54 ± 5.19 and 17.88 ± 5.01 degrees. Post-test measurements were averaged at 14.08 ± 3.00 and 18.75 ± 3.18 degrees for group A, and at 13.85 ± 5.11 and 17.69 ± 4.90 degrees for group B. The 8 minute post treatment measurements were averaged actively and passively at 12.77 ± 3.23 and 16.94 ± 2.88 degrees for group A, and at 13.59 ± 5.02 and 17.36 ± 5.30 degrees for group B. As previously stated there was significance found in both active and passive range of motion measurements over time regardless of the treatment group; however, there was no significance found when comparing the two treatment groups over time. The graphs and data show no statistical significance; however they both clearly show a clinical difference in range of motion changes over measurement times.

When comparing active and passive range of motion for both the treatment (A) and control (B) groups there was a significantly greater increase in passive range of motion over active range of motion at all measurement times. This accepts hypothesis number three, which states, there will be a significantly greater increase in passive range of motion over active range of motion with ankle dorsiflexion after the application of a therapeutic thermal ultrasound treatment, when compared to a control group.

In summary, there was a significant multivariate interaction within both the treatment and control groups over time for both active and passive ankle dorsiflexion range of motion. There was also a significant increase in passive ankle dorsiflexion range of motion over active range of motion. However, when univariate tests were run there was no statistical significance found between the two treatment groups over time. Statistically, this study showed no significant increases in range of motion in regards to a therapeutic thermal ultrasound treatment when compared to a control group; however, a clinical increase was noted, which could be beneficial in the field of athletic training.

CHAPTER 5
DISCUSSION

Purpose of the Study

The purpose of this study was to determine whether thermal ultrasound on the Achilles tendon effects active and passive ankle dorsiflexion range of motion inside and outside the stretching window. It compared the mean of three pre-treatment, post-treatment, and 8 minute post-treatment range of motion measurements of ankle dorsiflexion in regard to a single therapeutic ultrasound treatment.

Results Related to Hypotheses

The results of this study revealed that a single therapeutic thermal ultrasound treatment showed a significant interaction within both the treatment and control groups over time for both active and passive ankle dorsiflexion range of motion. However, the therapeutic ultrasound treatment did not significantly increase range of motion between the two treatment groups over time. This means that a therapeutic thermal ultrasound treatment does significantly and individually increase active and passive ankle dorsiflexion range of motion from pre-test to post-test and post-test to post 8 minute test measurements. It also means that a single therapeutic thermal ultrasound treatment does not increase ankle dorsiflexion range of motion significantly more when compared to a control group.

These results indicate that when an increase in tendon extensibility is needed, either actively or passively, a therapeutic thermal ultrasound treatment can be used to achieve these results. However, an increase in tendon extensibility can also be achieved under the treatment conditions of the control group. This was possibly found to be true due to several factors. The increase in range of motion for the treatment group was likely confirmed due to the previously established and published effects of therapeutic thermal ultrasound.[2] The increase in range of motion for the control group could likely be due to the soundhead movement of the placebo ultrasound treatment. Although no acoustic energy was produced during the treatment, the soundhead movement may have created a thermal mediated massage effect, which increased blood flow and ultimately lead to an increase in tissue extensibility. Another factor that may have contributed to the significant increase in ankle dorsiflexion range of motion in the control group could have been due to the randomization order of the participants in each treatment group. Participants were randomized by alternating every other participant into the same treatment group. Also, several participant investigations were conducted each day. Since the treatment group alternated with each participant and no time was scheduled between each treatment session, the temperature of the ultrasound soundhead may have remained elevated from the prior treatment. This temperature elevation may have contributed to raising the tissue temperature more than expected, especially when a placebo ultrasound treatment was performed immediately after a thermal ultrasound treatment.

We have shown that a significant increase in ankle dorsiflexion range of motion was not achieved through a single therapeutic thermal ultrasound treatment when compared to a control group. Yet, there was an apparent clinical increase in range of motion seen in the treatment group over the control group. This proves that a therapeutic thermal ultrasound treatment does heat tissue to some degree; however it was not proven to heat tissue to the beneficial degree previously established in prior research.[2]

This study also revealed that there was a significant increase in passive ankle dorsiflexion range of motion over active range of motion. This finding supported the original hypothesis that passive ankle dorsiflexion range of motion would be significantly greater than active ankle dorsiflexion range of motion at all measurement times. The most apparent reasoning for this outcome is that range of motion, regardless of the joint, is greater when performed passively than actively by approximately five degrees.[38]

Applicability

Based on the results of this study it was shown that ankle dorsiflexion following a therapeutic thermal ultrasound treatment increased range of motion significantly; however there was also a significant increase in range of motion found in the placebo treatment group. It was also shown that active ankle dorsiflexion range of motion was significantly maintained after an 8 minute cool down period following a therapeutic thermal ultrasound treatment. However, there was no significantly maintained increase in passive ankle dorsiflexion range of motion following the 8 minute post treatment measurements. These results only half support prior research[11-13] on the stretching window. Since an increase in range of motion is technically only maintained 2 to 4 minutes following the termination of a therapeutic thermal ultrasound treatment;[11-13] we can conclude that there are no performance benefits achieved in healthy tissue from a therapeutic thermal ultrasound treatment. For performance benefits to be achieved the range of motion gains would have to be maintained for a much longer period than established. Although there are no performance benefits achieved, thermal ultrasound can show promising results on unhealthy tissue. When dealing with patients who have scar tissue build-up or limited range of motion after a cast removal, a thermal ultrasound treatment should be incorporated into their beginning stages of rehabilitation. According to this study there were averages of 2.50 and 2.12 degrees of ankle dorsiflexion range of motion actively and passively following a therapeutic thermal ultrasound treatment. Although these increases may not have been significant, an increase of more than two degrees of ankle dorsiflexion can be clinically beneficial when dealing with a joint that has baseline range of motion measurements of 12.56 and 17.25 degrees actively and passively.

This study showed a significant increase within both active and passive ankle dorsiflexion ranges of motion, as well as a significantly maintained increase in active range of motion and clinical increases in both active and passive ranges of motion at the 8 minute post treatment measurements. Why there is a maintained increase in active over passive range of motion is a question that should be further investigated with future research. Looking at the data from this study, we conclude that the maintained increase in active over passive range of motion is attributed to the minimal beginning range of ankle dorsiflexion. The therapeutic thermal ultrasound treatment for group A may have elevated the baseline tissue temperature enough to increase the active range of motion to the point of the baseline passive range. It is hard to explain this particular finding because there is no other research to date that remeasures ankle dorsiflexion outside the stretching window. With these results, there is still justification for the use of a therapeutic thermal ultrasound treatment. Since the thermal effects only last for 2 to 4 minutes, clinical treatment must be performed within this limited time frame. The clinical benefits of a therapeutic thermal ultrasound treatment have been seen when used in the aspect of rehabilitation. According to this study and prior research,[30] we know that range of motion is significantly gained immediately after a thermal ultrasound treatment. Since there are significant gains noted it may be beneficial to perform range of motion exercises or joint mobilizations immediately following and within this stretching window. This study only looked at the range of motion gains following a single therapeutic thermal ultrasound treatment, but according to other research[12] these gains are permanently maintained following a series of thermal ultrasound treatments. There were promising results found from this study; however, this particular study does not change anything we already know and practice in the field of athletic training.

Applications and Past Research

Choosing the appropriate therapeutic modality for individual athletes is essential in the field of athletic training. Whether ultrasound is being used for prophylactic measures or in the treatment of acute and chronic injuries the appropriate settings must be used. According to prior research,[2,6,11,18] a continuous ultrasound treatment using a 3 MHz frequency, 1.5 W/cm^2 intensity, at an 8 minute duration, significantly increased the range of motion of ankle dorsiflexion. Vigorous heating ($\geq 4°C$) performed with therapeutic ultrasound is often used in an effort to lengthen connective tissue. This study proved that fact clinically, yet not significantly. Although the same ultrasound parameters in each study were applied, the differences may be due to various ultrasound devices being used. Each device reports its own calibrations, which can not always be exact with one another.

The availability of methods to increase the extensibility of tissue is vast in the field of athletic training. Therapeutic thermal ultrasound is only one of many modalities used to aid in increasing joint range of motion. Numerous studies[8,12,14,30] have reported the effects of thermal ultrasound in conjunction with other heating modalities and stretching routines. Wessling et al[14] found that static stretching following a thermal ultrasound treatment increased muscle extensibility by 20 percent over stretching alone. The current study was limited to only a single therapeutic thermal ultrasound treatment per participant. Using other thermal modalities or stretching interventions along with a thermal ultrasound treatment may contribute to a larger and perhaps significant increase in ankle dorsiflexion range of motion.

When measuring range of motion, specifically at small joints such as the ankle, range of motion measurements have been shown to have poor intrarater reliability.[34] This study demonstrated intrarater reliability by having the same clinician measure and record all range of motion measurements. Although intrarater reliability was good, this study lacked the help of a second examiner to assist in the passive range of motion measurements. Having a single examiner simultaneously find subtalar neutral, position and move the goniometer, and apply a passive force in the direction of dorsiflexion may have been too much for one examiner to effectively perform.

The time period of vigorous heating when tissues undergo the greatest extensibility and elongation is referred to as the stretching window.[11] The stretching window has been reported to last approximately 2 to 4 minutes after the termination of a continuous therapeutic ultrasound treatment;[11-13] however, current research[11,14] has reported otherwise. Due to the variance of the exact stretching window, this study aimed to measure ankle dorsiflexion range of motion immediately and 8 minutes after the termination of a therapeutic ultrasound treatment. Eight minutes was chosen because it was double the maximum stretching window time frame. The results of this study showed a significantly maintained increase in active range of motion from pre-test to post 8 minute measurements. However, there was not a significantly maintained increase in passive range of motion from pre-test to post 8 minute measurements between the treatment and control group.

Uniqueness

This study is unique because previous studies such as those performed by Draper et al,[11,32] tested the gastrocnemius and soleus muscle bellies instead of the triceps surae musculotendinous junction. No studies to date have tested ankle dorsiflexion range of motion before and after a therapeutic thermal ultrasound treatment at the musculotendinous junction. This study also checked range of motion measurements inside and outside the stretching window. Again, no other studies have remeasure ankle dorsiflexion range of motion after a specified cool down period, which extends outside the stretching window.

Limitations

There were a few limitations in the methods of this study. To begin with, it was assumed that critical temperatures were reached in the tissues being treated. Since tissue temperature was not measured, we do not know for certain that the appropriate therapeutic levels were achieved. The cooling mechanism of living tissue, which was not accounted for, may also have prohibited temperature increases of this nature to be reached and maintained. In addition, we also treated a relatively small area. The gastrocnemius-soleus complex is a very large muscle group, and the musculotendinous junction is hard to define and treat with an ERA of only two times.

In this study the primary investigator was not blinded to the participant groups, so some investigator bias may have been introduced. Investigator bias would have been more likely during the passive ankle dorsiflexion range of motion measurement because the investigator controlled the passive dorsiflexion force applied to the participants. This investigator bias could be eliminated with the use of a dynamometer, which is used to measure passive torque as each subject's ankle was moved from plantarflexion into dorsiflexion.

Finally, the participant sample was conveniently selected from a healthy population of college students, thus the results can not be generalized to the entire population. Also, our participants already possessed, on average, 12.52 ± 4.18 and 17.25 ± 4.08 degrees of active and passive ankle dorsiflexion as a baseline measurement, which perhaps left little room for range of motion gains. If the participants had been taken from a population limited in ankle dorsiflexion range of motion due to contractures or adhesions, the results might have been different.

Recommendations for Future Research

1. Replicate this study using a secondary examiner to find subtalar neutral and passively dorsiflexion the ankle joint while the primary investigator measures the

degree of range of motion. The secondary examiner should also be blinded to the participant treatment group so that a bias will not occur.

2. Replicate the study with an implemented time period between treatment sessions for a cool down of the ultrasound machine to occur.
3. Repeat the study by adding participants with limited ankle dorsiflexion range of motion and compare those with healthy participants.
4. Replicate this study in conjunction with other thermal modalities or stretching routines and compare with that of a therapeutic thermal ultrasound treatment alone.
5. Replicate the study using a series instead of just a single therapeutic thermal ultrasound treatment and average the series of data findings.
6. Replicate this study using a microprobe to measure the exact tissue temperature of the triceps surae musculotendinous complex.

Conclusion

In summary, this study revealed that a single therapeutic thermal ultrasound treatment showed a significant interaction within both the treatment and control groups over time for both active and passive ankle dorsiflexion range of motion. However, the therapeutic ultrasound treatment did not significantly increase range of motion between the two treatment groups over time. This study also revealed that there was a significant increase in passive ankle dorsiflexion range of motion over active range of motion.

There were a few limitations in this study, which could be eliminated if the study was replicated following the requested recommendations for future research. Although several hypotheses were rejected, there were still promising results found from this study. However, this particular study does not change anything we already know and currently practice in the field of athletic training.

APPENDICIES

APPENDIX A

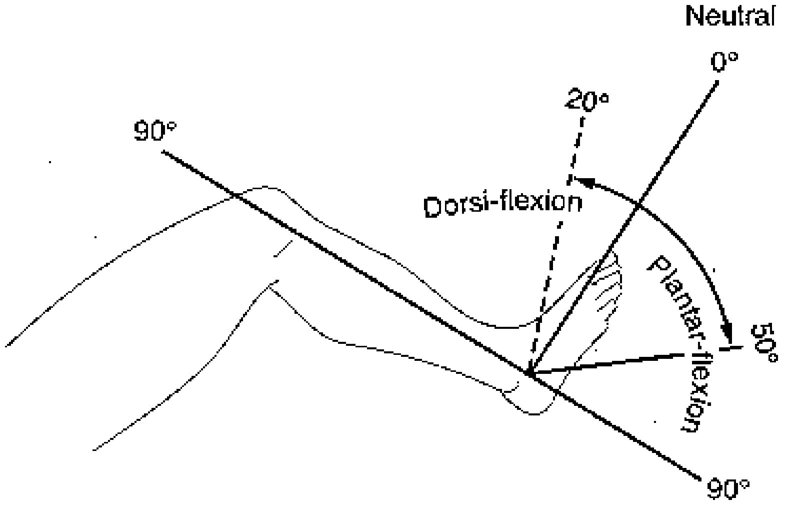
IRB Approval Letter

APPENDIX B

Informational Flyer

NOW SEEKING 40 BARRY UNIVERSITY STUDENTS TO PARTICIPATE IN A RESEARCH STUDY

This study will investigate the effects of thermal ultrasound on range of motion of the ankle joint



Interested students should be injury free to their right ankle in the last six months and have no contraindications to thermal ultrasound. The testing session will take approximately 25 minutes on a one time trial basis.

If interested, please contact:

Marti Greer, LAT, ATC, RT(R)
Graduate Assistant Athletic Trainer
(859) 539-2886
or in the
Barry University
Athletic Training Room

*** infection, malignancy, decreased circulation, decreased sensation, pacemaker, metal implants**

APPENDIX C

Pre-Participation Questionnaire

Pre-Participation Questionnaire

Identification Number: ____________________ Age: ____________________

Gender: __________________________________

1. **Have you had any injuries to the lower extremity in the last six months?**

   Yes _______ No _______

   If yes, what were the injuries and when did they occur?

2. **Have you ever received a therapeutic ultrasound treatment?**

   Yes _______ No _______

3. **Please check any conditions that a physician has told you, you may have:**

   _____ Acute or post-acute injuries

   _____ Areas of decreased temperature sensation

   _____ Areas of decreased circulation

   _____ Vascular insufficiency

   _____ Thrombophlebitis

   _____ Pacemaker

   _____ Total joint replacement

   _____ Areas of infection

   _____ Malignancy

   _____ Metal Implants

APPENDIX D

Informed Consent Form

Barry University

Informed Consent Form

Your participation in a research project is requested. The title of the study is, *The effects of thermal ultrasound on active and passive ankle dorsiflexion range of motion inside and outside the stretching window*. The research is being conducted by Marti Greer, ATC, LAT, RT(R), a graduate student in the Human Performance and Leisure Science department at Barry University, and is seeking information that will be useful in the field of athletic training. The aims of the research are to determine if therapeutic thermal ultrasound will increase the active and passive range of motion of ankle dorsiflexion within and outside of the therapeutic stretching window. The results of this study are aimed to determine the effectiveness of the stretching window and may aid in the reduction of athletic injuries. We anticipate the number of participants to be 40. In accordance with these aims, the following procedures will be used: you must be free of injury to the lower extremity in the last six months and report no contraindications, such as infection, malignancy, decreased circulation, decreased sensation, or metal implants, to a therapeutic ultrasound treatment. Those participants with previous injury or contraindications will be disqualified from the study. Once participation is granted, you will randomly be assigned to one of two groups; a treatment group (A) and a control group (B). Group A will receive an actual therapeutic ultrasound treatment, while group B will receive a placebo ultrasound treatment with no acoustic energy being delivered to the tissue. You will schedule a time to report to the Barry University athletic training room for your testing session, which will consist of three pre and post-test active and passive ankle range of motion measurements, a single therapeutic thermal ultrasound treatment, and three 8 minute post-test remeasurement of both active and passive range of motion at the right ankle. Participation will take approximately 25 minutes and if participants report pain at any time during the experiment, the study will be stopped immediately and without penalty.

You will short-sit, with the hip and knee joints both at a 90 degree angle on a standard treatment table while three trials of both active and passive ankle dorsiflexion range of motion are measured. A universal goniometer will be placed on the lateral aspect of the right ankle according to anatomical landmarks. You will be instructed to actively dorsiflex your right ankle while three active range of motion measurements are taken. You will then be instructed to relax while the examiner passively dorsiflexes the right ankle to a maximal degree. Simultaneously, the examiner will position and move the goniometer according to anatomical landmarks to measure the three trials of passive ankle dorsiflexion range of motion. Next, you will lie prone on a treatment table while a therapeutic ultrasound treatment is administered. A metronome will be used to regulate the movement speed of the transducer soundhead. Immediately after the ultrasound treatment you will resume the short-sit position on the treatment table while three trials of both active and passive ankle dorsiflexion range of motion are remeasured. You will then be instructed to relax with minimal movement of the right lower extremity for 8 minutes. Following the 8 minute delay you will resume the short-sit position for a repeated measurement of both active and passive ankle dorsiflexion range of motion.

If you decide to participate in this research study, you will be asked to do the following: report to the Barry University athletic training room on a one time occasion for the testing session. The testing session will consist of three pre trials of both active and passive ankle dorsiflexion range of motion, an 8 minute therapeutic ultrasound treatment, three post trials of both active and passive ankle dorsiflexion range of motion, and three post 8 minute trials of both active and passive ankle dorsiflexion range of motion. Total participation time for this study will be approximately 25 minutes on a one time basis.

Your consent to be a research participant is strictly voluntary and should you decline to participate or should you choose to drop out at any time during the study, there will be no adverse effects on your current status as a student at Barry University.

Therapeutic ultrasound is generally safe for all individuals; however if used improperly or by a person not experienced in its application, it may cause burns or unstable cavitation (collapse of gas bubbles in tissue, which may cause damage). To ensure these risks do not occur, each therapeutic ultrasound treatment will be administered by the primary researcher, who is a certified athletic trainer, and who is properly trained in ultrasound application. Since certain medical conditions may enhance the risks, participants will be screened using a pre-participation questionnaire so that anyone at risk for contraindications can be excluded from the study.

You may experience a feeling of mild warmth at the direct ultrasound treatment site. If any other symptoms are reported, treatment will be discontinued immediately. Although there are no direct benefits to you, your participation in this study may help our understanding of whether or not therapeutic thermal ultrasound effects active and passive ankle dorsiflexion range of motion. Your participation will also help us identify if the standard stretching window is supported by prior research.

As a research participant, the information you provide will be held in confidence to the extent permitted by law. Any published results of the research will refer to group averages only and no names will be used in the study. Data will be kept in a locked file in the researcher's office. This consent form will be kept separate from the data to ensure confidentiality. All data will be destroyed after three years.

If you have any questions or concerns regarding the study or your participation in the study you may contact any of the researchers or supervisors; Marti Greer, primary researcher, (859) 539-2886; Dr. Sue Shapiro, thesis chair, (305) 899-3574; Barbara Cook, IRB point of contact, (305) 899-3020. If you are satisfied with the information provided and are willing to participate in this research study, please signify your consent by signing this consent form.

Sincerely,

Marti Greer

****

Voluntary Consent

I acknowledge that I have been informed of the nature and purposes of this experiment by Marti Greer, ATC, LAT, RT(R), and that I have read and understand the information presented above, and that I have received a copy of this form for my records. I give my voluntary consent to participate in this experiment.

____________________ __________

Signature of Participant *Date*

____________________ __________

Signature of Researcher *Date*

APPENDIX E

Data Collection Sheet

Data Collection Sheet

Identification Number: ____________________   **Age: ____________________**

Gender: _________________________________

Pre-Test Measurements

Goniometric Range of Motion
Dorsiflexion: Right Ankle

Active ROM	**Passive ROM**
Trial 1: ________ degrees	**Trial 1: ________ degrees**
Trial 2: ________ degrees	**Trial 2: ________ degrees**
Trial 3: ________ degrees	**Trial 3: ________ degrees**

Ultrasound Treatment

_____ Group A
_____ Group B

Post-Test Measurements

Goniometric Range of Motion
Dorsiflexion: Right Ankle

Active ROM	**Passive ROM**
Trial 1: ________ degrees	**Trial 1: ________ degrees**
Trial 2: ________ degrees	**Trial 2: ________ degrees**
Trial 3: ________ degrees	**Trial 3: ________ degrees**

8 Minute Delay Post-Test Remeasurements

Goniometric Range of Motion
Dorsiflexion: Right Ankle

Active ROM	**Passive ROM**
Trial 1: ________ degrees	**Trial 1: ________ degrees**
Trial 2: ________ degrees	**Trial 2: ________ degrees**
Trial 3: ________ degrees	**Trial 3: ________ degrees**

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