The Efficiency of Forced Inhalation in Promoting Venous Return

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Abstract

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The Efficiency of Forced Inhalation in Promoting Venous Return

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The physiological respiratory pump has the potential of encouraging a more efficient venous return of the lower extremity. This study examined the effects of a diaphragmatic breathing pattern coupled with three common swelling reduction techniques on venous return of the ankle. A pretest-posttest true experimental design was used in this study to compare ankle swelling reduction rates of selected venous return interventions.

Venous return in the lower limbs is substantially decreased as a result of gravitational forces acting down on the body. This does not eliminate the possibility of allowing for faster return of blood to the heart, however. When a patient has swelling to a body site, there are several interventions that are clinically practiced to promote venous return. These interventions include: elevation, sequential compression, and muscle pumps. The respiratory pump is the most powerful mechanism of venous return, but it has not yet been clinically tested or applied. This study randomly placed participants into three intervention groups and implemented each with or without the respiratory pump using a diaphragmatic breathing pattern.

This study determined that there was no statistical or clinical significance between elevation, sequential compression, or muscle contraction with forced inhalation compared to elevation, sequential compression, or muscle contraction without forced inhalation.

There was also no statistical or clinical significance between the swelling reduction techniques. Forced inhalation using a diaphragmatic breathing pattern did not significantly promote a faster venous return and reduction of swelling. However, the study was underpowered; a larger number of participants was needed to find both statistical and clinical significance. Further research is needed to investigate the power of the respiratory pump in venous return to the lower extremity.

Dedication

This thesis is dedicated to my family for their unending love and support. Thank you for always encouraging me through my professional growth, and recognizing my passion as an Athletic Trainer. Because of you, I can always find light in the darkness. You are all truly a blessing in my life.

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Chapter 1: Introduction

Over 25,000 acute ankle sprains occur daily.[1] Nearly one-half of all ankle sprains occur during sporting activities, causing disability and substantial loss of time from participation for an athlete and ankle sprains are one of the most common reasons for primary care office and emergency department visits.[2] When a soft tissue injury is sustained, a common reaction produced is the physiological inflammatory response of redness, heat, pain, and swelling. Swelling is the collection of blood and fluids in and around the joint, which is a direct result of the increase in osmosis from dilated and permeable blood vessels into the surrounding tissues. This formation of swelling is a burden to the healing process, causing pain, reduced range of motion, decreased strength, and decreased overall function to the joint.

Blood that leaves the veins during an injury causes swelling and must be returned via the lymphatic system. When the delivery of fresh blood and oxygen to the injured structures is blocked due to rising osmotic pressure, venous return from the site is also inhibited.[3] Venous return insufficiency occurring from the trauma results in blood pooling to the ankle joint, rather than being returned to the heart. The pooling of blood, or swelling, inhibits the healing process, and normal function is not regained until the extra volume of fluid is eliminated through venous return.

Venous Return of the Lower Extremity

Under normal conditions, venous return must equal cardiac output when averaged over time as a result of the cardiovascular system essentially being a closed loop.[4] Otherwise, there would be an accumulation of blood in the system. This can be observed through the venous return curve. This curve also shows that when heart pumping capability is decreased, right atrial pressure rises, and the backward force of the rising atrial pressure on the veins reduces venous return of blood to the heart. Even a slight rise in right atrial pressure causes a large decrease in venous return because of the systemic circulation that can be thought of as a distensible bag, meaning any increase in back pressure will cause blood to become blocked in this bag instead of returning to the heart.[5]

The functions of the peripheral venous system are to provide a reservoir to hold excess blood and fluid volume and to be a channel to return blood from the periphery to the heart. This excess volume is received against a pressure gradient, moving against gravity and changing thoracoabdominal pressures. Though both arteries and veins function to transport blood throughout the body, there are minor structural differences between the two that affect venous return.[6]

Both veins and arteries are composed of three types of tissues arranged in layers: the tunica media, tunica intima, and tunica adventitia. Arteries, however, are more efficient at pumping blood as a result of the thicker tunica media, which is composed of smooth muscle and elastic tissue. This elasticity allows the arterial walls to expand and contract in response to cardiac output. While blood is moved through arteries by the activity of the tunica media, movement of blood through veins depends on the mechanism of the skeletal muscle pump. This mechanism delivers a massaging action as muscle contracts around the membranous walls, causing a milking effect proximally back towards the heart. Another structural factor affecting venous return is the presence of valves in veins. These valves ensure that blood returning to the heart by the skeletal muscle pump cannot flow back and start to pool in the lower extremities. These anatomic and physiologic aspects of the skeletal muscle pump of the lower leg suggest its potential to serve as a circulatory pump for venous return.

Otto Frank and Ernest Starling, two German physiologists, studied the relationship between muscle fiber contraction length, stroke volume, and end diastolic volume. They concluded that increased ventricular volume facilitated ventricular contraction and enabled the ventricles to pump a greater stroke volume, resulting in an exact match at equilibrium between the cardiac output and the increased venous return.[7] Starling also observed the exchange of fluid between capillaries and tissues and the forces needed to increase capillary filtration. The distribution of extracellular fluid between the interstitial compartments and plasma is at an equilibrium due to the constant circulation of tissue fluids formed from and returning to the vascular system.[4] Whether these fluids will move into or out of a capillary depends on opposing forces. Starling concluded that fluid movement is proportional to hydrostatic pressures in the capillary, colloid osmotic pressure of the tissue fluid, hydrostatic pressure of tissue fluid, and colloid osmotic pressure of blood plasma. Through the action of the these forces, plasma and tissue fluid are continuously interchanged through capillary filtration and the lymphatic system.[7]

Venous Return Interventions

There are several mechanical factors that affect swelling reduction through venous return including gravity, external compression, the skeletal muscle pump, and the respiratory pump. Clinicians commonly use the assistance of gravity by elevating the lower leg above the level of the heart to promote venous return. When a swollen body part is elevated above the heart through the intervention of elevation, the veins collapse and the negative hydrostatic pressure acted upon by the gravitational forces reduce the pressure within the veins. When pressure within the veins is reduced, blood is more easily carried towards the heart, and cannot return to the body site due to the venous valves.

External compression applied to a body segment decreases the gradient between the hydrostatic pressure of the tissue and the pressure of capillary filtration, which facilitates the reabsorption of interstitial fluids. This reabsorption is carried out through the venous system and spreads the swelling proximally along lymphatic ducts. Clinicians often use sequential compression for venous return via a sequential compression device. This device uses a series of compressions, starting distally and working proximally, to promote the reduction of swelling. This particular device uses multiple bladders filled with air to compress the veins in a "milking" mechanism similar to the skeletal muscle pump.

The use of the skeletal muscle pump is essential for lower extremity venous return and the reduction of swelling. Because veins pass between groups of skeletal muscle, the action of muscle contraction provides a massaging action around the membranous walls. When skeletal muscle squeezes the veins with contraction, a one-way flow of blood to the heart is made possible by valves within the veins.[8] Though elevation, sequential compression, and muscle contraction are all effective in the reduction of swelling, the respiratory pump is one of the most powerful venous return mechanisms.[8]

During inhalation, expansion of the lungs and pulmonary tissues causes pulmonary blood volume to increase, momentarily decreasing the flow of blood from the lungs to the left atrium. As a result, left ventricular filling decreases during inhalation. When right atrial pressure falls during inhalation, the pressure gradient for the return of blood to the heart associated with the right ventricle increases, causing a suction-like mechanism.[9] In association with these events, the respiratory pump is evident in the promotion of swelling reduction through venous return.

Statement of the Problem

Numerous treatment protocols are used to control swelling in the acute phase of ankle sprains. The treatment of rest, ice, compression, and elevation (RICE) is the most standard treatment protocol used, but only compression and elevation are significant for the promotion of venous return. Clinically, swelling reduction is promoted using elevation, sequential compression, and muscle pumps. Respiration, through the respiratory pump, is one of the most powerful venous return mechanisms, yet it remains untapped in the succession of clinical techniques used to reduce swelling.

There have been few studies investigating the respiratory pump for lower extremity swelling. Furthermore, these studies have only looked at the respiratory pump versus other mechanical factors affecting venous return and not at the inclusion of respiration coupled with those factors. Clinicians already often combine venous return interventions, for example elevation and muscle contraction, or elevation combined with external compression. However, the respiratory pump remains left out in the clinical application of swelling reduction.

Purpose of the Study

The purpose of this study was to determine if forced inhalation using a diaphragmatic breathing pattern would promote a faster venous return and reduction of swelling. The secondary purpose was to determine if one intervention, with or without the breathing pattern, would significantly promote a more efficient venous return than the other interventions.

Significance of the Study

Ankle injuries account for a significant amount of sports related injuries due to the ankle's susceptibility from the amount of force placed on the joint from one's own body weight and the amount of motions that can occur at the ankle. When trauma to the ankle occurs, the initial reaction activated by the body is the inflammatory response to protect the joint from further injury and prepare the ankle for healing. Though this response serves as a beneficial purpose, the inflammatory process and the consequential formation of swelling is a burden to the healing process. In addition, swelling causing pain, reduced range of motion, decreased strength, and decreased overall function of the joint. The faster the swelling can move out of the injured area, the faster a patient can progress in the rehabilitative process and return to normal function. This makes initial control of swelling following an ankle injury essential.

Research Questions

The research questions guiding this thesis were:

1. Will forced inhalation with elevation reduce swelling more than elevation alone?

2. Will forced inhalation with sequential compression reduce swelling more than sequential compression alone?
3. Will forced inhalation with muscle pumps reduce swelling more than muscle pumps alone?
4. Will there be a significant difference exiting between using forced inhalation versus not using forced inhalation?
5. Will there be a significant difference exiting between the control and elevation, sequential compression, and muscle pumps?

Hypothesis

The hypotheses investigated in this study were:

1. The use of a diaphragmatic breathing pattern coupled with the swelling reduction techniques will not promote a faster venous return than the swelling reduction techniques alone.
2. The use of a diaphragmatic breathing pattern coupled with muscle pumps will not promote the quickest venous return compared to a diaphragmatic breathing pattern coupled with elevation or sequential compression.
3. The intervention of elevation without a diaphragmatic breathing pattern will have the most effect on venous return.

Delimitations of the Study

Delimitation of the study included:

1. Setting: All testing was conducted at a specific location at Ohio University with controlled room temperature at 68 degrees.

2. Increase in lower extremity volume: All participants had swelling induced to the ankle via the same method.
3. Volumetric measurement: All volumetric measurements were taken in degassed water controlled at 70 degrees.
4. Intervention time period: All venous return interventions lasted for a predetermined time of 10 min.
5. All participants sign a human consent form prior to participation in the study.
6. This study was approved by the Institutional Review Board at Ohio University.

Limitations of the Study

1. Participants were individuals ages 18 to 29 years.
2. The foot size of participants was limited to a size 7 to 12 (men) and 5 to 14 (women) due to the size of the volumetric measuring device.
3. Participants with a history of previous injury to the left or right ankle 6 months prior to the study were excluded.
4. Participants with circulatory disorders were excluded from the study.
5. Participants with contraindications for warm whirlpool were excluded from the study.
6. The number of participants was determined through a power analysis from a pilot study and limited the amount of data per intervention.
7. Some participants were more educated on diaphragmatic breathing patterns than others prior to the study.

Definitions of Key Terms

Ankle pumps. Performed by repeatedly dorsiflexing and plantar flexing the ankle.

Diaphragmatic breathing. Performed by inhaling deeply through the nose while gently pushing out the abdomen until lungs are full, then exhaling slowly, using pursed lips, while gently pulling the abdomen inward until lungs are emptied.

Gravity. A force that attracts a mass towards the center of the earth.

Inflammatory response. The acute response of the body to injury characterized by redness, heat, pain, swelling, and loss of function.

Respiratory pump. The mechanism of causing changes in right atrial pressure to influence venous return through a suction effect of lower extremity veins.

Skeletal muscle pump. The pumping effect of skeletal muscle on venous blood flow.

Swelling. The collection of blood and fluids in and around a joint resulting from an increase in passage of fluid.

Venous return. The flow of blood from the venous system into the right atrium of the heart.

Chapter 2: Literature Review

Swelling, which results from the inflammatory response to an acute injury, causes a burden to the affected individual by decreasing the overall function of the injured body part. Ankle injuries account for a significant amount of sports-related injuries, with swelling being a common consequence. When there is swelling to an area, it is commonly reduced in the clinical setting using elevation, intermittent compression, and muscle contractions or pumps. Respiration, by the respiratory pump, however, is one of the most powerful mechanisms of venous return, yet it remains untapped clinically as a technique to reduce swelling**.** There are studies that have looked at this concept and have found that inhalation does, in fact, promote a quicker venous return.[8] None, though, have coupled the different interventions together to determine if combining respiration with standard techniques promotes a faster venous return, essentially leading to a faster recovery from an acute injury.

Acute Ankle Injury

Acute ankle injuries account for approximately 10-30% of all sports injuries and approximately 23,000 injuries annually.[10] It is the most frequent single type of acute sport trauma, causing disability and substantial loss of time from participation for an athlete.[11] Nearly one-half of all ankle sprains occur during sporting activities, and ankle injuries are one of the most common reasons for primary care office and emergency department visits.[2]

The true ankle joint, otherwise known as the talocrural joint, is a synovial joint formed by the articulation between the talus, tibia and fibula. The second joint associated with the ankle is called the subtalar joint, formed by the talus and the calcaneus. The ligamentous anatomy of the ankle consists of the anterior tibiofibular, anterior and posterior talofibular, calcaneofibular and deltoid ligaments. Muscular support to the ankle is provided by the gastrocnemius, soleus, tibialis anterior, posterior tibialis, extensor hallucis longus, extensor digitorum longus, flexor digitorum longus, flexor hallucis longus, and the peroneus longus, brevis, and tertius muscles. These muscles are innervated by the tibial, saphenous, sural, and deep and superficial peroneal nerves. Blood is supplied to the ankle via four vessels: the anterior and posterior tibial, peroneal and dorsal pedis arteries.

The ankle is very susceptible to injury due to the amount of force placed on the joint from one's own body weight and the ranges of motion that can occur at the ankle. The numerous acute injuries that can result from trauma to the ankle joint include: sprains, which is a stretching or tearing of a ligament; a strain, which is the stretching or tearing of a musculotendinous structure; or, a fracture, which is a complete or incomplete break in a bone. Additionally, there are many different types of sprains, strains, and fractures that can occur to the ankle in relation to the amount of anatomical structures to the joint.

The most common mechanism of injury to the ankle is forced inversion with some degree of plantar flexion. This mechanism usually occurs during sporting activities and results in a lateral ankle sprain, which represents 77% of all ankle sprains.[10] Other mechanisms of injury include landing on an object, uneven surfaces, foot abnormalities, and high intensity activity involving lateral movement, jumping, or running. When a traumatic injury occurs, the initial response activated by the body is the inflammatory response to protect the joint from further injury and prepare the ankle for healing. The inflammatory response, despite its benefits, commonly causes pain, loss of function, ecchymosis, edema, and swelling.

Swelling

The immediate tissue damage associated with an injury is referred to as primary injury, occuring immediately with trauma and often involving disturbances of several anatomical structures. When a primary injury occurs, blood enters damaged tissues as a result of the acute inflammatory response; and blood plasma transmits essential substances to the injury site. These substances include: clotting factors to stop the bleeding and spread of infection, antibodies to fight off any infection, nutrients used for producing energy to promote tissue repair, and proteins that attract phagocytes, which are cells responsible for surrounding microorganisms and removing the damaged cells.[3,12]

Swelling is the collection of blood and fluids in and around a joint resulting from an increase in osmosis, or passage of fluid, from dilated and permeable blood vessels into the surrounding tissues. This increase in osmosis results directly from trauma to the area and blocks the delivery of fresh blood and oxygen to the injured structures. When this delivery is blocked, venous return from the site is inhibited and blood pools to the ankle joint rather than being returned to the heart.

Ordinarily, membrane homeostasis is maintained between the volume of plasma entering the tissues from the capillaries and the volume of blood that is returning to the circulatory system from the tissue. When the tissue is damaged, the homeostatic mechanism shifts and allows more fluid to enter the tissues. This increase in permeability is due to complement-derived peptides and bradykinins, which are the chemical mediators released during inflammation that causes capillaries to become leaky when tissues are damaged. Additional mediators, histamine and serotonin, are derived from injured tissue cells causing capillary dilation, increased capillary permeability, contraction of nonvascular smooth muscle, and stimulation of nociceptors responsible for pain response.[3,12] The pooling of blood, or swelling, inhibits the healing process and causes pain, reduced range of motion, decreased strength, and an overall decrease in function. When these factors exist, normal function is not regained until the extra volume of fluid is eliminated.

Most of the body's total blood volume is contained in the venous system, which is made up of blood vessels that form a tube-like system throughout the body that allows blood flow to and from the heart to all living cells. Arteries provide resistance to the flow of blood from the heart, whereas veins are able to expand to accumulate a large volume of blood. To be specific, the average hydrostatic pressure in the veins is only 2 mmHg, as opposed to a much higher average arterial pressure of roughly 100 mmHg.[4] Because of such a low pressure, veins are insufficient for returning blood to the heart. Due to gravitational forces acting down on the body, venous return in the lower limbs is substantially decreased; this does not eliminate the possibility to allow for faster return of blood to the heart, however. When a patient has swelling to a body site, there are several interventions that can be clinically practiced to promote venous return. These interventions include: elevation, sequential compression, muscle pumps, and the respiratory pump.

Muscle Contraction

Since blood pressure in the veins is lower than in arteries, and veins are generally traveling against gravity, muscle contraction (skeletal muscle pump) is crucial in venous return. Veins pass between groups of skeletal muscle that provide a massaging action as they contract around the membranous walls. When skeletal muscle squeezes the veins with contraction, a one-way flow of blood to the heart is made possible by valves within the veins.[8] These venous valves prevent the flow of blood distally (away from the heart). This massaging effect of skeletal muscle is known as the muscle pump.

The repeated series of contraction and relaxation of lower extremity skeletal muscles successfully pumps blood back up to the heart. With ankle injuries, ankle plantar flexion helps to activate the gastrocnemius muscle, which plays an important role in driving swelling and blood away from the lower leg towards the heart. Dorsiflexion then stretches the calf muscle, which results in an increase in pressure within the vein, opening the superior one-way valve and forcing the swelling upwards.[13] A single muscle contraction has been shown to be effective at emptying the venous vessels and enhancing the central translocation of more than 40% of the intramuscular blood volume.[14] Another intervention that helps increase venous return is the external pressure, or squeezing, of the muscles and veins by compression.

Compression

Compression is used to mimic the action of skeletal muscle pushing against the venous walls. In fact, the muscle contraction action is an important concept in compression therapy and can be seen as inversely the same mean of venous return. Specifically, sequential compression uses a series of compressions, starting distally and working proximally, to promote venous return.[15] Sequential compression devices use multiple bladders filled with air to compress the veins in a "milking" mechanism. The cuffs are sequential because the most distal bladder inflates first and the most proximal bladder last. Graded sequential compression is when the most distal bladder will inflate to the highest pressure, and the most proximal will inflate the lowest.[15]

To put it into perspective, the sequential compression cuff, pushes the blood proximally towards the heart, can be viewed as the physical pushing of the swelling back up the veins. As mentioned earlier, blood that is pushed proximally cannot return to the injured site due to venous valves that prevent such distal blood flow. This type of intervention is typically used in acute injuries prior to muscle pumps if the patient is unable to produce a muscle contraction or this intervention is contraindicated at that stage in rehabilitation. Additionally, both muscle contraction and sequential compression can be used with another common intervention: gravity.

Gravity

Circulating blood in humans is subjected to gravity, which is a force that attracts a mass towards the center of the earth. Gravity applies significant factors affecting central venous pressure and venous return. When a person is standing, gravity acts on the volume of blood, causing it to accumulate more substantially in the lower extremity. This factor makes venous return to the heart more difficult. When a patient is in supine, or a lying position, blood vessels are put in a position close to the hydrostatic level of the heart, causing an even distribution of the blood between the head, thorax, abdomen, and legs.[4]

When an acutely injured body part is elevated above the heart, the hydrostatic pressure changes and blood is acted upon by the gravitational force, pushing it back down towards the heart. Through the intervention of elevation, the veins collapse and the negative hydrostatic pressure reduces the pressure within the veins.[4] When pressure within the veins is reduced, blood is more easily carried towards the heart, and cannot return to the body site due to the venous valves. Gravity can be compared to the force produced by compression and muscle contraction, because it is a force that promotes the pushing of blood towards the heart. There is another force that aids in the promotion of venous return, however this force is not pressure, but instead suction.

Respiration

Respiratory activity through the respiratory pump influences swelling reduction through changes in right atrial pressure, which is an important element of the pressure gradient for venous return. The activity of respiration can also affect the diameter of the thoracic vena cava and cardiac chambers, which either indirectly affects the return of blood to the heart by changing cardiac preload or directly changes it through compression of the vena cava.

Pressures in the right atrium and thoracic vena cava are dependent on the pressure within the thoracic space between the lungs, heart, vena cava, and the intrapleural space. During the act of inhalation, the chest wall expands and the diaphragm descends, making the intrapleural space become more negative. This leads to expansion of the cardiac chambers including the right atrium and right ventricle, the thoracic vena cava, both superior and inferior, and the lungs. The expansion of the lungs causes the intravascular and right atrial pressure to fall. Because the pressure inside the cardiac chambers falls less than the intrapleural pressure, the transmural pressure (pressure inside the heart chamber minus the intrapleural pressure) increases. This event leads to cardiac chamber expansion and an increase in cardiac preload and stroke volume. Consequently, as right atrial pressure falls during inhalation, the pressure gradient for the return of blood to the heart associated with the right ventricle increases, causing a suction-like mechanism.

The left chambers of the heart have an opposite reaction. During inhalation, expansion of the lungs and pulmonary tissues causes pulmonary blood volume to increase, momentarily decreasing the flow of blood from the lungs to the left atrium. This results in left ventricular filling decreasing during inhalation. Inversely, during expiration, lung deflation causes blood flow to increase from the lungs to the left atrium, increasing left ventricular filling.[9] In association with these events, the respiratory pump is evident in the promotion of venous return.

Previous Studies

A study conducted at the University of Wisconsin-Madison, *Skeletal Muscle Pump Versus Respiratory Muscle Pump: Modulation of Venous Return from the*

Locomotor Limb in Humans, by Miller, Pegelow, Jacques, and Dempsey quantitatively examined the effects of different breathing mechanisms on venous return from the locomotor limbs, or the lower extremity. Thirty-five men, aged 25 ± 6 years, were screened for adequate venous velocity, free from cardiovascular or pulmonary disease and signed an informed consent.[8]

Subjects in the study breathed through a mouthpiece that was connected to a non-rebreathing valve, with the nose occluded. Using this equipment, subjects' airflow rates, tidal volume, mouth pressure, and end-tidal partial pressure of carbon dioxide were measured. For the estimation of abdominal and intrathoracic pressure, gastric and esophageal balloons were placed in the stomach and lower one-third of the esophagus. Electromyogram recordings were taken from the surface electrodes on the right quadriceps and gastrocnemius muscles to ensure inactivity of the upper thigh muscles, and consistent activation of the gastrocnemius during contraction.[8] Using a direct current-coupled respiratory inductive plethysmograph, researchers measured changes in volume, ribcage, and abdominal efforts. Mean arterial (MAP) pressure was measured beat-by-beat using a finger photoplethysmography technique. This technique is used to accurately identify aortic pules pressure changes. Subjects' MAP was also measured using a drift corrected at 1 min intervals using an automated sphygmomanometer. Measurement of regional blood velocity, blood vessel cross-sectional areas, blood flow, and regional vascular conductance were also taken.[8]

There were two breathing patterns used within the study: ribcage and diaphragmatic breathing. Ribcage breathing had the subjects inspire using their intercostal and neck muscles primarily. During diaphragmatic breathing, subjects were instructed to inspire so that the diaphragm descended, forcing an outward exertion of the abdominal wall during inhalation and relating inspiratory increase in gastric pressure.[8]

For calf contraction, subjects were placed in a semirecumbent position with their knees extended and parallel to the floor. The calf was contracted via plantar flexion at a frequency of 30 min, with a duty cycle of 0.50, allowing contraction to be synchronized with the onset of respiration.[8]

The results concluded that there was a significant modulation of femoral venous return from the lower extremity by respiration at rest, and to a lesser degree during various intensities of gastrocnemius contractions.[8] The nature of the breathing patterns were dependent on abdominal pressures over the course of a breath and the diaphragmatic breathing pattern showed the highest significance of variation of femoral venous return during the inhalation phase.[8]

Conclusion

Respiration remains untapped in the clinical setting to increase venous return and reduce swelling. This powerful modulation can be validated through trials of combining respiration with elevation, muscle compression, and muscle contraction. These interventions have been shown to increase venous return and, therefore, reduce the consequences of swelling to the ankle joint of pain, reduced range of motion, and decreased strength. Finding an intervention or combination of interventions that is significantly more effective than the rest could improve not only the patient’s recovery to normal function, but also the clinical application of swelling reduction by health professionals.

Chapter 3: Methods

Design

This study used a pretest-posttest quasiexperimental design to compare swelling reduction rates between various interventions. The independent variables were the interventions of sequential compression, elevation, muscle contraction and respiration. The dependent variable was the reduction in swelling as determined using volumetric measurement.. The testing for the study was conducted at a university in southeast Ohio and was approved by Ohio University's Institutional Review Board.

Participants

A power analysis was conducted to find the sample size needed for this study using the G*Power computer program. The indicated sample size for this study was 18 participants distributed across three groups.

The inclusion criteria for this study were individuals aged 18 to 29 years, with a foot size of 7 to 12 (men) or 5 to 14 (women). Exclusion criteria for this study were circulation disorders, respiratory disorders, contraindications for warm whirlpool, or a history of an ankle injury to both ankles within the past 6 months. Master codes for participants were maintained throughout statistical data.

Instruments

To induce swelling, participants stood in a 110-gallon warm whirlpool bath, filled with 110˚F water. A foot/ankle volumetric measure device, liquid measuring cup, and 500 mL graduated cylinder were used to obtain volumetric measurements of participants' involved ankle. For volume (swelling) reduction, a half-leg PresSion compression device was used for the interventions of sequential compression.

Procedures

Prospective participants completed a medical history form to confirm the inclusion and exclusion criteria for the study. Individuals who met the criteria signed an informed consent form prior to testing. Resting blood pressure measurements were obtained prior to testing and documented. Baseline volumetric measurements, using a foot/ankle volumetric measure device, of the right ankle were obtained from the participants and documented.

Before implementing an experimental intervention, participants stood calf-deep in a 110°F warm whirlpool with a thigh blood pressure cuff placed on both left and right thighs and inflated to a pressure 25% of participants' resting diastolic pressure to increase lower limb volume. A wrist blood pressure cuff remained on the participant; blood pressure was monitored throughout the session to identify any adverse effects of the intervention. After 20 min of standing in the whirlpool, volumetric measurements of participants' ankles were obtained and documented to observe a measurable amount of swelling. Participants then underwent their assigned interventions. Elevation with and without forced inhalation, sequential compression with and without forced inhalation, or muscle contraction with and without forced inhalation were all used in this study.

Participants were randomly assigned to one of three groups: (1) group E ($n = 6$) received elevation alone and elevation with a diaphragmatic breathing pattern; (2) group C ($n = 6$) received sequential compression alone and sequential compression with a diaphragmatic breathing pattern; and (3) group M (n = 6) used muscle contraction alone and muscle contraction with a diaphragmatic breathing pattern. Participants underwent two sessions, one trial involving a diaphragmatic breathing pattern and the other trial without. The order of the trials were randomized. At least 48 hours were allotted between each session for each participant.

Elevation. Group *E* used the intervention of elevation. When elevation alone was used, participants had their involved leg raised 12 in on a bolster for 10 min. When elevation coupled with forced inhalation was used, participants had their involved leg raised 12 in on a bolster while performing a diaphragmatic breathing technique for 10 min. This technique is performed by inhaling deeply through the nose while gently pushing out the abdomen until lungs are full, then exhaling slowly, using pursed lips, while gently pulling the abdomen inward until lungs are emptied.

Sequential compression. Participants in group *C* applied sequential compression. When using compression alone, the participants were placed in the PresSion compression device, set to sequential compression, for 10 min. Sequential compression devices use sleeves with separated pockets of inflation, which works to squeeze on the lower leg in a "milking" action, starting distally and ending proximally. When sequential compression was coupled with forced inhalation, participants were placed in the PresSion compression device, set to sequential compression, while performing a diaphragmatic breathing pattern for 10 min.

Muscle contraction. Group *M* used muscle contraction in the study. When muscle contraction alone was used, the participants performed ankle pumps with their ankle off the edge of the treatment table for 10 min. Ankle pumps were performed by having the participants repeatedly dorsiflex their ankle, or point their toes towards them, then plantar flex their ankle, or point their toes towards the floor. When muscle contraction coupled with forced inhalation was used, participants performed ankle pumps with their ankle off the edge of the treatment table for 10 min while performing a diaphragmatic breathing pattern.

Following each intervention, posttest volumetric measurements of the participant's ankle were taken and documented. Participants were involved in the study until both assigned trials were completed, or until deemed excluded from the experiment.

Data Analysis

Data were collected and the mean variables were calculated for each group. Then the percent of change between using a breathing pattern versus not using a breathing pattern were calculated for each group.

Statistical significance. The independent variables in this study are the treatment methods of: elevation, sequential compression, muscle contraction, and respiration. The dependent variables in this study are the reduction of swelling (volume). Data were recorded for each participant, with the repeated measures entered as separate variables on that same line. Using SPSS, a repeated-measures 3 x 2 ANOVA analyzed the differences between using forced inhalation and not using forced inhalation, and the differences between the control and elevation, sequential compression, and muscle pump groups. Post hoc Tukey testing between groups and within groups was completed if the overall ANOVA was significant. Three independent t-tests analyzed the difference between using elevation, sequential compression, or muscle contraction with forced inhalation compared to elevation, sequential compression, or muscle contraction without forced inhalation. A Bonferroni correction was used to reduce the chances of obtaining false-positive results with type I error where the alpha value of .05 was corrected to .01.

Clinical significance. Clinical significance was determined to assess the relevance of the interventions if there were no effect in the population. To identify clinical significance, effect size and the Reliable Change Index measures were obtained.

Effect size was calculated using eta-squared to identify the total variance that is attributed to the effect. According to the eta-squared cut offs, a small effect is 0.1, a medium effect is 0.3, and a large effect is 0.5.[16]

The Reliable Change Index (RCI), which was developed by Jacobson and Truax provided a measure of both statistical and clinical significance taking into account the intervention reliability.[17] The RCI was used to measure how reliable the interventions were from a clinical standpoint. Any value greater than 1.96 was considered clinically significant.[18]

Chapter 4: Results

Participants

Eighteen university students, 8 females and 10 males, aged 20.7 years ± 1.8 participated in this study. This study was approved by the Ohio University Institutional Review Board and all participants provided informed consent prior to data collection. The elevation group consisted of 2 female aged 20.5 years ± 3.5 and 4 males aged 21.8 years ± 0.5. The sequential compression group consisted of 4 females aged 20.5 years ± 2.9 and 2 males aged 20.5 years ± 2.1. The muscle contraction group consisted of 2 females aged 19.5 years ± 0.7 and 4 males aged 20.5 years ± 1.3.

Data Values

Control volumes. The participant's left ankle was used as the control. The control ankle was not physically involved in the interventions of elevation, sequential compression, or muscle contraction.

Table 1. Control Values

	Without Breathing Pattern		With Breathing Pattern		Change	
Group	**Increase (mL)**	**Decrease (mL)**	**Increase (mL)**	**Decrease (mL)**	**Increase**	**Decrease**
Elevation	56.7	2.5	62.5	8.3	9.3%	69.8%
Sequential Compression	45.8	2.5	53.3	11.6	14.0%	78.4%
Muscle Contraction	79.2	4.2	77.5	9.2	2.1%	54.3%

Percentage of change amongst groups from volume increases to volume decreases with and without a breathing pattern.

There was an average of 6.60 mL ± 4.67 difference of decrease in volume between using the breathing pattern versus not using the breathing pattern in the control.

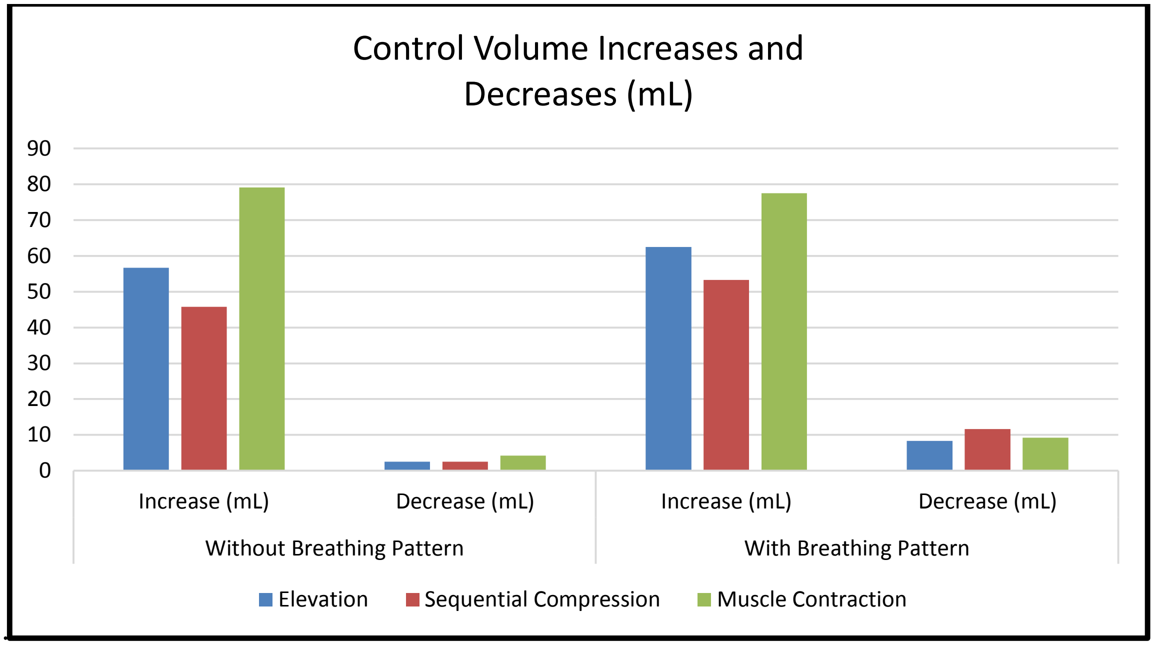

Figure 1. Increases and decreases in milliliters of volume for the control of elevation (blue), sequential compression (red), and muscle contraction (green) with and without a breathing pattern.

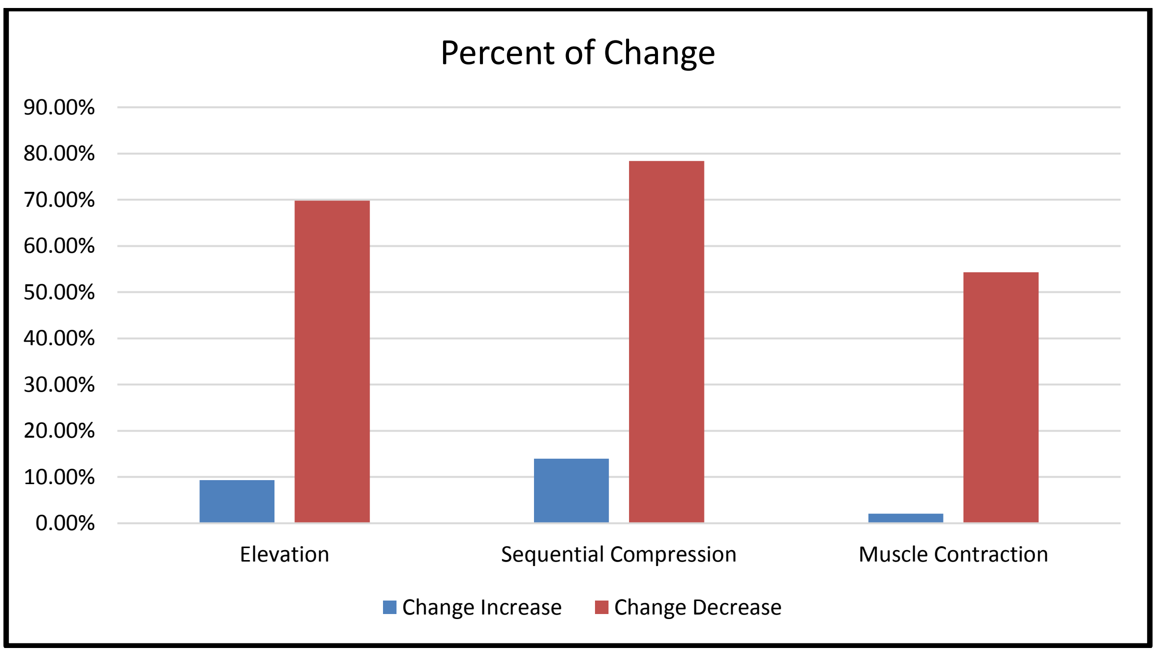

Figure 2. Percent of change between volume increases (blue) and decreases (red) for the control with and without the use of a breathing pattern.

Intervention group volumes. The participant's right ankle was used for the interventions. The intervention ankle was physically involved in elevation, sequential compression, or muscle contraction.

Table 2. Intervention Group Values

	Without Breathing Pattern		With Breathing Pattern		Change	
Group	**Increase (mL)**	**Decrease (mL)**	**Increase (mL)**	**Decrease (mL)**	**Increase**	**Decrease**
Elevation	56.7	10.5	62.5	38.8	9.3%	72.9%
Sequential Compression	47.5	34.1	53.3	57.5	10.9%	40.7%
Muscle Contraction	75.8	25.8	80	54.2	5.2%	52.4%

Percentage of change amongst groups from volume increases to volume decreases with and without a breathing pattern.

There was an average of 24.04 mL ± 23.46 difference in the reduction of volume between using the respiratory pump versus not in the intervention group.

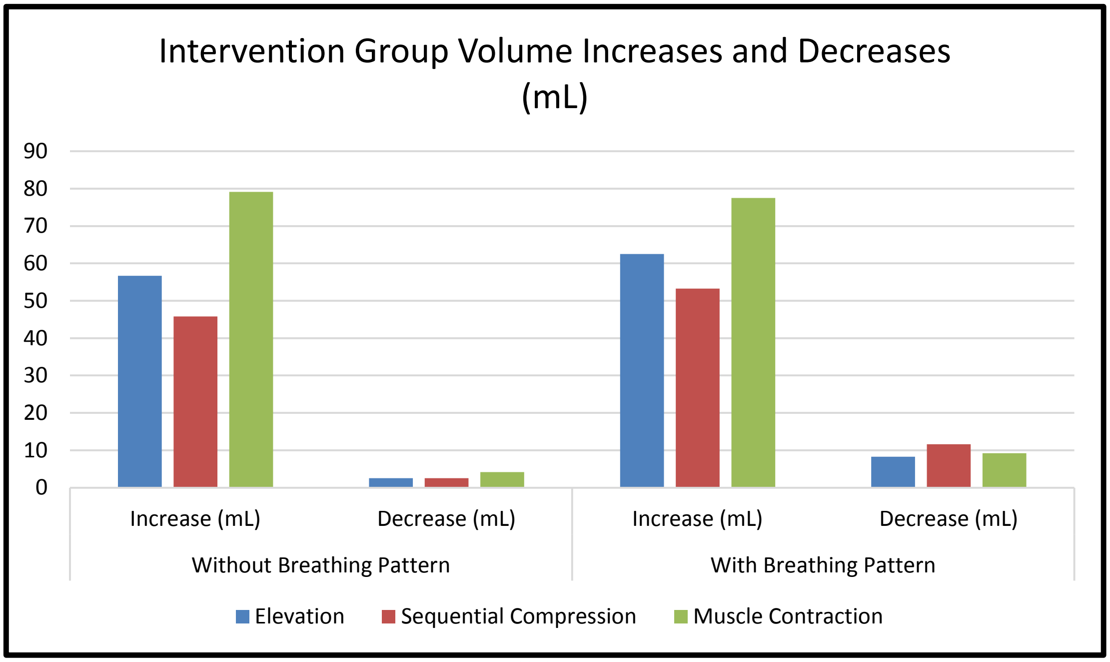

Figure 3. Increases and decreases in milliliters of volume for the intervention groups of elevation (blue), sequential compression (red), and muscle contraction (green) with and without a breathing pattern.

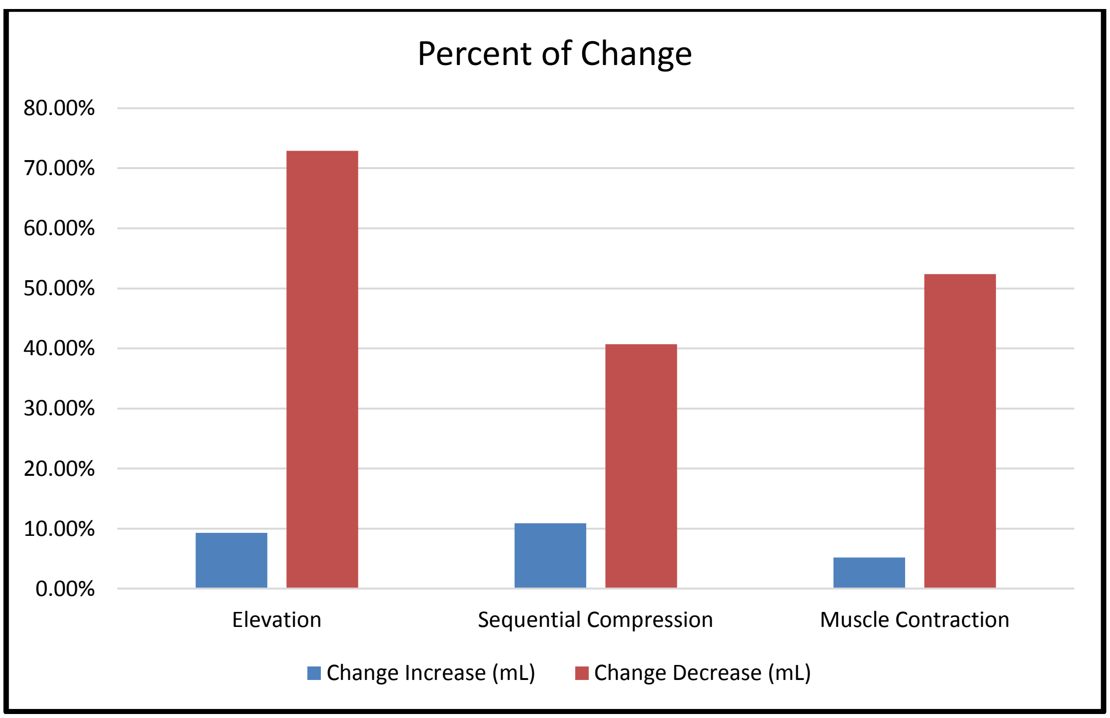

Figure 4. Percent of change between volume increases (blue) and decreases (red) for the intervention groups with and without the use of a breathing pattern.

Statistical Significance

Forced inhalation. A repeated measures 3 x 2 ANOVA revealed that there was no significant difference in volume reduction between the group using forced inhalation and the controlt ($F_{4.000, 58.000} = 2.552$, $P > .05$). The Between Subjects-Effects was $F_{3.838, 5975.926} = 2.661$, $P > .05$.

Swelling reduction techniques. A repeated measures 3 x 2 ANOVA revealed that there was no significant difference between the four swelling reduction techniques ($F_{4.000, 58.000} = 1.499$, $P > .05$). Mauchly's Test of Sphericity yielded at $P = .539$, violating the Sphericity assumption thus the Greenhouse-Geisser was adjusted to an Epsilon value of $P = .959$. The Between Subjects-Effects was $F_{3.838, 2959.259} = 1.318$, $P > .05$.

Forced inhalation with interventions. The addition of forced inhalation with other interventions had no statistically significant effect on total volume reduction**.** Independent t-tests revealed that there were no significant differences between forced inhalation with elevation and elevation alone ($t = -0.121$, $P = .906$), between forced inhalation with sequential compression and sequential compression alone ($t = -0.239$, $P = .816$), and between the group using forced inhalation with muscle pumps and muscle pumps alone, $t = 0.338$, $P = .7$.

Clinical Significance

Effect size using eta squared revealed that there was no clinical significance with a value of 0.05 for elevation, sequential compression, and muscle contraction, 0.00 for with and without forced inhalation, and 0.00 for with and without inhalation in combination with elevation, sequential compression, and muscle contraction. The Reliability Change Index revealed no clinical significance where RCI $1.582 < 1.96$.

Chapter 5: Discussion

There is an anticipated benefit to the clinical application of swelling reduction techniques for acute injuries. When an acute soft tissue injury is sustained, the common inflammatory signs of redness, heat, pain, and swelling burden the healing process, reducing range of motion, decreasing strength, and inhibiting overall joint function. Elevation of the body part reduces hydrostatic pressure, promoting blood return towards the heart. Skeletal muscle pumps use muscle contractions to providing a “milking” action around the membranous walls of the veins causing one-way flow of blood to the heart. Sequential compression is used to decreases the gradient between the hydrostatic pressure of the tissue and the pressure of capillary filtration, facilitating the reabsorption of interstitial fluids and moving blood proximally along lymphatic ducts. What remains untouched in the clinical application of swelling reduction is the most powerful mechanism of venous return, the respiratory pump.

The specific aim of this study was to determine if forced inhalation using a diaphragmatic breathing pattern would promote venous return to reduce swelling. The secondary aim was to determine if one intervention, with or without the breathing pattern, would significantly promote a more efficient swelling reduction than the other interventions. This study determined that there were no statistical or clinically significant differences between elevation, sequential compression, or muscle contraction with forced inhalation compared to elevation, sequential compression, or muscle contraction without forced inhalation. There were also no statistically or clinically significant differences between the swelling reduction techniques. Forced inhalation using a diaphragmatic breathing pattern did not significantly promote swelling reduction. However, the power analysis that was used prior to this study to determine the amount of participants needed did not give us an adequate number. The pilot study was looking at the increase of swelling as opposed to the decrease of swelling, therefore results of the power analysis should not have been used for this study.

The Respiratory Pump

There have been many studies determining the positive effects of the skeletal muscle pump, gravity, and compression on blood flow and swelling reduction.[4,8,11,12] Although previous studies have observed the effects of the respiratory pump versus skeletal muscle pump, to our knowledge no study has observed the interaction of the respiratory pump in combination with the skeletal muscle pump or any other common swelling reduction techniques such as elevation and sequential compression.

Observing our actual data values, they can support previous research showing the positive effects of the respiratory pump. There was a 24.04 mL ± 23.46 decrease of volume using the breathing pattern versus not using the breathing pattern in the intervention group. Specifically, sequential compression showed the biggest decrease in volume with a 57.50 mL ± 25.84 decrease when using the breathing pattern versus not. Furthermore, a difference of 6.60 mL ± 4.67 can be seen in volume decrease between using a diaphragmatic breathing pattern and not using the breathing pattern for the control. The control ankle was not physically involved in the interventions of elevation, sequential compression, or muscle contraction. Instead, it remained lying inactive on the treatment table used so that their lower extremity blood vessels would be closest to the hydrostatic level of the heart which causes an even distribution of blood.[4] It could be presumed by looking at the data values that the control ankle was still affected by the breathing pattern due to the fact that breathing has a bilateral effect. However, this study found no statistical or clinical significance to support the data collected that showed a decrease in swelling. Previous studies investigating the respiratory pump have indeed found statistical significance to support its positive effects on venous return of the lower exremity.[5,8]

The use of diaphragmatic inspiration through the diaphragmatic breathing pattern supports the concept that it is the inspiratory change in abdominal pressure that facilitates the changes of lower extremity venous blood flow over the course of a breath. Respiratory activity through the respiratory pump also influences swelling reduction through changes in right atrial pressure, which is an important element of the pressure gradient for venous return. As Ernest Starling concluded, fluid movement is proportional to hydrostatic pressures in the capillary, colloid osmotic pressure of the tissue fluid, hydrostatic pressure of tissue fluid, and colloid osmotic pressure of blood plasma.[4] In saying this, it is important to look at more than one factor that can be used to reduce swelling to the lower extremity.

Sphericity

Mauchly's Test of Sphericity revealed an insignificance of $P = .539$, violating assumption and causing insignificant Sphericity. This violation of Sphericity can be serious for the Repeated Measures ANOVA in that it results in a loss of power. To produce a more valid critical F-value, Tests of Between Subjects-Effects was adjusted.

We used a univariate adjustment of the Greenhouse-Geisser with an Epsilon value of $P =$ .959. Even with that adjustment however, the statistics still revealed insignificance.

Limitations

The number of participants must be large enough to limit any influence from an outlier and increase the chance to find a significant difference between groups. The study must have an adequate sample size, relative to the goals and the possible variations of the study. To determine the sample size, effect size was calculated with data obtained from the previous pilot study, and was included in the power analysis for this proceeding study. Using G*Power, the α probability of error was set at 0.05, power was set at 0.95, number of groups being 3 (elevation, compression, and muscle contraction) with the control and intervention conditions each being measured twice, correlation among repeated measures was set at 0.5, and nonsphericity correction € was set at 1. Results from the pilot data showed an effect size of 0.68. Therefore, with using G*Power, a repeated measures ANOVA for within-between interactions power analysis calculated the total sample size to be 9. However, realizing that the effect size is high, we were conservative and dropped the value down to 0.5, resulting in the total sample size of 15. Seeing that each group would have 5 participants, we were once again conservative and increased the number of participants per group to 6, making the total sample size 18. Additionally, pilot data showed a high power of 1.0, so we were also conservative in using a power of 0.95 instead. However, calculating sample size from pilot data looking at the increase of swelling did not yield an adequate number of subjects for this study, which examined the decrease in swelling. Six participants in each intervention group was insufficient. The sample size did not have enough power to reveal statistical or clinical significance. Interestingly, when looking at the hard data, there is an average decrease in ankle volume of 47.50 mL with using three swelling reduction interventions with the breathing pattern as opposed to an average 23.46 mL decrease in ankle volume when using the three swelling reduction techniques without the diaphragmatic breathing pattern. That makes a difference of 24.04 mL in swelling reduction. However, there were not enough subjects in the subsamples to test for significant differences.

Future Research

Future studies should aim to use a clinical population with actual ankle swelling following acute trauma, rather than inducing ankle volume through the method used in this study. This approach would validate the outcomes of the research making it more appropriate to clinical settings. Future research should also focus on the power analysis for determining the sample size and recruit the number of participants sufficient to show significance clinically and statistically. Furthermore, rather than combining elevation, muscle contraction, and sequential compression with the respiratory pump alone, combinations should expand to interactions of several swelling reduction techniques together (ie, elevation and muscle contraction with the respiratory pump, or elevation and sequential compression with the respiratory pump).

The powerful modulation of the respiratory pump can be validated through future research that combines respiration with other swelling reduction techniques that have been proven, such as elevation, muscle compression and muscle contraction. Further research should be conducted to find a combination of interventions that is significantly more effective in facilitating the patients' recovery to normal function, by restoring venous return after injury.

Conclusion

Although this study failed to validate the effects of the respiratory pump in combination with the three swelling reduction techniques, there is enough prior research supporting their positive effects to pursue future comparative effectiveness studies of these interventions. Elevation, muscle contraction, sequential compression, and the respiratory pump are all shown to increase venous return and therefore reduce the consequences of swelling to the ankle joint of pain, reduced range of motion, and decreased strength.[4,8,9,15]

Data collected in this study show a clear difference between using the respiratory pump versus not, supporting the strong need for a more in depth study examining this venous return technique. Despite the lack of statistical significance in our results, previous research has demonstrated that forced inhalation decreases swelling. This study brings attention to the need for additional data to support a clinical intervention of a breathing pattern that can combine the respiratory pump with other venous return techniques to reduce swelling of the lower extremity in a more effective and efficient manner.

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Appendix A: Consent Form

Ohio University Consent Form

Title of Research: The Efficiency of Forced Inhalation in Promoting Venous Return

Researchers: Kayla Beck, AT; Chad Starkey, PhD, AT, FNATA

You are being asked to participate in a research study. For you to be able to decide whether you want to participate in this project, you should understand what the project is about, as well as the possible risks and benefits in order to make an informed decision. This process is known as informed consent. This form describes the purpose, procedures, possible benefits, and risks. It also explains how your personal information will be used and protected. Once you have read this form and your questions about the study are answered, you will be asked to sign it. This will allow your participation in this study. You should receive a copy of this document to take with you.

Explanation of Study

This study is being done to determine if there is a more efficient treatment for the reduction of swelling. Though respiration is known to be the most powerful mechanism of venous return, it has not been clinically tested or practiced in the rehabilitation process. The purpose of this study is to see if respiration combined with three common interventions for swelling reduction will promote a quicker outcome in venous return.

If you agree to participate, you will complete a pre-test questionnaire to validate that the inclusion and exclusion criteria for the study are met. You will be instructed to wear shorts and a t-shirt for the study and will remove your shoes and socks prior to testing. Baseline blood pressure and volumetric measurements will be taken prior to testing.

At the start of this study, you will be asked to stand in a warm whirlpool of approximately 110°F (the temperature of a warm bath) for 20 minutes and have a blood pressure cuff placed around your lower-thigh and safely inflated to 25% of your resting diastolic pressure. Blood pressure will be monitored using a wrist blood pressure cuff to insure a safe session. Volumetric measurement of the involved ankle will be taken following the whirlpool.

During this study you will be randomly placed in an intervention group: group E, C, or M. Participants in group E will have their involved leg raised twelve inches on a bolster for 10 minutes for one of the trials, and repeat the same method coupled with a diaphragmatic breathing pattern for another trial. Participants in group C will have their involved lower leg in a PresSion compression device for 10 minutes for one of the trials, and repeat the same method coupled with a diaphragmatic breathing pattern for another trial. The PresSsion device consists of a sleeve that is places around the lower leg and inflated with air into chambers to achieve compression therapy. Participants in group M will perform ankle pumps for 10 minutes for one of the trials, and repeat the same method coupled with a diaphragmatic breathing pattern for another trial. Ankle pumps are performed by moving the ankle down and up as if pushing on and off a gas pedal. Volumetric measurement of the involved ankle will be taken after each trial.

You should not participate in this study if you have circulation disorders (deep vein thrombosis, Raynaud's phenomenon, anemia, arteriosclerosis, diabetes), contraindications for warm whirl pool (impaired sensation, open wound, impaired circulation), heat sensitivity, or have a history of previous injury to either left or right ankle within the past six months.

Your anticipated time commitment for this study is to complete two separate 45 minute sessions during a two week time period.

Risks and Discomforts

You may experience discomfort from the temperature of the warm whirlpool (110°F) or from the pressure of the blood pressure cuff (25% of resting diastolic pressure). You will be monitored to assure there is no discomfort throughout the process. If you do experience discomfort, inform the researcher who will immediately stop the treatment.

Benefits

There are no personal benefits for your participation in this study.

This study is important to science/society because there is an anticipated benefit to the clinical practice of swelling reduction associated with acute injuries. This study also anticipates the possibility of changing the manner clinicians execute a patient’s intervention who is suffering from acute swelling.

Confidentiality and Records

No personally-identifiable information will be collected. The results of your study will be recoded using a code number. Data will be stored in E332 Grover Center at Ohio University and the code key will be destroyed after all the data has been analyzed.

Additionally, while every effort will be made to keep your study-related information confidential, there may be circumstances where this information must be shared with:

* Federal agencies, for example the Office of Human Research Protections, whose responsibility is to protect human subjects in research;
* Representatives of Ohio University (OU), including the Institutional Review Board, a committee that oversees the research at OU;

Contact Information

If you have any questions regarding this study, please contact:

Kayla Beck, AT
kb144412@ohio.edu
(xxx) xxx-xxxx

OR

Chad Starkey, PhD, AT, FNATA
E332 Grover Center
Ohio University
starkeyc@ohio.edu
(xxx) xxx-xxxx

If you have any questions regarding your rights as a research participant, please contact Jo Ellen Sherow, Director of Research Compliance, Ohio University, (740)593-06

By signing below, you are agreeing that:

- you have read this consent form (or it has been read to you) and have been given the opportunity to ask questions and have them answered
- you have been informed of potential risks and they have been explained to your satisfaction.
- you understand Ohio University has no funds set aside for any injuries you might receive as a result of participating in this study
- you are 18 years of age or older
- your participation in this research is completely voluntary
- you may leave the study at any time. If you decide to stop participating in the study, there will be no penalty to you and you will not lose any benefits to which you are otherwise entitled.

Signature____ Date____________

Printed Name______________________________________

Version Date: *[3/02/14]*

Appendix B: Medical History Questionnaire

Medical History Questionnaire

Title of Research: The Efficiency of Forced Inhalation in Promoting Venous Return

Primary Investigator: Kayla Beck, AT
Graduate Assistant
Ohio University
(xxx) xxx-xxxx
kb144412@ohio.edu

Purpose
This pre-test questionnaire is a necessary part of the recruitment process. This will determine participant eligibility, ensuring that all selected subjects are qualified for the study by following the inclusion and exclusion criteria.

Instructions
Please answer the following questions to the best of your knowledge.

1. Are you currently a student at Ohio University? (Y / N)

2. What is your sex? (M / F)

3. What is your shoe size? (M____ / W____)

4. Do you have any of the following:

    a. Chronic venous insufficiency (Y / N)

    b. Deep vein thrombosis (Y / N)

    c. Raynaud's phenomenon (Y / N)

    d. Anemia (Y / N)

e. Arteriosclerosis (Y / N)

f. Diabetes? (Y / N)

5. Do you have impaired sensation to either of your lower legs? (Y / N)

   If yes, please describe.

6. Do you have any new or open wounds on either of your lower legs? (Y / N)

   If yes, please describe.

7. Do you have sensitivity to heat? (Y / N)

   If yes, please describe.

Thank you for completing the pre-test questionnaire.

By signing below, you are stating that all questions have been read, understood, and answered to the best of your knowledge.

Signature____ Date____________

Printed Name____