

WETTED ICE BAGS: DOES THE TEMPERATURE OF THE WATER ADDED TO THE ICE
BAG REALLY MATTER?

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Wetted Ice Bags: Does the Temperature of Water Added to the Ice Bag
Really Matter?

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ABSTRACT

Currently, no consensus exists on how many degrees to decrease tissue temperature for a beneficial cryotherapy treatment,^{1,2} so it is accepted that colder tissue temperatures achieve more beneficial treatments.³ There is evidence supporting the superiority of wetted ice bags over non-wetted ice bags for decreasing tissue temperature. Wetted ice bags can be further altered through changing the water temperature inside the bag. Thus, the water inside the bag would cause a phase change inside the modality; in turn, more heat transferred from the body to the modality, resulting in cooler skin temperatures. The purpose of this study was to determine the skin temperature differences between two wetted ice bags with 5°C and 15°C water. The 5°C wetted ice bag decreased skin temperature slightly greater than the 15°C wetted ice bag, indicating that temperature of water inside an ice bag played a role in the decrease of skin temperature.

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CHAPTER 1. INTRODUCTION

Cryotherapy is a frequently used modality in the treatment of acute injuries.⁴⁻¹¹ It is widely accepted as a modality used in the acute phase of injuries because of the many physiological and biological properties. Cold is accepted as a treatment in the management of acute injuries because of its ability to reduce blood flow via vasoconstriction,⁴⁻⁹ prevent hemorrhage,¹² prevent edema,^{4, 12-13} decrease nerve conduction velocity,^{1, 4-8, 12, 13} relieve pain,^{1, 5-8, 12-13} decrease muscle spasm,^{1, 5-6, 12-13} decrease cellular metabolism, which can limit the amount of secondary tissue death,^{1, 4-7, 13} and decrease the inflammatory response.^{5, 7-8, 13}

Unlike thermotherapy, the research on cryotherapy is inconclusive for both depth and penetration of cryotherapy treatments and the ideal tissue temperature for treatment of acute and chronic injuries. Research reports that cold modalities achieve the coldest skin and intramuscular temperatures.^{4-7, 9-12} However, there is no conclusive research found to indicate what amount of tissue temperature is best to achieve a therapeutic effect.¹⁻² Therefore, the consensus is that the modality that produces the greatest reduction in tissue temperature will have the most beneficial physiological results.^{9, 3}

One reason differences occur in the amount of temperature decrease among cold modalities is whether or not a phase change has occurred.⁴ A phase change is the transition from solid to liquid without a chemical and temperature change of the substance.¹⁴ Cryotherapy modalities that transition through a phase change are supported in the literature with ice bags decreasing tissue temperature more than frozen peas and gel packs.^{7, 9} However, ice bags can be broken up into three different types: crushed ice, cubed ice, and wetted ice. Wetted ice bags are any combination of ice (cubed or crushed) and water (temperature or volume) mixed together in an ice bag. These are three different variations of cold modalities that achieve different levels of

tissue temperature decreases. Dykstra et al.⁴ discovered that wetted ice bags allow the greatest tissue temperature reduction because they transition through the greatest phase change,⁴ and cover a greater amount of surface area,⁴ because water is a greater conductor of thermal energy.⁴ However, only a few studies have been performed on wetted ice bags. In addition, Carvalho et al.¹⁰ performed another study in 2012 to compare ice and wetted ice for a 15-minute treatment over the thigh. Dykstra et al.⁴ defined his wetted ice bags as a combination of 2000mL of cubed ice and 300mL of room temperature water. Carvalho et al.¹⁰ did not define their specific research information in their article, but upon interview stated their wetted ice bags were a mixture of 760g cubed ice and 240g of water which they used out of a faucet at room temperature.^{10, 15} Both Dykstra et al.⁴ and Carvalho et al.¹⁰ reported that a wetted ice bag produced colder results than just the ice bag alone.

Statement of the Problem

Researchers have often compared cold modalities and their effect on surface and intramuscular temperatures.^{4-7, 9-12} In addition, it has been established that the greater the temperature difference between the cold modality and the body part, the more rapidly energy is transferred from the body to the modality.³ This results in colder tissue temperatures and deeper temperature penetration due to a greater amount of energy transfer.³ Research also supports that wetted ice bags produce colder skin temperatures than both cubed and crushed ice bags.⁴ Furthermore, two studies were performed comparing wetted ice to crushed and/or cubed ice. In both studies, wetted ice produced lower surface temperatures.^{4, 10} The rationale for the results was that water is a better thermal conductor than air. However, there is no additional research studying differences in wetted ice bags. Only room temperature water has been applied inside a wetted ice bag to determine the effect on skin and intramuscular temperature decrease.^{4, 10, 15} Up

to this point, different water temperatures in a wetted ice bag have not reported. This research could help clinicians use the appropriate water temperature to achieve the coldest tissue temperature for acute injuries.

Purpose of the Study

The purpose of this study was to determine the possible differences in the effects of wetted ice bags using 5°C and 15°C water on the decrease of skin temperatures.

Research Questions

1. Will the use of 5°C water in a wetted ice bag result in a decrease in the skin temperature more than the 15°C water in a wetted ice bag?
2. Will the use of 5°C water in a wetted ice bag result in a greater phase change than 15°C water?

Definition of Terms

Cryotherapy- The application of therapeutic cold to living tissues. ³

Latent Heat of Fusion- Quantity of heat required to make the material change phase from solid to liquid. ^{5, 9, 11}

Law of Thermodynamics- Heat transfer is always unidirectional from high heat to low heat. ^{4, 9, 13}

Zerth Law of Thermodynamics- If two bodies are in thermal equilibrium with a third body then the first two bodies are in thermal equilibrium with each other. ¹⁶

Thermal Equilibrium- The condition under which two substances in physical contact with each other exchange no heat energy, the two substances are said to be at the same temperature. ¹⁷

Metabolism- The sum of physical and chemical reactions taking place within the body. ³

Phase Change- A change from one state (solid, liquid or gas) to another without a change in chemical composition. ¹⁴

Physiological- The scientific study of function in living systems. ¹⁸

Specific Heat- Amount of heat required to raise a specific mass by a specific number of degrees.

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Surface Area- The extend of a two-dimensional surface enclosed within an boundary. ¹⁹

Temperature Gradient- The rate of change of temperature with displacement in a given direction from a given reference point. ²⁰

Thermal Energy- Energy that is generated and measured by heat. ²¹

Thermodynamics- A branch of physics that deals with the relationships and conversions between heat and other forms of energy. ²²

Cryocompression- Squeezing of a body part in an ice-cold device, wrap, or sleeve. ²³

Intermittent Compression- Device to provide compression in an on-off timing sequence to include inflated pressure sleeves and compression pumps. ²⁴

Game Ready®- Provides the continuous circulation of ice water through a flexible fabric and plastic wrap and dynamic intermittent pneumatic compression. ²⁵

Wetted Ice Bag- Ice bag that has a mixture of both ice and water. ⁴

Importance of the Study

There is no general consensus on how many degrees a cryotherapy treatment must decrease the tissue in order for a physiological benefit to occur, ^{1,2} so it is accepted that the colder the tissue temperature, the more beneficial the cryotherapy treatment. ³ If the rationale for an effective cryotherapy modality is one that decreases the tissue temperature the most, there is evidence supporting the effectiveness of a wetted ice bag for decreasing tissue temperature more than any other cryotherapy modality. However, only two studies have been performed on wetted ice and both studies use room temperature water. ^{4, 10, 15} It is important to examine the water

temperature in a wetted ice bag because it is currently unknown whether or not water temperature impacts tissue temperature decrease. In addition, there is a possibility that wetted ice bags can be further enhanced to make them an even more effective treatment. This is because the greater the temperature difference between the modality and the tissue (temperature gradient), the more rapid the thermal energy is exchanged; therefore, more energy is transferred—resulting in colder tissue temperatures.^{1,2} Wetted ice bags can be altered though changing the water temperature inside the bag with either crushed or cubed ice. Thus, the water inside the ice bag would theoretically cause a phase change inside the modality, in turn causing more heat to be transferred from the body to the modality, and resulting in cooler skin temperatures.

Limitations

1. The researcher asked the subjects to not eat, drink, or exercise 1 hour prior to the study; however, subjects self-reported adherence to the request.
2. This experiment was performed on uninjured tissue.
3. Participants were healthy individuals with no injury to the right calf in the last six months.
4. The results of this study were generalized to college aged healthy individuals.

Delimitations

1. The wetted ice bag consisted of 170mL of water.
2. The wetted ice bag consisted of 1kg of ice.
3. Participants were males and females ages 18-26.
4. The subjects were instructed to not eat, drink, or exercise 1 hour prior to the study.

CHAPTER 2. REVIEW OF LITERATURE

The purpose of this study is to determine the possible differences in the effects of wetted ice bags using 5°C and 15°C water on the decrease of skin temperatures. The following research questions guide this study: Will the use of 5°C water in a wetted ice bag result in a decrease in the skin temperature more than the 15°C water in a wetted ice bag? Will the use of 5°C water in a wetted ice bag result in a greater phase change than 15°C water? This review of literature is organized into the following areas: cryotherapy thermodynamics, cryotherapy parameters, cryotherapy techniques, barriers to heat transfer, compression, and wetted ice.

Ice is generally used as a modality for an acute injury due to the many biological and physiological benefits, including the following: ability to reduce blood flow via vasoconstriction, ^{4-8, 12} prevent hemorrhage, ¹² prevent edema, ^{4-7, 12-13} decrease nerve conduction velocity, ^{1, 4-8, 12-13} relieve pain, ^{1, 5-8, 12-13} decrease muscle spasm, ^{1, 5-6, 12-13} decrease cellular metabolism which can limit the amount of secondary tissue death, ^{1, 4-7, 13} and decrease the inflammatory response, ^{1, 5, 7-8, 13} More specifically, cryotherapy is a commonly used modality in the athletic training room for musculoskeletal injuries. ^{1, 4, 7, 12}

Cryotherapy Thermodynamics

All cryotherapy treatments follow one law. It is the law of thermodynamics: heat transfer is always unidirectional from high heat to low heat. ^{4, 9, 13} This means when an ice pack is applied, the heat is going to be drawn out of the tissue (high heat) and put into the ice pack (low heat), cooling the tissue and melting the ice pack, until both reach an equilibrium. The bigger the difference between the two temperatures, the faster equilibrium will be reached. ³

With a phase change, more energy is required to change a solid to a liquid. The energy comes from the body in the form of heat. Therefore, more heat is transferred with a modality that

can go through a phase change. The ability of a modality to absorb heat depends on the size and type. A phase change is the transition of a substance from one state to another, such as from a solid to liquid, without a change in chemical composition.²⁶ In this instance, it is the ice melting from an ice cube to water. The amount of energy required to melt ice into water is called the latent heat of fusion.^{5,9,11} It requires 80 cal/kg to change ice to water and the energy used to melt the ice is coming from another object. However, in the example of the modality, the energy is coming from the body.²⁶ The specific heat is the amount of heat required to raise 1 kg of substance 1 degree Celsius.²⁶ The specific heat of ice is 0.50 C/gm°C, while water has a specific heat of 1.0 C/gm°C. Therefore ice requires more energy than water to raise its temperature because it has a lower thermal conductivity.³ Additionally, the higher the specific heat, the more energy it can withdraw. This transfer of energy results in a phase change from solid to liquid and melting of the ice. With this example, liquid (water) is a much more efficient thermal conductor than the solid (ice).⁴ The water between the ice cubes in wetted ice bags makes them better thermal conductors because the water is a better thermal conductor than the air that surrounds the ice in non-wetted ice bags.⁴

Cryotherapy Parameters

There are inconsistencies in the literature regarding recommended cryotherapy application. Mac Auley et al.²⁷⁻²⁸ discovered inconsistencies in the duration, frequency, and mode of cryotherapy application in acute soft tissue injuries. Smith et al.²⁹ also studied treatment duration and found discrepancies. Since there is no general consensus in the optimal decrease of tissue temperature for cryotherapy treatments,¹⁻² it is accepted that the modality that achieves the coldest temperature reduction is the best.³

There are multiple factors that affect tissue temperature decrease in a single cryotherapy treatment. These factors include: temperature gradient, surface area, size of modality, and duration of treatment. The temperature gradient is the difference between tissue and modality temperatures.²⁰ The greater the difference, the more rapid the energy is exchanged and the deeper the modality will penetrate the tissue.³ In addition, surface area is an integral part of a cryotherapy treatment because a modality that conforms well over a large surface area will be able to draw more heat out of the tissues, therefore lowering tissue temperatures more efficiently and effectively.⁴ Furthermore, the size of the modality can also impact tissue temperature change because the tissue temperature and the sizes of both modality and surface area are correlated. Thus, the larger the surface area, the more tissue is affected, and consequently, more heat is transferred to the modality, resulting in cooler tissue temperatures.¹⁰ The final factor is the duration of treatment. Theoretically, the longer the treatment, the more time to draw heat out of the tissue.³ This extra time allows the modality and body temperature to attempt equilibrium. If these two temperatures reach and maintain equilibrium, then according to the zeroth law of thermodynamics, they must reach an equal temperature with a third outside source to achieve thermal equilibrium.³⁰⁻³¹

Cryotherapy Techniques

Research supports the notion that different forms of ice treatments are superior to all other forms of cryotherapy. Merrick et al.⁹ compared the cooling effects of a crushed ice bag, wet-ice, and a frozen gel pack. In this study, wet-ice is a commercial cryotherapy pack which is described as frozen water encased in a plastic bag and wrapped in a terry cloth. The researchers measured temperatures for 20 minutes at superficial and intramuscular depths. Merrick et al.⁹ reported the crushed ice bag and wet-ice produced cooler temperatures that was statistically

significant to those of the gel pack. The authors reported that this was because cryotherapy modalities that go through a phase change absorb substantially more heat than those that do not.⁹ This was supported with the crushed ice and wet-ice as compared to the gel pack. Both the crushed ice and wet-ice transitioned through a phase change, whereas the gel pack did not.⁹

Furthermore, another study performed by Kanlayanaphotporn et al.⁷ compared skin surface temperatures after the application of crushed ice, gel pack, frozen peas, and a 4:1 mixture of water to 70% alcohol cooled in a freezer.⁷ The researchers reported the crushed ice and water and alcohol mix reduced skin surface temperatures more when compared to the gel pack and frozen peas. This is again more evidence to support the argument that cryotherapy modalities that transition through a phase change produce colder tissue temperatures, in this instance the crushed ice changed from solid to liquid.⁷ In previous research, different forms of ice compared frozen peas, gel pack, or an alcohol and water mix.⁷ However, Chesterton et al.¹¹ compared frozen peas to gel cold packs. The researchers reported that the frozen peas produced significantly colder surface skin temperatures. The researchers theorized that this was due to the fact that frozen peas have a small amount of water content between them and therefore transitioned through a phase change, whereas the gel pack did not have any water content. This phase change resulted in heat from the tissues moving into the frozen peas, thus achieving the lower tissue temperature.¹¹ This evidence supports the notion that modalities that transition through a phase change lead to a greater tissue temperature reduction because of the greater heat transfer.^{5,7}

Barriers to Heat Transfer

Barriers put between a cryotherapy modality and the treatment area have been theorized to help prevent allergic reactions and frostbite from a cryotherapy treatment, but the research has

yet to support this theory.⁵ For example, towel/elastic wraps are theorized to be effective barriers between cold modalities and skin, which then can protect skin from adverse effects while allowing cold to treat muscle pathologies. However, these wraps not only protect skin, but also limit the effectiveness of the cryotherapy treatment on the intramuscular tissue.^{5,32} In 2004, Janwantanakul et al.⁵ compared skin surface temperature during a 20-minute application of a chipped ice bag, both with and without a damp towel wrap. The researcher reported that the ice bag was wrapped with a towel to measure skin temperature with and without a barrier. They found that the barrier significantly hindered the skin temperature reduction as compared to the skin temperature reduction after the use of the non-wrapped ice bag. Janwantanakul et al.⁵ speculated that barriers as a prevention strategy are unnecessary because as the ice melts, its temperature increases. In addition, Janwantanakul et al.⁵ argued that the barrier is unnecessary because the heat is absorbed directly from the tissues into the ice bag; this absorption decreases the chances of adverse reactions. Janwantanakul et al.⁵ stated that the barrier only acted as an insulator preventing the tissue from the full effects of the cryotherapy treatment.⁵

Similarly, Tsang et al.³² examined the effects of cryotherapy and barriers on surface skin temperatures for a 30-minute treatment and a 20-minute post treatment using dry towel, dry elastic wrap, and cubed ice treatments applied directly to the skin. In this experiment, a dry towel was a single layer of 100% cotton towel wrapped over the skin; a dry elastic wrap was a 3-inch elastic bandage wrapped from distal to proximal overlapping by one half. The control treatment, a cubed ice bag, resulted in the greatest mean surface skin temperature reductions ($31.51 \pm 1.12^{\circ}\text{C}$ to $10.12 \pm 2.65^{\circ}\text{C}$). The second greatest mean surface skin temperature reduction was the dry towel wrap, which reduced skin temperature from $31.19 \pm 0.93^{\circ}\text{C}$ to $20.9 \pm 2.29^{\circ}\text{C}$. Finally, the lowest mean surface skin temperature reduction resulted from the dry elastic wrap treatment,

which reduced skin temperature from $30.72 \pm 1.86^{\circ}\text{C}$ to $25.67 \pm 2.42^{\circ}\text{C}$. The results from this study are similar to the results from Janwantanakul et al.⁵ in that both barriers limited the effectiveness of the cryotherapy treatment.

Adipose Tissue

In addition to non-physiological barriers, adipose tissue separates muscle tissue from skin, thus slowing the cooling of the intramuscular tissue. Therefore, adipose tissue works similarly to a towel/elastic wrap barrier in that it prevents the full effects of the treatment. It acts as a barrier between skin and intramuscular tissue preventing heat from being withdrawn from the tissue.³³ Research shows that because of this barrier effect, more time is needed to withdraw heat from tissue.³³ Furthermore, adipose tissue thickness differs among genders and activity levels, and throughout the body.³³ Jutte et al.³³ compared skinfold thickness in 8 common cryotherapy application sites in both male and female Division I student-athletes and recreationally active college athletes. The researchers stated adipose thickness varied throughout 8 different locations (scapula, deltoid, ulnar groove, forearm, thigh, MCL, calf, and ATF) and among genders and activity levels. The data showed that female athletes had larger skinfold measurements than their male counterparts, for both elite and recreational athletes and for most skinfold sites except the ATF, scapula, and ulnar groove. Their evidence also showed that intramural athletes on average had larger adipose tissue measurements than their division I counterparts at all skinfold sites except the ATF, deltoid, and ulnar groove. In addition, this research revealed different adipose tissue depths at varying sites, with the smallest variation occurring between gender and activity level in the ATF (DIM 3.5 ± 1.6 , RecM 2.4 ± 1.1 , DIF 2.6 ± 0.6 , RecF 2.8 ± 3.8) and ulnar groove (5.3 ± 1.9 , 5.3 ± 1.5 , 5.4 ± 1.8 , 5.8 ± 2.6); the greatest variations occur in the thigh (13.0 ± 5.4 , 15.8 ± 7.2 , 19.5 ± 4.7 , 25.7 ± 8.5) and MCL (11.0 ± 4.4 ,

13.1±5.6, 17.3±4.6, 22.0±7.7). This information is important to consider because adipose tissue not only varies between men and women and location on the body, but also affects the temperature reduction rate during a cryotherapy treatment.

Based on these differences in adipose tissue, researchers questioned cryotherapy treatment times and theorized that a longer treatment time is needed for two reasons. The first reason was that the more adipose tissue a person has, the greater the distance the cold has to penetrate to reach intramuscular tissue, ultimately requiring longer treatment durations. The second reason was that the low thermodynamic properties of adipose tissue suggest that it is an insulator. This indicates that heat does not transfer well through adipose tissue, therefore also requiring a longer duration to allow the heat time to move from the body to the modality. Consequently, the more adipose tissue, the longer the process.¹ These results are supported in another study by Jutte et al.,⁶ in which they reported time as the strongest predictor of muscle temperature during cooling and rewarming when compared to skin and intramuscular temperature, room temperature, body core temperature, and adipose tissue. A similar study, conducted by Otte et al.,¹ examined the effects of subcutaneous adipose tissue thickness on cryotherapy duration. This study provides further evidence for the correlation between adipose tissue and time. The data supports the supposition that the greater the adipose tissue depth, the greater the treatment time required to achieve the same desired results. The authors also provided a recommended cryotherapy treatment duration chart: for adipose thickness of 0-10mm, 12 minutes are required to achieve optimal temperatures; for adipose thickness of 11-20mm, 30 minutes are required; for adipose thickness of 21-30mm, 40 minutes are required; and for adipose thickness of 31-40mm, 60 minutes are required.¹ However, because an optimal temperature is yet to be established, these authors chose a 7°C decrease from baseline because

they thought it was a fairly typical effect during a cryotherapy treatment.¹ In addition to increases in treatment times according to increases in adipose tissue, Myrer et al.³⁴ evaluated intramuscular temperatures (1cm and 3cm) of three separate calf skinfold thicknesses (8mm or less, 10-18mm, 20mm or greater) for a 20 minute treatment and 30 minute recovery period. They reported the more adipose tissue, the more treatment time is required to achieve desired results. Furthermore, they also discovered that with increasing adipose tissue, more time was needed to return the tissue to normal temperatures post-treatment. These results support the theory that adipose tissue is an insulator. This evidence also supports the theory that cryotherapy treatment durations need to vary based on location and amount of adipose tissue. Therefore, similar to the results found by Janwantanakul et al.,⁵ adipose tissue acts as an insulator like a damp towel wrap. This also means that barriers, such as adipose tissue, can limit the effectiveness of treatment. In addition, because barriers other than adipose tissue are unnecessary, treatment durations need to be adjusted according to the amount of adipose tissue present.

Compression

Compression has been combined with cryotherapy to help increase direct contact and to help decrease edema formation in acute injuries.^{12-13, 35-37} Specifically, compression wraps have been used over ice bags to help increase direct contact and therefore help decrease tissue temperature faster than an ice bag alone.¹³ Compression is most commonly applied using elastic wraps or intermittent compression devices, which combine ice and compression. For example, a Game Ready® machine is a well-known intermittent compression device. In addition, cryocompression devices are successful in helping decrease edema because they increase the external pressure on tissues and prevent edema from traveling to the afflicted areas.^{35, 37}

Elastic Wraps

Research supports the notion that compression wraps help reduce tissue temperature by decreasing blood flow to the afflicted area, increasing surface area of the modality, and reducing heat loss to the environment.^{12-13, 14} Janwantanakul et al.¹³ examined the effects of a chipped ice bag with five different levels of compression (0, 14, 24, 34, and 44 mmHg) on the cold pack/skin interface temperature in the left thigh for a 20-minute treatment. He reported temperatures during the chipped ice with compression were significantly lower than temperatures during chipped ice without compression. There was no difference in cold pack/skin interface temperature for different levels of compression. However, the higher the level of compression, the shorter the time to reach the lowest recorded temperature. Janwantanakul et al.¹³ theorized that the different levels of compression did not affect cold pack/skin interface temperature, but instead affected the rate of cooling. This was conceivable because, as the level of compression increased, the blood flow decreased, therefore reducing the blood's ability to rewarm the area being cooled.¹³

Similarly, Merrick et al.³⁵ examined the skin and intramuscular temperatures (skin, 1cm, and 2cm) when comparing compression, crushed ice, and crushed ice plus compression at baseline, after a 30-minute treatment and after a 20-minute recovery period. They reported, at all tissue depths, ice and ice plus compression resulted in significant temperature decreases. However, ice plus compression resulted in significantly colder tissue temperatures for skin, 1cm intramuscular depth, and 2cm intramuscular depth than just ice alone. Not only was ice plus compression colder than ice, but it also reached the colder temperature faster, suggesting that compression wraps also impact the rate of cooling. Merrick et al.³⁵ and Janwantanakul et al.¹³ similar findings support the theory that the rate of cooling increases because compression decreases local blood flow to the area, therefore reducing the body's ability to rewarm the area.

Similar to the effects of ice and cold seen in humans, the effects of cold and compression have also been observed in animals. Barlas et al.¹² examined intramuscular temperatures at baseline and every ten minutes for an hour using a chemical instant cold pack on the thigh in mongrel dogs. Researchers reported intramuscular temperature was lower for the compressed cold pack with the lowest temperatures recorded at 20 minutes into the one-hour treatment session. Researchers did not mention any consistency in applying the compression wrap on the thigh of the dogs. However, according to the research performed by Janwantanakul et al.,¹³ the rate of cooling would only be affected and not the temperature.

Cryocompression Devices

Cryotherapy has been used on inflammation with success to decrease pain,^{1, 5-8, 12-13} muscle spasms,^{1, 5-6, 12-13} and edema.^{1, 5, 7-8, 13} In addition, compression has also had success in decreasing pain, muscle spasm, and edema.¹²⁻¹³ In theory, if the two were combined, the results may be even more beneficial than either modality alone. In fact, in order to help reverse edema in the tissues, compression devices have been developed to help ‘push’ the edema back into the lymphatic system.³⁸⁻³⁹ Cryocompression then, is the combination of ice and compression to theoretically combine the benefits of both modalities. Healy et al.³⁶ performed a study comparing a cryocompression device against a crushed ice bag and ace wrap to test the effectiveness of range of motion, swelling, wound drainage, and narcotic requirements after a total knee arthroplasty. Researchers did not demonstrate a statistically significant effect of either modality in this study. In a similar study, Dervin et al.³⁷ also failed to show any clinical significance of cryocompression helping with postoperative Anterior Cruciate Ligament Reconstruction knee drainage, pain requirements, and hospital stay. However, both studies used a barrier between the cryocompression modality and skin, and both neglected to observe tissue

temperature. As supported by both Janwantanakul et al.⁵ and Tsang et al.³², the use of the barrier acts as an insulator, and prevents the full effects of the treatment. Current research supports that in order to reach an analgesic effect for cryotherapy, the skin has to reach a temperature of 13.6-15.6°C.^{7, 10-11, 32} With the barrier in between the skin and the modality, the modality is less likely to reach analgesia. As stated before, both Healey et al.³⁶ and Dervin et al.³⁷ neglected to look at skin temperature in their research studies. However, without observing tissue temperature, researchers cannot insure analgesia is reached, therefore decreasing the potential pain reducing effects of the treatment, which, in the end, is what both Healey et al.³⁶ and Dervin et al.³⁷ were trying to measure.

Cryocompression may not have success in decreasing pain in patients with knee surgeries,³⁶⁻³⁷ but it has shown more success in patients with ankle edema.³⁸⁻³⁹ Airaksinen et al.⁴⁰ in a study on intermittent compression therapy in lower limb edema, reported a decrease in edema in the subcutaneous compartment. Airaksinen et al.⁴⁰ also reported a mean increase of muscle tissue density, but since none of their patients were involved in rehabilitation during the experiment, they theorized that the change was most likely due to the decrease in edema. Furthermore, Mora et al.³⁸ examined the effects of cryocompression in edema reduction following ankle fractures. One group was given cryocompression prior to surgery to help reduce edema while the other group stayed in their bi-valve long leg cast. In this study, cryocompression was found to significantly decrease edema as compared to the control group at 24, 48, and 72 hours. Additionally, Stockle et al.³⁹ observed the effects of intermittent compression and cryocompression devices on posttraumatic edema. These researchers compared intermittent compression and cryocompression devices against a cold pack to see which had the greatest reduction in posttraumatic edema, and a significantly greater decrease in ankle circumference

was observed at 24, 48, and 72 hours for both the intermittent compression and cryocompression devices. In addition, intermittent compression showed a slightly greater reduction of edema than cryocompression, but it did not reach the significance level. Given these points, both Mora et al.³⁸ and Stockle et al.³⁹ concurred that compression devices work in decreasing edema because they activate the venous pump in the foot without activating the muscles. Compression devices function just like muscle contractions that pump blood back to the heart. However, because the muscle is not contracting, the compression device allows the injured tissue adequate time to heal without interrupted blood flow. For both the Mora et al.³⁸ and Stockle et al.³⁹ experiments, researchers put barriers between the skin and the cryocuff of the cryocompression device. Their theory was this can prevent frostbite, however, as mentioned above and by Janwantanakul et al.,⁵ placing a barrier between the modality and the skin only detracts from the treatment. So theoretically, both Mora et al.³⁸ and Stockle et al.³⁹ may have had better results without the barrier.

Game Ready® is an intermittent device that combines compression and cryotherapy. It has four different settings: no compression, low (5-15 mmHg), medium (5-50 mmHg), and high (5-75 mmHg).⁴¹ Patients are fitted with a sleeve through which cooled water flows. The sleeve also varies between inflated and deflated pressure settings. Hawkins et al.⁴² compared the Game Ready® device, a slush bucket, and a crushed ice bag and compression wrap on the ankle measuring intramuscular and skin temperatures at baseline, 10, 30, and 50 minutes. They reported that intramuscular and skin temperatures were similar between the crushed ice bag, the compression wrap, and the slush bucket methods, and all produce a greater cooling than the Game Ready® device. Similarly, Holwerda et al.²⁵ compared crushed ice and compression wrap to the Game Ready® device applied over the quadriceps muscle at three settings: no

compression, medium compression, and high compression. They measured oral, skin, and intramuscular temperatures at baseline, after a 30-minute treatment, and after a 30-minute recovery, and reported the medium and high Game Ready® settings produced greater intramuscular temperature decreases. They also reported the average skin temperature was between 4-15°C, which falls within the range of reaching analgesia 13.6-15.6°C.^{7, 10-11, 32} So at the superficial level, Game Ready® is able to decrease pain. Furthermore, in order to decrease the tissue metabolic rate, the intramuscular and skin temperatures need to be maintained at 10-11°C.^{1, 6} Furthermore, Holwerda et al.²⁵ measured intramuscular temperature as between 22-31°C, suggesting Game Ready® is not as beneficial as other cryotherapy modalities at decreasing pain and metabolic rate. Hawkins et al.⁴² theorized that this was because the sleeve of the Game Ready® continually inflates and deflates and this cyclical compression detracts from decreasing tissue temperatures. This indicates that the Game Ready® may be better suited for edema reduction as supported by Mora et al.³⁸ and Stockle et al.³⁹

Wetted Ice

Current research supports the theory that the cryotherapy treatment that achieves the coldest tissue temperature will have the most beneficial results;^{4, 7, 9} therefore it is understandable for researchers to search for the modality that achieves the coldest tissue temperature. One such modality is the wetted ice bag, which are ice bags that have a mixture of ice and water in them. In light of this search, current research indicates that wetted ice bags decrease tissue temperatures more than ice bags.^{4, 10} There are two main factors that cause wetted ice bags to produce colder tissue temperatures than non-wetted ice bags. The first is that the wetted ice bags have an ability to conform closely to the body part.^{4, 10} This is because water increases the area and space between each ice cube, as compared to the air that is between each

ice cube in a non-wetted ice bag. This leads to not only a greater surface area, but also to better direct contact between the modality and the skin. Second, the water in wetted ice bags is a better thermal energy conductor than the air that is between the ice cubes in crushed and cubed ice bags.⁴

These two factors are apparent in a research study performed by Dykstra et al.⁴ These researchers compared superficial and intramuscular temperatures after a 20 minute treatment period and 120 minute recovery period using wetted, cubed, and crushed ice bags over the right gastrocnemius muscle. In this study, researchers reported wetted ice decreased superficial temperatures significantly more than either cubed or crushed ice bags. The researchers also reported wetted ice had lower intramuscular tissue temperatures during the recovery phase, meaning that the muscle retained the cold in the tissues longer after the ice bag was removed. The total change in temperature throughout the entire treatment was 17.0°C for wetted ice, 14.1°C for cubed ice, and 15.0°C for crushed ice. Again, this supports that wetted ice produces colder tissue temperatures than either cubed or crushed ice.

Furthermore, the importance of the factors of increased surface area and ability to conform are supported in a study performed by Carvalho et al.¹⁰ These researchers compared cubed ice bags to wetted ice bags to determine which caused a greater superficial temperature decrease in the rectus femoris muscle 0, 15, and 30 minutes post application. Results from this study also demonstrated that wetted ice produced colder superficial temperatures than ice bags. The authors of this study did not mention which type of ice was used in the regular ice bags, whereas the Dykstra et al.⁴ compared wetted ice bags to cubed and crushed ice bags. Both the Dykstra et al.⁴ and Carvalho et al.¹⁰ studies also did not specify the water temperature used in the wetted ice bags. However Dykstra et al.⁴ stated they used room temperature water in their

wetted ice bags. Because wetted ice bags contain a mixture of water and ice, the addition of water increases the surface area and this greater area is theorized to cause a greater decrease in the tissue temperature. However, a study performed by Janwantanakul et al.⁴³ compared ice pack/skin interface temperature after application of different amounts (0.3, 0.6, 0.8kg) and sizes (18x23cm and 20x25cm) of crushed ice bags. In this study, the size of the contact area did not significantly affect the skin temperature but instead slightly affected the rate of cooling. Due to the lack of evidence to support any theory as to why increased surface area decreased tissue temperature, researchers suggested wetted ice bags are less affected by increased surface area and more affected by the transfer of thermal energy.^{4, 10} Although there have been only two studies performed on wetted ice bags, both studies supported wetted ice bags as effective for decreasing superficial and intramuscular temperature as compared to non-wetted ice bags.^{4, 10} However, there is still not enough research to support wetted ice bag superiority over a non-wetted ice bag. Moreover, there are no studies to date that examine different variations of wetted ice bags, including: water volume, water temperature, ice amount, and ice type.

Summary

Cryotherapy has many physiological effects. These effects are based on two main physiological effects: vasoconstriction and a decrease in local nerve conduction velocity. Once blood vessels are constricted, blood flow is decreased. This decrease in blood flow also decreases cellular metabolism and ultimately secondary tissue death. In addition, these decreases also reduce the signs of inflammation and thus the formation of edema. In addition, a decline in local nerve conduction velocity decreases pain and muscle spasm.^{1, 4-5, 8, 12-13}

Research supports the notion that ice is superior to gel packs, frozen peas, and a water and alcohol mix when trying to establish physiological effects for a cryotherapy treatment.^{7, 9}

This is because the ice goes through a phase change and conforms to the body better, which allows more heat to be withdrawn from the tissues, thus in turn allowing the tissue to reach colder temperatures.^{5,7,9,11} There is substantial research on different variations of cryotherapy, but no general consensus has been established on how many degrees tissue temperature should be decreased for optimal physiological benefits.^{1,2} Because of this lack of consensus, the only established agreement has been that the cryotherapy modality that achieves the coldest temperatures will have the most beneficial results.³ The most current research supports wetted ice bags are more beneficial than non-wetted ice bags for achieving lower tissue temperatures. This is due to the fact that they have water in the bag instead of air. The literature maintains that water is a better thermal energy conductor than air, which is the main component in the cubed and crushed ice bags.⁵ Even though wetted ice bags have research supporting their effectiveness over cubed and crushed ice bags, there is no current research testing different variations of the wetted ice bag.

CHAPTER 3. METHODOLOGY

The purpose of this study was to determine the possible differences in the effects of wetted ice bags using 5°C and 15°C water on the decrease of skin temperatures. The following are research questions that guided this study: Will the use of 5°C water in a wetted ice bag result in a decrease in skin temperature more than the use of 15°C water in a wetted ice bag? Will the use of 5°C water in a wetted ice bag result in a greater phase change than 15°C water in a wetted ice bag? This chapter focuses on: experimental design, population, instruments for data collection, procedures, and data analysis.

Experimental Design

A repeated measures cross over research design was used in this study. The independent variables in this experiment were 5°C wetted ice, 15°C wetted ice, and time. The dependent variables for this experiment were superficial skin temperature and volume of water.

Population

North Dakota State University's Institutional Review Board approved this study. A mass recruitment e-mail was sent out to the entire student population and the first 15 males and 15 females to respond were selected to participate. However, this source of recruitment may have been biased towards individuals who had prior injuries or who were athletes. Due to these biases inclusion and exclusion criteria were established to eliminate bias. If all 30 volunteers met all of the inclusion and exclusion criteria specified they were then able to participate in the study.

Of the forty-one volunteers that responded via e-mail thirty (response rate 75.6%) were selected for this study because this sample size was greater than similar studies.^{4, 10} One subject was withdrawn from the study due to an injury sustained to the right leg, thus contributing to a dropout rate of 3.23%. After this subject was withdrawn, the next subject to email the researcher

was asked to participate. Inclusion criteria included men and women between the ages of 18 and 26. The subjects were excluded from the study if they had a prior history of smoking,^{5, 7, 11, 13, 43} cardiovascular^{5, 7-8, 11, 13} or peripheral disease,^{5, 7, 11, 13} diabetes,^{5, 7, 11, 13} neurological^{1, 5, 7, 11, 13} or muscular pathologies,^{7, 11, 13, 43} history of trauma or injury 1 month prior to the study on the right lower extremity,^{2, 4-5, 12-13} presence of any sores or open wounds on the right calf,^{5, 7-8, 11, 13} hot or cold sensitivity^{4, 7, 10, 13} or allergy,^{4-5, 7, 13} Raynaud's phenomenon,⁸ or vascular disease in the lower leg.^{1, 4-5, 7, 13} The subjects were also instructed to not consume alcohol^{11, 13, 25, 43} or anti-inflammatory medications at least 2 hours prior to arriving at their appointed date to help stabilize extremity blood flow.^{11, 13} They were also instructed to avoid caffeine,^{5, 11, 13, 25, 43} food consumption,^{11, 13, 43} and vigorous exercise 2 hours prior to arriving at their appointed date.^{5, 13, 25, 43} The subjects met with the researcher on the first day of testing to have a sensitivity test performed. The researchers used a sensitivity test that was different than what was reported in the literature.^{5, 7, 11} The researchers choose to use an ice massage to assess for cold allergies rather than an assessment commonly found in the literature: test tubes filled with hot or cold water.^{5, 7, 11} The researchers hypothesized that actually assessing ice on the skin as compared to the test tubes experiment was relevant to sensitivity test accuracy. Furthermore, an ice massage allows researchers to assess the entire treatment area throughout the duration of the treatment and allows them to discontinue the treatment as soon as signs of cold allergy appear. Furthermore, the ice massage sensitivity test allows researchers to assess the treatment area with the type of cryotherapy modality that was used in this experiment, allowing better assessment for cold allergies. Potential subjects had an ice massage performed on their right calves for 5 minutes. After 5 minutes, the ice massage was discontinued and the researcher assessed for urticaria or cold hives, which result from an allergy to the cold. If no urticaria was present, the researcher

concluded that the potential subject did not have a cold allergy and was considered fit to participate in the study.

Instruments for Data Collection

A 16-lead Iso thermex electrothermometer (Columbus Instruments, Columbus OH) was used to collect all temperature readings from the surface thermocouples (Physitemp Inc, Clinton, NJ). A volume of 170mL of water was measured with a graduated cylinder (ASTM International, West Conshohocken, PA) and added to 1kg of cubed ice measured on an industrial scale (Denver Instruments, Bohemia, NY) to form the wetted ice bag. The amount of water (170mL) was selected because that is the volume of water that was in a cubed ice bag after it melted for 30 minutes placed on the right calf of a non-trial volunteer during pretesting in the testing room. The testing room's temperature measured at 19.57°C. This amount of ice (1kg) was chosen because it is the amount of ice seen commonly in the literature and thus allows for appropriate comparisons between studies.^{10, 35} Researchers chose 5°C and 15°C water because they hypothesized that this temperature range produces significant skin temperature decreases. Both of these temperatures are still below room temperature water, which was what both Dykstra et al.⁴ and Carvalho et al.¹⁰ used in their experiments. A temperature of 5°C was selected for the colder wetted ice bag because it was the temperature of the water that was removed from a cubed ice bag after it was placed on a body during pretesting for 30 minutes. Initially, an elastic wrap was also going to be used in this experiment. However, during pretesting, if the ice bag had a hole in it, some of the water was absorbed into the elastic wrap reducing the volume of melted water from the wetted ice bag. Since researchers are collecting volume of water as data, it is not suitable to have an elastic wrap over the wetted ice bags to risk skewing the data.

Procedures

When the subjects first arrived at pretesting, they were verbally informed of the data collection procedures, given the informed consent document to sign (Appendix A), and given a health history form to fill out (Appendix B). Following the documentation, the subjects partook in sensitivity testing^{5,7,11} to rule out allergies to the cold. This was performed with an ice massage to the right calf for 5 minutes. Throughout the 5 minutes the researcher checked for urticaria, or cold allergy. If none was present, the subject was deemed fit to partake in the study and they set up their next two trial dates with a minimum of 24 hours between each testing session. The treatment order of subjects was randomized using a random number generator. Thirty numbers between 1 and 30 were randomized in a random number generator (22, 24, 26, 7, 5, 18, 30, 12, 16, 3, 29, 8, 10, 19, 6, 27, 13, 20, 11, 2, 21, 17, 9, 1, 28, 4, 23, 25, 14, 15).⁴⁴ Numbers between 1 and 15 were assigned the 5°C wetted ice bag treatment first and any numbers between 16 and 30 were assigned the 15°C wetted ice bag first.

Upon arrival at their first appointed session, participants were instructed to lie in a prone position on a treatment table. The widest circumference of the right medial gastrocnemius was measured with a centimeter tape measure (DONJOY, LLC Vista, CA) and marked with a sharpie. This location was then measured from the crest of the popliteal fossa and documented. A 5cm x 5cm treatment area was shaved and cleaned with 70% isopropyl alcohol. One surface thermocouple (Physitemp Inc, Clinton NJ) was secured to the widest part of the medial head of the gastrocnemius with tape. The subjects were monitored every 5 seconds until they stabilized at a consistent baseline temperature for at least 1 minute. Wetted ice bags were made by mixing 1kg of cubed ice with 170mL (5°C or 15°C) water in an ice bag. After a baseline temperature was established, whichever treatment was randomly assigned (5°C or 15°C) for that session was

placed over the thermocouple for 30 minutes. During this 30-minute treatment, the temperature was monitored every 5 sec, but recorded at baseline, 10 minutes, 20 minutes and 30 minutes. After this 30-minute treatment, the wetted ice bag was removed. Next, a corner of the ice bag was cut with a scissors and the water was drained into a graduated cylinder (ASTM International, West Conshohocken, PA) to be measured and recorded. The difference between the pretreatment and post-treatment volumes was the result of the phase change that occurred during the treatment session. After all temperatures were recorded, the surface thermocouple (Physitemp Inc, Clinton NJ) was removed, and the area was cleaned with isopropyl alcohol. The subject was reminded of their next appointed treatment date and they were free to leave.

When the subjects arrive at their second treatment session they were again instructed to lie prone on a treatment table. The previous treatment area was measured from the reference at the crease of the popliteal fossa and marked with a sharpie. The treatment area was cleansed with 70% Isopropyl Alcohol and the surface thermocouple was secured over the treatment area with tape. Baseline temperatures were monitored every 5 seconds until they stabilized for 1 minute. The researcher then made a wetted ice bag by mixing 1kg of cubed ice with 170mL of the temperature of water that had not been used yet. Skin temperatures were monitored every 5 seconds, but only recorded at baseline, 10, 20, and 30 minutes. After the 30-minute treatment had subsided the ice bag was removed and the volume of water remaining in the wetted ice bag was documented. The surface thermocouple was removed and the treatment area was cleansed with 70% Isopropyl Alcohol. After all subjects have completed the study, five participants were randomly selected and rewarded \$10.00 cash for their time and participation in the study.

Data Analysis

Descriptive statistics were reported for all temperatures and water volumes collected and reported as mean \pm SD. All statistical tests were calculated using SPSS version 21 software. A repeated measures analysis of variance (ANOVA) was used to compare the surface skin temperatures of both the 5°C and 15°C wetted ice bags at the 10, 20, and 30 minute marks and a descriptive t-test was used to compare the baseline and post-treatment volumes of water in the 5°C and 15°C wetted ice bags. A significance level of $P \leq 0.05$ was used for all comparisons. A sample size of 30 was calculated using a power of 0.8. Post hoc tests will be measured in the case of an interaction.

CHAPTER 4. RESULTS

The purpose of this study was to determine the possible differences in the effects of wetted ice bags using 5°C and 15°C water on the decrease of skin temperatures. The following research questions guided this study: Will the use of 5°C water in a wetted ice bag result in a decrease in skin temperature more than the 15°C water in a wetted ice bag? Will the use of 5°C water in a wetted ice bag result in a greater phase change than 15°C water in a wetted ice bag? The results are presented in the following manner: descriptive statistics, response rates, statistical results, and a summary.

Descriptive Statistics

Thirty subjects (16 females, 14 males) volunteered to participate in this study, with a mean age of 20.84 ± 2.14 years old. The goal of the starting water temperature for the 5.0°C wetted ice bag was $5.0 \pm 0.2^\circ\text{C}$ and the goal for the 15.0°C wetted ice bag was $15.0^\circ\text{C} \pm 0.2^\circ\text{C}$. The starting water temperature for the 5°C wetted ice bag had a mean temperature of $5.09^\circ\text{C} \pm 0.17^\circ\text{C}$, while the starting water temperature for the 15°C wetted ice bag had a mean temperature of $14.98^\circ\text{C} \pm 0.19^\circ\text{C}$. Both wetted ice bags were within the set parameters for acceptable starting water temperatures.

The 5°C wetted ice bag group had a room temperature range between 21.31°C-21.32°C per subject with a mean of $21.26^\circ\text{C} \pm 0.14^\circ\text{C}$, while the 15°C wetted ice bag group had a room temperature range between 21.79°C-21.79°C per subject with a mean of $21.73^\circ\text{C} \pm 0.10^\circ\text{C}$. Although the ranges were similar between groups, the means had a variance of 0.47°C. This is 0.84°F, which is unlikely to be a factor in the transfer of energy. Furthermore, there was little variance between the starting water temperatures and room temperatures recorded for each

subject throughout the experiment, so it is improbable that either starting water temperature or room temperature was a significant factor in the reduction of skin temperature between groups.

Response Rate

A mass recruitment e-mail was sent out to the NDSU student population. The first 15 males and 15 females to respond were selected to participate. Inclusion and exclusion criteria were established to eliminate bias. A list of the inclusion and exclusion criteria specified for this study is provided in Appendix B. If all 30 volunteers met the inclusion and exclusion criteria specified, they were able to participate in the study. Of the forty-one volunteers that responded via e-mail (a response rate of 75.6%), thirty were selected for this study. One subject withdrew from the study due to an injury sustained to the right leg, thus contributing to a dropout rate of 3.23%. After this subject withdrew from the study, the next individual who contacted the researcher via email replaced the withdrawn subject. If subjects' failed to attend their scheduled pretest appointments, they were not counted in the drop-out rate; they were removed from the study. This did occur in two instances. However, subjects were only counted in the drop-out rate if they failed to show up to a scheduled appointment after they qualified for the study during the pretest session.

Statistical Results

A repeated measures analysis of variance was used to compare the surface skin temperatures of the 5°C and 15°C wetted ice bags at the baseline, 10, 20, and 30 minute marks. Results were observed for the main effects of skin temperature differences and time between the 5°C and 15°C wetted ice bags. The main effect of skin temperature was not significant between the 5°C and 15°C wetted ice bags: $F(1,29) = 0.79$, $p = 0.38$, (Table 1). Conversely, the decrease in skin temperature of each individual wetted ice bag throughout the duration of the treatment was

significant: $F(3,27)= 2623.40$, $p<0.001$, indicating that both wetted ice bags continued to cool the surface temperature throughout the duration of the treatment (Table 1). Furthermore, the results also showed a non-significant effect between the two wetted ice bags over time: $F(3,27)= 0.31$, $p=0.82$, indicating there was no significant difference in skin temperature between the 5°C and 15°C wetted ice bags throughout the duration of the treatment (Table 1).

Table 1. Multivariate Tests for Skin Temperatures Differences Between a 5°C Wetted Ice Bag and a 15°C Wetted Ice Bag

	Value	F	Significance
Temperature Between Bags (Bags)	0.03	0.79	0.38
Temperature Decrease Throughout the Duration of the Treatment (Time)	291.49	2623.40	^a <0.001
Temperature Difference Between Bags Throughout the Duration of the Treatment (Bags/Time)	0.03	0.31	0.82

^a Significance in each wetted ice bag to continue to decrease skin temperature at each time increment throughout the treatment duration

However, the 5°C wetted ice bag had slightly lower means than the 15°C wetted ice bag at all measurement points: 10 minutes (5°C: 15.96°C, 15°C: 16.19°C), 20 minutes (5°C: 12.30°C, 15°C: 12.84°C) and 30 minutes (5°C: 10.06°C, 15°C: 10.31°C). The temperatures did not reach the significance level (Table 1). Furthermore, skin temperatures continued to decrease

in both the 5°C and the 15°C wetted ice bag groups throughout the duration of the treatment (Table 2).

Table 2. Descriptive Statistics for Skin Temperatures Differences Between a 5°C Wetted Ice Bag and a 15°C Wetted Ice Bag

	Mean (°C)	Standard Deviation (°C)
5°C Baseline Temperature	28.32	1.31
5°C Temperature @ 10 Minutes	15.96	2.40
5°C Temperature @ 20 Minutes	12.30	2.02
5°C Temperature @ 30 Minutes	10.06	1.63
15°C Baseline Temperature	28.46	1.21
15°C Temperature @ 10 Minutes	16.19	2.44
15°C Temperature @ 20 Minutes	12.84	2.86
15°C Temperature @ 30 Minutes	10.31	1.76

Lastly, a dependent t-test was used to compare the volumes of water inside the 5°C and 15°C wetted ice bags. The results indicated with 95% confidence that both the 5°C wetted ice bag and 15°C wetted ice bag had changes in volume of water (Table 3). However, the 15°C wetted ice bag produced a significantly greater volume of water (230.13mL ± 27.47mL) as compared to the 5°C wetted ice bag (202.80mL ± 26.06mL) ($t(29) = 45.89, p < 0.001$) (table 4). This indicated that the 15°C wetted ice bag melted more ice inside the modality than the 5°C wetted ice bag throughout the treatment (Table 3). Although, the 15°C wetted ice bag was able to produce a greater volume of water inside the modality, it did not decrease skin temperature as greatly as the 5°C wetted ice bag (Table 2).

Table 3. Multivariate Tests for the Change in the Volume of Water Between a 5°C Wetted Ice Bag and a 15°C Wetted Ice Bag

	T	Sig.	Mean	95% CI
5°C Change in Volume	42.63	^b <0.001	202.80	193.07
15°C Change in Volume	45.90	^b <0.001	230.13	219.88

^bSignificance between mean volume of change in water between the 5°C wetted ice bag and the 15°C wetted ice bag groups

Table 4. Descriptive Statistics for the Change in the Volume of Water Between a 5°C Wetted Ice Bag and a 15°C Wetted Ice Bag

	Mean (mL)	Standard Deviation (mL)
5°C Change in Volume	202.80	26.06
15°C Change in Volume	230.13	27.47

Summary

There was a difference between the 5°C and 15°C wetted ice bags, however the decrease in skin temperature did not reach significance. Nevertheless, both the 5°C and 15°C wetted ice bags continued to decrease skin temperature throughout the duration of the treatment. In addition, there was no significant difference noted between the skin temperatures of the 5°C and 15°C wetted ice bags throughout the duration of the treatment. Furthermore, there was consistency in the starting water temperatures of both wetted ice bags and the room temperatures throughout the duration of the treatment, therefore ensuring that starting water temperatures and room temperatures did not play a factor in the transfer of energy and the decrease of skin temperature.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to determine the possible differences in the effects of wetted ice bags using 5°C water or 15°C water on skin temperature reduction. The following research questions guided this study: Will the use of 5°C water in a wetted ice bag result in a decrease in skin temperature more than the use of 15°C water in a wetted ice bag? Will the use of 5°C water in a wetted ice bag result in a greater phase change than the use of 15°C water in a wetted ice bag? This chapter focuses on: discussion, clinical relevance, recommendations for future research, and conclusions.

Discussion

Current literature accepts the notion that whichever cryotherapy modality attains the coldest temperatures will provide the most beneficial treatment.³ In acute injuries, the cryotherapy treatment is crucial in order to decrease the inflammation to the area, decrease pain, and lower the metabolic rate.^{4,10} All of these physiological benefits work by decreasing blood flow to the area and decreasing nerve conduction velocity. Additionally, research states cryotherapy can target all of these requirements.^{4,10} Analgesia, or pain alleviation, is reached by achieving skin temperatures between 13.6-15.6°C.^{7,10,11,32} Furthermore, a decrease in blood flow is attained by skin temperatures between 12.83-15.00°C.^{10,32} Lastly, a decrease in the metabolic rate is reached by achieving, and then maintaining, skin temperatures between 10-11°C.⁶

Based on the temperature requirements found in the literature,^{7,10,11,32} both types of wetted ice bags used in this study achieved analgesia and a decrease in blood flow between the 10 and 20 minute marks for superficial skin depths (Table 2). Furthermore, according to temperature recommendations,⁶ both the 5°C and 15°C wetted ice bags also maintained a

lowered metabolic rate at the 30 minute mark at superficial tissue depths (Table 2). These findings are supported by similar research which showed that the use of water inside wetted ice bags allowed for a greater transfer of thermal energy, resulting in colder tissue temperatures than non-wetted ice bags.^{12,13} More specifically, studies performed on wetted ice bags over the calf by Dykstra et al.¹ (13.3°C) and over the thigh by Carvalho et al.⁷ (8.00°C) achieved analgesia and decreased blood flow for superficial temperatures. Similar to both Dykstra et al.⁴ and Carvalho et al.,¹⁰ the current study also achieved analgesia and a decrease in blood flow at the 20 minute mark for both the 5°C and 15°C wetted ice bags (Table 2). Furthermore, only Carvalho et al.¹⁰ (8.00°C) and the current study were also able to maintain a lowered metabolic rate at the 30-minute mark (Table 2). This finding is important as failing to achieve a decrease in metabolic activity could result in delayed healing due to secondary hypoxic damage to the injury.³ Overall, the findings on analgesia, blood flow, and metabolic activity from this study yielded positive results during a 30 minute treatment with both the 5°C wetted ice bag and the 15°C wetted ice bag. However, slightly colder skin temperatures were noted with the 5°C wetted ice bag (Table 2).

While various cryotherapy modalities have been used to target tissue temperature reduction, many seem to achieve similar surface reduction and recovery patterns. After studying wetted ice bags superficial temperature reduction patterns, both Dykstra et al.⁴ and Carvalho et al.¹⁰ reported results similar to the current study results. All three found a decrease in wetted ice bags skin temperature. Furthermore, both Dykstra et al.⁴ and Carvalho et al.¹⁰ found a greater skin temperature decrease for wetted ice bags as compared to cubed or crushed ice bags. In addition, for all three wetted ice bag experiments, skin temperatures began to return to the baseline temperature as soon as the treatment subsided. Current literature suggests this

immediate rise in surface temperature after the removal of the modality is due to the surface tissues using the intramuscular tissues to reheat themselves.⁴

In addition to surface temperature, intramuscular temperature also effects how well the modality affects the injury. Even though the current study did not research intramuscular temperature, other research shows intramuscular temperatures continuing to decrease and superficial temperatures continuing to increase after the wetted ice bag is removed.

Again, Dykstra et al.⁴ found intramuscular tissue temperatures to continue to decline while superficial temperatures rose after the removal of the cryotherapy modality, suggesting intramuscular tissues help rewarm the superficial tissues after the discontinuation of the cryotherapy treatment. This same study also found wetted ice bags to not only decrease surface temperatures greater than cubed and crushed ice, but also found that intramuscular tissues retained the cold longer during the recovery period. This suggests that a colder skin temperature allows for colder intramuscular temperatures during the recovery period and ultimately more physiological benefits. Thus, a 5°C wetted ice bag could have the potential to decrease intramuscular temperature greater than a 15°C wetted ice bag, a cubed ice bag, or a crushed ice bag. However, research needs to be conducted in this area to verify this assumption.

Furthermore, according to the zeroth law of thermodynamics, two temperatures must reach and maintain equilibrium with a third outside source to achieve thermal equilibrium.³⁰⁻³¹ In the current study, this means that the starting water temperature inside the ice bag (5°C or 15°C) and the ice cubes will reach and maintain equilibrium with the skin on the subject's body. In addition, this indicates that the starting water temperature could play a role in the decrease of skin temperature. Applying the zeroth law of thermodynamics to this scenario means that a 15°C wetted ice bag should take more time to achieve equilibrium inside the ice bag than a 5°C wetted

ice bag because the 15°C wetted ice bag has a larger temperature difference that must be equalized. This research supports this hypothesis because the 15°C wetted ice bag (230.13mL) produced a greater volume of water than the 5°C wetted ice bag (202.80mL). However, after equilibrium is attained inside the modality, then, according to the zeroth law of thermodynamics, heat can be withdrawn from the body. Conversely, when the 5°C wetted ice bag was applied, the equilibrium inside the modality was achieved sooner, therefore indicating that heat was dissipated from the body faster than when the 15°C wetted ice bag was applied. This was evident in both the lower volumes of water inside the modality (Table 4) and the lower skin temperatures than measured for the 15°C wetted ice bag at all time increments (Table 2).

The differences between the 5°C and 15°C wetted ice bags occurred inside the ice bag. As a whole, the 5°C wetted ice bag took less time reaching equilibrium inside the modality; therefore, the 5°C wetted ice bag had a colder starting modality temperature overall. Furthermore, this created a greater temperature gradient between the wetted ice bag and the body, thus causing slightly colder skin temperatures than the 15°C wetted ice bag at all measured time increments (Table 2). However, none of these temperature differences reached the significance level (Table 1). This skin temperature data was also supported by the change in volume of water removed from the ice bags after the 30-minute treatment (Table 4). The 15°C wetted ice bag melted significantly more water than the 5°C wetted ice bag (Table 3). If this excess water from the 15°C wetted ice bag was only due to the withdrawal of heat from the body, then the 15°C wetted ice bag would have produced colder tissue temperatures and a greater volume of water. However, only one of these outcomes resulted: the 15°C wetted ice bag produced a greater volume of water. In contrast, it was the 5°C wetted ice bag that produced colder skin temperatures. This data supports the notion that a greater phase change occurred

inside the 15°C wetted ice bag due to both the withdrawal of heat from the body and the warmer starting water temperature. As a result, the 15°C wetted ice bag had an overall warmer modality starting temperature which created a smaller temperature gradient between the modality and body. Consequently, these results indicate that a 5°C wetted ice bag decreased skin temperature slightly better than a 15°C wetted ice bag.

Furthermore, current literature supports wetted ice bags superiority to non-wetted ice bags due to their ability to increase surface area and the water's ability to transfer thermal energy better than air.^{4, 10} However, a study performed by Janwantanakul et al.⁴³ contradicts this assumption. They studied two different sized crushed ice bags, 18cm x 23cm and 20cm x 25cm, for a 20 minute treatment over the thigh and found that surface area did not significantly affect the skin temperature. In addition, they noticed the ice bag with the larger surface area affected the rate of cooling rather than skin temperature directly. In fact, the larger ice bag cooled the skin to the same temperature as the smaller ice bag at 8 minutes rather than 9 minutes. This supports that although not a significant factor, surface area can play a minor role in the rate skin temperature decreases.

In contrast, other researchers report that cold agents that pass through a phase change while cooling are generally more effective than those that do not.⁴ They argue that wetted ice bags use water to transfer energy from a solid to a liquid, while cubed and crushed ice bags use air. In fact, the effectiveness of this thermal energy transfer has been supported in a study performed by both Dykstra et al.⁴ and Carvalho et al.¹⁰ in which both found wetted ice bags produced colder skin temperatures than non-wetted ice bags. However, when examining the current study that involved two wetted ice bags, a greater energy exchange was noted when a greater temperature gradient was involved (5°C wetted ice bag) (Table 2). However, this study

did not compare the results to a non-wetted ice bag. Nevertheless, this theory can still be applied to the previous scenario comparing wetted ice bags to non-wetted ice bags. Wetted ice bags allow a greater energy exchange due to the larger temperature gradient the water and ice cubes produce along with water providing an efficient medium for thermal energy exchange. Non-wetted ice bags rely solely on the withdrawal of heat from the body as their source of energy exchange. Overall, thermal energy transfer plays a bigger role than surface area in wetted ice bags superiority over non-wetted ice bags. In addition, water is a more efficient medium than air for this thermal energy exchange to occur.

In summary, wetted ice bags are superior to non-wetted ice bags because they allow for a larger surface area than non-wetted ice bags. Wetted ice bags also allow a more efficient thermal energy exchange between the body and modality than non-wetted ice bags. Unlike non-wetted ice bags, the temperature gradient can be manipulated in wetted ice bags to create a colder starting modality temperature. As a result, colder tissue temperatures are created and greater physiological benefits occur.

Clinical Relevance

The data provided from this study supports that the 5°C wetted ice bag is superior to the 15°C wetted ice bag for decreasing skin surface temperatures. However, other research completed on wetted ice bags used room temperature water.^{4,10} These researchers never specified a temperature for their water, nor did they insure the water was within set starting parameters.^{4,10} Nonetheless, room temperature in this scenario was greater than 15°C. Applying the zeroth law of thermodynamics to this scenario, room temperature water is going to spend more time achieving equilibrium inside an ice bag than both the 5°C and 15°C wetted ice bags. Hence, theoretically the closer the water temperature applied inside the ice bag is to freezing

(0°C) or the temperature of the ice cubes, the less time will be spent achieving equilibrium; therefore more energy can be spent withdrawing heat from the body. Thus, the colder the water temperature inside the ice bag, the colder the overall modality. This would lead to a greater temperature gradient, which in turn would lower the skin temperature and lead to greater physiological benefits. Furthermore, when applying a cryotherapy modality to an acute injury clinicians should strive for a wetted ice bag with the coldest water to achieve the greatest physiological benefits for their patients.

Recommendations for Future Research

In this study, variances in water temperature inside the ice bag were not significant enough to show major differences in skin temperature between the 5°C and 15°C wetted ice bags. However, other variables that have yet to be explored regarding a wetted ice bag are: type of ice, amount of ice, amount of water inside the ice bag, and intramuscular and skin temperatures pertaining to these factors. In addition, intramuscular temperatures were not studied pertaining to different temperatures of water inside the ice bag, so future studies should address these factors. This study also did not measure the temperature inside the modality, so future studies should also assess the temperature inside wetted ice bags. This could help researchers better understand the temperature gradient concept. Other future research could address blood flow and cellular metabolism and how these factors relate to both skin and intramuscular temperature reduction. Lastly, future research could study adipose tissue depth and the necessary skin and intramuscular tissue temperatures to achieve physiological benefits pertaining to these adipose tissue levels.

The key to attaining the coldest tissue temperature is finding a mixture of ice and water that can cause the coldest temperature within the modality, which in turn causes the greatest

temperature gradient between the body and modality. Whichever type of ice and amount of water can achieve this will, theoretically, be able to achieve the most beneficial physiological effects.

Conclusion

Cold tissue temperatures are essential after an acute injury because they can target key physiological benefits to limit inflammation. The aforementioned data supports the notion that the 5°C wetted ice bag decreased skin temperature more effectively than the 15°C wetted ice bag. This decrease in skin temperatures was because the 5°C wetted ice bag spent less time achieving equilibrium inside the modality; therefore a greater temperature gradient between the modality and body was achieved. The literature supports wetted ice bags' superiority for decreasing tissue temperature over non-wetted ice bags because the water in a wetted ice bag is a better thermal energy conductor than the air found between the ice cubes or other materials in non-wetted ice bags. ^{4, 10}

Currently, research states that whichever cryotherapy modality achieves the coldest tissue temperatures will have the most beneficial treatment. ³ In theory, wetted ice bags are the key to this principle because they are the only cryotherapy modality that can be manipulated for a colder starting temperature to target a larger temperature gradient and therefore faster energy exchange between the modality and body. A water temperature close to 0°C added to an ice bag is essential to this idea. It can cause a greater temperature gradient between the cryotherapy modality and the body, thus decreasing skin temperature more than any other cryotherapy modality. This increased temperature gradient leads to more physiological benefits.

As a practicing Athletic Trainer, patients have reported cubed ice bags are uncomfortable due to the sharp edges against the injured extremity. However, wetted ice bags will achieve more

physiological benefits for patients, and the water inside the bag will also help the ice bag conform better to the extremity making it a more comfortable modality.

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APPENDIX A. INFORMED CONSENT FORM

NDSU North Dakota State University
Health, Nutrition, and Exercise Sciences
Department # 2620, PO Box 6050
Fargo, ND 58108-6050
701-231-5590

Title of Research Study:

WETTED ICE BAGS: Does the Temperature of the Water Added to the Ice Bag Really Matter?

This study is being conducted by:

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(701) 630-2846

Kara Gange, PhD, ATC, LAT
Assistant Professor
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(701) 231-5777

Why am I being asked to take part in this research study?

This study is looking for 30 subjects (men and women) ages 18-26 years old. There will be three sessions that consist of the following: one cold sensitivity testing for 15 minutes, session two ice bag testing for 45 minutes, and session three ice bag testing for 45 minutes. This will be a total of one hour and 45 minutes for all three sessions. You will not be allowed to participate if you have any of the following: heat or cold allergies, history of smoking, cardiovascular disease, peripheral disease, vascular disease, diabetes, trauma or injury one month prior in the right lower extremity, open wounds on the right calf, hot/cold insensitivity/allergy, or Raynaud's phenomenon.

What is the reason for doing the study?

The reason for this study is to help expand the research in the field of cold therapy. Currently, cold therapy is to treat acute and chronic injuries. There is no research stating which cold treatment is best for which type of injury. There is also not enough research to state which cold treatment is best at decreasing skin temperature. The purpose of this study is to determine the skin temperature differences between two ice bags, one with 5°C water added to it and one with 15°C water added to it. This study will help provide more research into the field of cold therapy and also give more insight into which cold treatment is the best at decreasing skin temperature.

What will I be asked to do?

When you first arrive for pretesting, the experiment procedures would be described to you. If you agree to partake in the study, this consent form will be given for you to sign stating you understand the experiment and the risks and you agree to participate. The researcher would then perform a cold sensitivity test over your right calf to guarantee you don't have any cold

allergies/sensitivities. This is done by performing an ice massage for 5 minutes, throughout which the researcher is checking for any negative reactions or rashes from the cold. If you do experience any the ice massage will be discontinued and you would be free to wait with the athletic training staff until the rash disappears. You would also be withdrawn from the study at this time. However if you don't have a negative reaction you would qualify for the study. After the cold sensitivity test the researcher would set up two treatment sessions with 24 hours between for you to come back and partake in the study. Each would last approximately 45 minutes.

Upon arriving at your first appointment date, you will be instructed to lie on your stomach on a treatment table. The treatment area will be measured and marked over your right calf. If needed, any hair will be shaven from the treatment area and the area will be cleaned with 70% Isopropyl Alcohol. Next, a surface thermocouple will be secured on top of the skin with tape. A thermocouple is a small flexible thermometer used to measure temperature changes in the skin. A wetted ice bag (either the 5°C or 15°C) will then be placed over the treatment area for 30 minutes. A wetted ice bag is a mixture of ice and water in an ice bag. After 30 minutes, the wetted ice bag would be removed and you would be reminded of your next appointment. After arriving at your next appointment date, all of the steps would be the same as above, except the other temperature wetted ice bag will be used. Lastly, after everyone has completed the study 5 participants will be randomly selected and rewarded \$10.00 cash.

Where is the study going to take place, and how long will it take?

The study will take place in Bentson Bunker Fieldhouse room 14. Participants will be asked to arrive for pretesting, which will take approximately 15 minutes. Next, the participants will come back two more times with at least 24 hours between each session and these sessions will last 45 minutes each.

What are the risks and discomforts?

Some subjects may also find ice application uncomfortable. If it is too uncomfortable, the test can be discontinued. Some individuals may be allergic to cold/ice. In order to determine if you are allergic, the researchers have taken steps to minimize this risk by prescreening for the allergy during the pretesting portion of this study. Researchers will pretest for cold sensitivity by performing an ice massage over the right calf for 5 minutes. If cold allergies appear during this treatment, the treatment will be discontinued and the subject will be withdrawn from the study.

If you are known to have a sensitivity to cold or heat application, or have had violent allergic reactions to cold or heat treatments, you should not take part in this study.

What are the benefits to me?

You are not expected to get any benefit from being in this research study.

What are the benefits to other people?

This study could help advance the knowledge of cryotherapy (the use of cold to treat injuries) and further determine the most effective type of ice bag to use with injuries.

Do I have to take part in the study?

Participation in this research project is your choice. If you choose to participate and meet all the criteria you can still change your mind at any time and stop participating without any penalty.

What are the alternatives to being in this research study?

Participants don't have to partake in this research study. It is their choice whether to participate or not.

Who will see the information that I give?

We will keep private all research records that identify you. Your information will be combined with information from other people taking part in the study. When we write about the study, we will write about the combined information that we have gathered. We may publish the results of the study; however, we will keep your name and other identifying information private.

We will make every effort to prevent who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under lock and key.

If you withdraw before the research is over, your information will be (retained in the research record) OR (removed at your request), and we will not collect additional information about you.

Can my taking part in the study end early?

If you fail to show up at your scheduled appointments, you will be removed from the study.

Will I receive any compensation for taking part in this study?

After everyone has completed the study, five participants will be randomly selected and rewarded \$10.00 cash. There will be a 1 in 6 chance that you will be rewarded the cash.

What happens if I am injured because of this research?

If you receive an injury in the course of taking part in the research, you should contact either member of the research team at the phone numbers listed at the beginning of the consent form. Treatment for the injury will be available including first aid, emergency treatment and follow-up care as needed. Payment for this treatment must be provided by you and your third party payer (such as health insurance or Medicare). This does not mean that you are releasing or waiving any legal right you might have against the researcher or NDSU as a result of your participation in this research.

What if I have questions?

Before you decide whether to accept this invitation to take part in the research study, please ask any questions that might come to mind now. Later, if you have any questions about the study, you can contact the researchers, Kelly Shaner at Kelly.shaner@ndsu.edu, (701) 630-2846 or Kara Gange at kara.gange@ndsu.edu, (701) 231-5777.

What are my rights as a research participant?

You have rights as a participant in research. If you have questions about your rights, or complaints about this research or to report a research-related injury, you may talk to the researcher or contact the NDSU Human Research Protection Program by:

- Telephone: 701.231.8908 or toll-free 1-855-800-6717
- Email: ndsu.ird@ndsu.edu
- Mail: NDSU HRPP Office, NDSU Dept. 4000, PO Box 6050, Fargo, ND 58108-6050.

The role of the Human Research Protection Program is to see that your rights are protected in this research; more information about your rights can be found at: www.ndsu.edu/ird .

Documentation of Informed Consent:

You are freely making a decision whether to be in this research study. Signing this form means that

1. You have read and understood this consent form
2. You have had your questions answered, and
3. You have decided to be in the study.

You will be given a copy of this consent form to keep.

Your signature

Date

Your printed name

Signature of researcher explaining study

Date

Printed name of researcher explaining study

APPENDIX B. HEALTH HISTORY FORM

HEALTH HISTORY QUESTIONNAIRE		
ALL QUESTIONS CONTAINED IN THIS QUESTIONNAIRE ARE STRICTLY		
Name	<input type="checkbox"/> M <input type="checkbox"/> F	Age:
HEALTH HISTORY FORM		

History of Smoking	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Cardiovascular Disease	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Peripheral Disease	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Diabetes	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Neurological Pathologies	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Muscular Pathologies	<input type="checkbox"/> Yes	<input type="checkbox"/> No
History of trauma 1 month prior in the right lower extremity	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Open wounds/sores on the right calf	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Hot or cold insensitivities/allergies	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Raynaud's Phenomenon	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Vascular Disease in the lower legs	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Did you consume caffeine 2 hours prior to arriving here	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Did you consume food 2 hours prior to arriving here	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Did you vigorously exercise 2 hours prior to arriving	<input type="checkbox"/> Yes	<input type="checkbox"/> No
Cold Sensitivity Testing	<input type="checkbox"/> (+)	<input type="checkbox"/> (-)