

ICE AND ACE WRAP AND GAME READY® IN DECREASING
QUADRICEPS TEMPERATURE

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Ice and Ace Wrap and Game Ready® in Decreasing Quadriceps Temperature

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ABSTRACT

The Game Ready® system is a popular cooling modality, but little is known about its ability to decrease intramuscular temperature. The purpose of this study was to compare intramuscular temperature decreases caused by six different modalities at different levels of compression. The independent variables were modality (ice, ice and ace wrap, Game Ready® no, low, medium, high) and time (0, 1, 5, 10, 15, 20, 30 minutes). The dependent variable was intramuscular temperature.

Fifteen volunteers participated in this study. The only significant difference in absolute intramuscular temperature was between ice and ace wrap and Game Ready® low. Ice and ace wrap had significantly greater change in quadriceps intramuscular temperature than Game Ready® no and low. Because it created the lowest intramuscular temperature and the greatest change in temperature, ice and ace wrap should be selected as a cooling modality over the Game Ready® device during the immediate care of injuries.

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CHAPTER 1. INTRODUCTION

Cryotherapy, “cold therapy,” is the use of ice or any cooling agent to remove heat from the body.¹ Clinicians use cryotherapy most commonly during immediate and acute injury care, but it also can be used during rehabilitation after the acute stage is over. Cryotherapy is used primarily because it decreases tissue temperature. Benefits of tissue temperature decrease include: minimized signs of inflammation, decreased pain, decreased muscle spasm, decreased nerve conduction, and decreased cell metabolism.² A decrease in cell metabolism is the most important of these effects during the immediate care because it reduces the amount of cell death caused by hypoxia.¹ Common forms of cryotherapy include: ice bag (filled with crushed, cubed or ice with water), chemical pack, and cold water immersion. Much research has been performed to determine which forms of cryotherapy most effectively decrease tissue temperature. Ice has been shown to decrease skin and intramuscular temperatures more effectively than gel packs, frozen peas, and cold water immersion.^{3,4}

Clinicians frequently pair cryotherapy with compression to minimize signs of inflammation, prevent swelling, and decrease blood flow. Research supports cryotherapy with compression causes greater decreases in tissue temperature.^{5,6,7} Because cryotherapy with compression have shown to be effective in decreasing tissue temperature, companies have begun to market devices such as Game Ready® that combine cold with intermittent compression. Game Ready® pumps ice water through a sleeve that encompasses the injured body part while applying compression at three possible settings in 3-minute cycles: low (5 to 15 mmHg), medium (5 to 50 mmHg), and high (5 to 75 mmHg).⁸ Treatment duration can be as long as 90 minutes. The device is portable and has sleeves for the ankle, knee, lower back, wrist, and shoulder. Although Game Ready® is getting more popular in the clinical setting; it may not

decrease tissue temperature as greatly as a traditional ice bag and ace wrap. Little is known about which pressure settings on the Game Ready® are appropriate to decrease tissue temperature enough to achieve the benefits of cryotherapy. Since no data exist at this time about the ideal temperature at which cryotherapy is most beneficial, it is assumed the colder, the better.⁹

Statement of Problem

Game Ready® is an increasingly popular modality in the athletic training clinical setting because of its convenience and versatility. However, little is known about the ability of this device to decrease tissue temperature in comparison to the traditional treatment of ice bag and compression from an ace wrap. It is uncertain if patients using Game Ready® are getting the same amount of tissue temperature decrease as they would if they were using an ice bag and ace wrap. Recent studies suggest Game Ready® does not decrease intramuscular temperature as well as ice and ace wrap.

Purpose of Study

The purpose of this study was to determine if Game Ready® decreases quadriceps temperatures as much as or more than an ice bag paired with an ace wrap. This knowledge will allow clinicians to decide which treatment to use to ensure patients receive optimal treatment.

Research Hypothesis

1. Ice bag and static compression (ace wrap) will induce a greater decrease in quadriceps intramuscular temperature than the Game Ready® system.

2. Of all the Game Ready® settings, the high pressure will induce the greatest decrease in quadriceps intramuscular temperature.

Definition of Terms

1. *Cryotherapy*: The therapeutic use of cold; the application of a device or substance with a temperature less than body temperature, thus causing heat to pass from the body to the cryotherapy device.¹
2. *Cell Metabolism*: The chemical and physical processes that occur in the body and enable it to function and grow.¹⁰
3. *Pneumatic*: Relating to, or using gas (as air or wind): a: moved by air pressure, (1): adapted for holding or inflating with compressed air and (2): having air-filled cavities.¹¹
4. *Modality*: The application of a form of energy to the body that elicits an involuntary response.¹²
5. *Hypoxia*: Lack of an adequate supply of oxygen.¹²
6. *Raynaud's phenomenon*: A circulatory disorder caused by cold or emotion, in which hands, and less commonly feet, become discolored or painful.¹
7. *Paresthesia*: Tingling sensation; "pins and needles," loss of normal sensation.¹⁰
8. *Anesthesia*: Decreased sensation caused by neurological dysfunction or pharmacological agent.¹⁰
9. *Urticaria*: Skin vascular reaction to an irritant characterized by red, itchy areas, wheals or papules. Commonly referred to as hives.¹²

Importance of Study

This study is important because it will help clinicians decide which cryotherapy treatment to use during the inflammation stage of healing, ensuring patients receive the best possible care. It will also help clinicians determine which pressure setting to use when using the Game Ready® system.

Assumptions

1. Both ice bag/ace wrap and Game Ready® are effective modalities for decreasing intramuscular temperature.
2. Temperature decreases in healthy individuals are representative of temperature decreases in injured individuals.
3. Temperature decreases in the quadriceps are representative of temperature decreases in all muscle.
4. Both Game Ready® and an ice bag penetrate treatment depths of 3.0 cm.
5. A blood pressure cuff between the ice bag and ace wrap is an accurate technique to measure ace wrap pressure consistency.
6. Males and females physically react to temperature change the same way.

Limitations

1. The blood pressure cuff used to measure pressure consistency in the ice and compression treatment may also insulate the modality, skewing the data.

Delimitations

1. There were six interventions: ice, ice bag with ace wrap, Game Ready® with no compression, Game Ready® with low compression, Game Ready® with medium compression, and Game Ready® with high compression.
2. Subjects were 18-30 year-old healthy male and female volunteers with no quadriceps injuries within the last year, no active infections or open wounds over the area of treatment, no allergy to cold, no allergy or sensitivity to betadine, no history of Raynaud's phenomenon, and no cardiovascular risk factors such as high blood pressure.
3. Subjects were excluded if they had a quadriceps adipose thickness greater than 1.5 cm, if any abnormalities were found in the muscle with diagnostic ultrasound, if they were pregnant, if they had any contraindications for cryotherapy, or if there was an active infection over the treatment area.
4. Subjects did not participate in physical activity 24 hours prior to testing.
5. All subjects received all interventions with at least 48 hours, but no more than two weeks between sessions.
6. Thermocouples were inserted into the quadriceps at a depth of 1.5 cm plus adipose thickness for all subjects. This depth was selected because it is commonly used in the literature.
7. The treatment duration was thirty minutes.
8. The blood pressure cuff used to measure pressure consistency in the ice and ace wrap treatment may have also insulated the treatment, allowing it to retain the cold and radiate less into the air. Insulation was monitored by measuring modality and air temperature throughout the treatment with surface thermocouples.

CHAPTER 2. LITERATURE REVIEW

The purpose of this study was to determine if Game Ready® decreases quadriceps temperatures as much as or more than an ice bag paired with compression. The hypotheses were ice and static compression (ace wrap) will induce a greater decrease in quadriceps intramuscular temperature than the Game Ready® system; and that the high pressure setting will induce the greatest temperature decreases of all the Game Ready® settings. This literature review discusses the uses of cryotherapy and its effects on acute injury, specifically decreasing tissue temperature and pain reduction. The review was organized by the following topics: Definition of cryotherapy, laws and principles of energy transfer, effects of cryotherapy, considerations for treatment duration, combined effects of cryotherapy and compression, Game Ready® studies, and summary.

Definition of Cryotherapy

Cryotherapy means “cold therapy,” so the application of ice or any other cooling agent to remove heat from the body is considered cryotherapy.¹ According to Starkey¹², the temperature range for cryotherapy is between 32°C and 65°F. The benefits of cryotherapy include: decreased tissue temperature, decreased pain, decreased muscle spasm, vasoconstriction, decreased nerve conduction velocity, and decreased cell metabolism.^{1,12} Indications of use include: acute injury, inflammation, pain, muscle spasm, and range of motion restoration.¹² Contraindications for using cryotherapy are: cardiac or respiratory disorders, open wounds, inadequate circulation, cold allergy (manifested by urticaria), advanced diabetes, Raynaud’s phenomenon, Lupus, peripheral vascular disease, or areas of paresthesia or anesthesia.¹² Cryotherapy should not be applied directly to the skin for over an hour as it may cause frostbite.¹ Traditionally, cryotherapy has been used in the immediate care of acute injuries. Acute injuries treated with cryotherapy

include: ligament sprains,^{13,14,15} muscle strains,^{16,17} and contusions.¹⁸ Cryotherapy is also used in post-immediate injury rehabilitation in the form of cryokinetics, which is a treatment technique that involves moving the injured body part while it is being treated with cold, thus decreasing pain while increasing range of motion.¹²

Laws and Principles of Energy Transfer

The first step in analyzing the effectiveness of a cold modality is understanding how that modality transfers energy from tissue. The first principle to be considered is energy gradients. Energy moves on a gradient from high to low concentration.¹² The larger the gradient, the faster the energy transfer occurs. In terms of temperature, a higher temperature means a higher amount of energy. Cold modalities remove heat from the body by having a lower temperature than the body. So, a 35°F ice bag will remove heat faster than a 40°F ice bag. But in order for energy gradients to have an effect on the body, energy must be absorbed by tissues at a level high enough to provoke a physiological response. This is called the Arndt-Schultz principle. Less than enough energy absorption will not cause a reaction and too much absorption will cause harm.^{1,12} Energy transfer caused by cryotherapy is also affected by how close the treated tissue is to the modality. The inverse square law states the intensity (I) of the energy going to the tissue is inversely proportional to the square of the distance (d) between the source and the tissue receiving the energy ($I=1/d^2$). As the distance between the tissue and the source increases, the intensity of the energy reaching the tissue decreases by a law of squares.¹² This means a cold modality placed directly on the skin will cool tissue more effectively than a cold modality placed with layers between the modality and the skin. In addition, the size of the cold modality makes a difference in the rate and magnitude of tissue cooling. Cold modalities with larger surface areas

remove more heat from the body than smaller ones.¹ For example, a larger ice bag will cool tissue faster and cause lower tissue temperatures than a smaller one.

Finally, thermal conductivity of the tissue treated and the cold modality itself must be considered in energy transfer. Thermal conductivity is defined by Starkey as “the quantity of heat (in calories per-second) passing through a substance 1 cm thick by 1 cm wide separating a temperature gradient of 1°C.”¹² Different cooling agents conduct thermal energy better than others. For example, water is a better agent for heat transfer than air.¹⁹ Also, different types of tissues are better thermal conductors than others. Skin and muscle have relatively high thermal conductivity at 0.96 and 0.64 W/m°C respectively, while adipose tissue has a very low conductivity rate at 0.19 W/m°C.² It is easier for heat to be transferred through skin than through adipose tissue. Tissues under a thick layer of adipose tissue do not cool as efficiently as tissue under little adipose.¹²

Effects of Cryotherapy

Decreasing Tissue Temperature

Body’s Response to Cold: When cold is applied to the body, several physiological reactions take place to compensate for the change in temperature and restore homeostasis. Cold stimulates the autonomic nervous system, which triggers the arterioles to constrict and reduces blood flow.¹ There have been disputes in the literature concerning whether or not cold application causes cold-induced vasodilation. Cold-induced vasodilation is the “dilation of blood vessels (increase in circumference) as a result of cold application.”¹ In 1930, Lewis²⁰ performed a study in which a subject placed a finger in cold water. He observed that the finger went through periods of cooling and warming. Lewis thought this reaction occurred during one of two possible times: during application (Hunting response) or after application (rebound effect).¹

These findings led many clinicians to believe the cause for the tissue warming was vasodilation and, as a result, that cryotherapy increased blood flow. This is not the case. The fingers in Lewis's study were held static in the water. In later studies similar to Lewis's design, the finger temperature rose when it was placed in ice water, but decreased when the finger was moved.¹ When the fingers were stationary in the water, the water around them pulled heat from the fingers and warmed the water around them. However, when the fingers were moved in the water, the water was circulated, causing the water and finger temperature to decrease again. This is an example of temperature gradient. By maintaining a lower water temperature, more heat was drawn from the fingers and the fingers were not allowed to rewarm. The hunting response, periods of tissue warming and cooling during cold application, was caused by a water temperature gradient, not a physiological response.¹

Variety of Cold Modalities and Tissue Temperature: Clinicians use cryotherapy because of its ability to reduce tissue temperature is believed to cause a decrease in cell metabolism.^{1,12} Decreased cell metabolism is important because it reduces cell death due to hypoxia during acute injuries. There are several cold modalities used to reduce tissue temperature. Some of the most commonly used ones are ice pack, ice bags with crushed, cubed or wetted ice, cold water immersion, and ice massage.^{4,3,9} Much research has been performed to determine which method of cryotherapy causes the greatest decreases in tissue temperature, yet researchers have been unable to define the ideal temperature that must be reached to produce the benefits of cryotherapy.⁹

All the studies discussed in this literature review observed ice (cubed, crushed, or wetted) was the most effective modality in reducing tissue temperatures.^{4,3,9} Dykstra et al.⁹ studied gastrocnemius intramuscular and skin surface temperatures after the application of cubed ice,

crushed ice, and wetted ice. Crushed ice caused the smallest temperature change and wetted ice (cubed with a certain amount of water in an ice bag) caused the largest temperature change. The mean cubed ice temperature changes were between crushed and wetted and were not significant.⁹ In another study, Kanlayanaphotporn and Janwantanakul³ compared four cold modalities in their study: ice pack, gel pack, frozen peas, and an ice and alcohol mixture. Each modality was applied to the thigh for 20 minutes and each caused a significant decrease in skin temperature. The ice/alcohol mixture caused the greatest the decrease in skin surface temperature at $10.0^{\circ} \pm 2.5^{\circ}\text{C}$ with ice pack in second at $10.2^{\circ} \pm 3.5^{\circ}\text{C}$. There was no significant difference between a gel pack and frozen peas. A study by Kennet et al.⁴ supports this conclusion. The ice pack likely reduced temperatures lower than frozen peas and a gel pack because ice must go through a phase change from ice to water. A phase change is the ability to change from one state (solid, liquid, or gas) to another without changing chemical makeup or temperature.¹ The amount of energy required to convert a solid to a liquid is called latent heat of fusion. A high latent heat of fusion is needed to change ice to water without changing the temperature of the substance. More energy is required to warm an ice bag than a gel pack because ice freezes solid, allowing more heat energy to be removed from the body.¹

All these studies are difficult to compare and contrast because they use such a wide variety of modalities, which is why each had different conclusions. While Dykstra et al.⁹ concluded wetted ice caused the greatest tissue temperature decreases, one cannot compare it to the ice/alcohol mixture from Kanlayanaphotporn and Janwantanakul.³ The scenarios and treatment protocols are different in each study. Dykstra et al. used the gastrocnemius as a treatment site, while Kanlayanaphotporn and Janwantanakul used the thigh. Kanlayanaphotporn and Janwantanakul measured skin temperature while Dykstra et al. measured skin and

intramuscular temperatures. Similarly, the crushed ice of Kennet et al.⁴ cannot be compared to the wetted ice of Dykstra et al. because of differences in treatment site and tissue depth measurement.

Cooling efficiency is another factor that must be taken into consideration, along with gross temperature decrease. There are several laws that affect cooling efficiency. The inverse square law states that as the distance between the tissue and the energy source increases, the intensity of the energy reaching the tissue decreases by a law of squares.¹² The frozen peas in Kennet et al.'s study⁴ were wrapped in a cold, terrycloth towel to prevent skin burns and may not have cooled as efficiently as cold water immersion and crushed ice because it had more distance to travel to the skin. Another law that affects cooling efficiency is the Fourier law. The Fourier law states that modalities with lower temperatures before application will cause greater decreases in tissue temperature because of a larger energy gradient.⁴ Kennet et al.'s findings did not observe this. Crushed ice and cold water immersion had higher pre-application temperatures than gel pack and frozen peas by 10°C.⁴ Yet, crushed ice and cold water immersion produced greater temperature reductions than frozen peas and gel pack.⁴ Kennet et al. associated this paradox to the Fourier law to be due to the phase change that occurred with crushed ice. In order for crushed ice to change into water (melt), it goes through a phase change. This transition produces high amounts of energy, increasing the energy transfer gradient. The Fourier law does not account for phase change.⁴ Phase change could also explain why wetted ice caused greater temperature decreases than cubed and crushed ice in Dykstra et al.'s study. Having water with the ice before application could start the phase change more quickly. Wetted ice may have decreased temperatures lower than crushed and cubed ice because water is a better conductor of thermal energy than air.¹⁹

Another aspect of cryotherapy and temperature decrease that must be examined is tissue rewarming. There were no differences in rewarming time for all cold modalities previously mentioned in this section. In Kanlayanaphotporn and Janwantanakul's study³, the tissue temperature increased 30 minutes after the removal of the cold modality, but it remained below pretest values. Kennet et al.⁴ supports this observation. Dystra et al.⁹ is the only study of the three to have a difference in rewarming time between modalities. Intramuscular temperatures in this study continued to decrease after the removal of wetted ice, crushed ice, and cubed ice with wetted ice causing the greatest decrease. The difference in results may be attributed to differences in tissue depth measured. Tissues closer to the surface rewarm by drawing heat from deeper tissues.²¹ The intramuscular tissues measured in Dykstra et al. were deeper than the skin temperatures measured in Kennet et al. and Kanlayanaphotporn and Janwantanakul.^{4,3,9}

Pain Reduction

Cryotherapy reduces pain by slowing sensory nerve conduction velocity (NCV), inducing a state of hypoalgesia or decreased sensitivity to painful stimuli.^{22,23} Algafly and George²⁴ assessed NCV, pain threshold (PTH) and pain tolerance (PTO) in the tibial nerve by stimulating the nerve with an EMG after applying crushed ice to the ankle until tissue temperature decreased to 10°C. Nerve conduction velocity was reduced by 33% and was slower for the ankles treated with ice than the ankles with no ice. Ice reduced PTH by 89% and PTO by 76% in the experimental ankles. Algafly and George suggested lower temperatures affect the rate of sodium and calcium exchanges in the neuron, decreasing NCV.

Considerations for Treatment Duration

There are several factors that need to be taken into consideration when determining cryotherapy treatment duration. Adipose tissue thickness, depth of tissue being treated, and exercise each affect how much time it takes to cool muscle tissue to desired levels.

Adipose tissue thickness plays a large role in how much and how quickly muscle cools. Muscle tissue under thicker layers of adipose takes longer to cool and does not cool as much as muscle tissue under thinner layers of adipose tissue.²⁵ Therefore, treatment areas with more adipose tissue should be treated for a longer duration. Myrer et al.²⁵ measured tissue temperatures and cooling rates at 1 cm and 3 cm depths in the triceps surae muscles in males and females with three ranges of adipose thicknesses (< 8 mm, 10-18 mm, \geq 20 mm) over 20 minutes of treatment. The muscle under < 8 mm layer cooled at a rate almost three times (0.72 °C/min) faster than muscle under \geq 20 mm (0.25°C/min) adipose thickness and almost two times (0.45 °C/min) faster than muscle in the 10-18 mm group at a 1 cm depth. Also at 1 cm, the < 8 mm group showed greater intramuscular temperature decreases than the 10-18 mm and \geq 20 mm groups. There were no differences in cooling rate or decrease in temperature between the 10-18 mm group and the \geq 20 mm group at 1 cm.²⁵ Cooling rates and temperature decreases at 3 cm were less pronounced than at 1 cm. Muscle in the <8 mm group still cooled almost three times faster than muscle in the \geq 20 mm group, but the actual rates for each were slower than at 1 cm (< 8 mm: 0.31°C/min, \geq 20 mm: 0.12°C/min).²⁵ Temperature decreases were not as low at 3 cm as they were at 1 cm, but the < 8 mm group still cooled the most.

Adipose thickness is affected by the individual's gender and physical activity level. Women tend to have greater thicknesses than men and the less physically active have greater thicknesses than more physically active individuals.²⁶ Less physically active women have more

adipose tissue than more physically active women. The same goes for men. Because gender and activity level affect adipose thickness levels, clinicians should determine cryotherapy treatment duration using these variables. Some suggested times for treatment based on adipose thickness skin-fold measurements are: 25 minutes for $\leq 20\text{mm}$, 40 minutes for 20-30 mm and 60 minutes for 30-40 mm.¹² Along with adipose thickness, clinicians must also consider the depth of the tissue being treated when determining treatment duration. The Law of Grothus-Draper states less energy reaches tissues at greater depths because it is absorbed by tissues closer to the energy source.¹² Therefore, it takes longer for deeper tissues to cool than superficial tissues. This was observed by Myrer et al.²⁵ Regardless of adipose thickness, intramuscular temperature decreases were greater at 1 cm than at 3 cm after a 20-minute treatment.²⁵

When cryotherapy is applied in relation to exercise affects how long a treatment should be. Cryotherapy applied after exercise cools tissue faster than with no exercise.²⁷ Long et al.²⁷ studied the effects of exercise on quadriceps cooling time. Each subject received all treatments: exercise and ice, exercise and no ice, and no exercise and ice. Subjects in the exercise groups exercised for 30 minutes on stationary bike at 70-80% of their predicted maximum heart rate. After exercise, subjects applied ice if assigned until muscle tissue decreased 10°C from baseline temperature. Temperatures were measured at 1 cm and 2 cm below the adipose layer. When comparing the exercise groups to the no exercise group, exercise decreased the time it took to drop quadriceps temperatures by 10°C below pre-exercise temperatures by almost 13 minutes.²⁷ The exercise and ice group cooled tissue at both depths to pre-exercise temperatures within 7 minutes of treatment and 32.2 ± 8.8 minutes at 1 cm and took 39.1 ± 7.1 minutes to decrease tissue temperature by 10°C. The ice and no exercise group took 45 ± 9.4 minutes at 1 cm and 53.6 ± 11.3 at 2 cm to decrease tissue temperature 10°C. The exercise and no ice group took

40.8 ± 4.4 minutes at 1-cm and 54.2 ± 8.2 at 2 cm to return to pre-exercise temperatures. The quicker cooling rate was due to a large energy gradient. Muscle temperature is elevated after exercise, creating a larger gradient than when there is no exercise. Therefore, treatment time should be increased for individuals who have not been exercising.

Combined Effects of Cryotherapy and Compression

Compression is commonly paired with cryotherapy for its effectiveness in inflammation management, but compression also plays a role in decreasing tissue temperature. Three out of three studies observed ice paired with some form of compression caused greater decreases in tissue temperature than ice alone. However, there are discrepancies in the methodologies of these studies that may skewed their data.

In a study using 40 women as subjects and five conditions (no compression, 14 mmHg, 24 mmHg, 34 mmHg and 44 mmHg compression with ace bandage), Janwantanakul⁵ observed all interventions decreased thigh skin surface temperatures significantly from baseline. In addition, ice paired with compression lowered temperatures more than no compression. There were no significant differences in skin temperature decreases between levels of compression. However, Janwantanakul did find a correlation between level of compression and rate of cooling: the higher the compression, the faster the cooling rate.⁵ A weakness of this study is they measured skin surface temperatures only, so the findings may not apply to intramuscular temperatures. The differences between no compression and compression may be contributed to insulation caused by the manometer and bladder placed between the ice bag and the elastic wrap used to measure the level of compression. Also, the study does not state if the ice bag in the no compression condition was held in place by an elastic wrap. The elastic wrap could also contribute to insulation. A study by Tomchuk et al.⁷ supports this idea. This study compared

elastic wrap to flexi-wrap (plastic wrap) in tissue cooling. The elastic wrap caused greater intramuscular cooling than flexi-wrap after 30 minutes of treatment.⁷ This difference in cooling is contributed to the insulation of the ace wrap and the increased modality contact with the skin.⁵ Merrick et al.²⁸ conducted a similar study to Janwantanakul⁵ with four treatment conditions: control (no treatments), ice only, compression (ace wrap) only, and ice paired with compression. Ice with compression caused greater decreases in skin surface temperature than all other conditions. At both 1 cm and 2 cm muscle depths, ice with compression still decreased tissue temperature more than ice alone. However, temperatures at 2 cm were not as cold as at 1 cm and temperatures at 1 cm were not as cold as at skin surface after a 30-minute application. This study also used a manometer and bladder to measure pressure consistency. Again, this technique could skew data by insulation. Unlike the study by Janwantanakul⁵, this study measured tissue temperatures at depths which the cryotherapy is attempting to treat. This study used only one level of compression, while Janwantanakul measured four. Regardless of their differences in study design, the authors of all three studies^{5,7,28} suggested that the increased surface area and modality contact with the skin caused by compression were reasons for the greater decreases in tissue temperature. The amount of pressure applied by the compression did not seem to matter to overall cooling, but it affected how quickly tissue cooled, as observed by Janwantanakul.³ In Tomchuk et al.'s study⁷, consistency of compression was not controlled.

Game Ready® Studies

Game Ready® is a cold modality that uses intermittent pneumatic compression to decrease tissue temperature, reduce pain, and control inflammation. It consists of a tank that pumps ice water through a hose connected to a sleeve that encompasses the injured body part while applying compression at one of four possible pressure settings. The pressure settings are

no compression (0 mmHg), low compression (5 to 15 mmHg), medium compression (5 to 50 mmHg), and high compression (5 to 75 mmHg).⁸ Ice water moves through the sleeve in three minute cycles. Some research has been performed to determine whether or not Game Ready® is more effective in decreasing tissue temperature than cryotherapy alone, but little of that research has been published. Some abstracts are available, but no studies have been published.²⁹⁻³¹

Game Ready® vs Cryotherapy and Static Compression in Decreasing Tissue Temperature

Two studies examined the decreases in intramuscular temperatures caused by ice and compression and the Game Ready® system.^{32,33} Researchers in both studies concluded traditional ice and compression (ace wrap) induced lower intramuscular temperatures more than Game Ready®. In the first study, Hawkins et al.³² compared ankle temperature decreases caused by a slush bucket, an ice bag with an ace wrap, and Game Ready® at medium compression. All treatments were applied for 20 minutes and researchers recorded temperatures at baseline, 20 minutes of treatment, and at 20 minutes after treatment. The ice bag and ace wrap decreased sinus tarsi tissue temperature 11 degrees lower than Game Ready® at the end of 20 minutes. Temperatures for the ice bag and ace wrap group continued to be lower 20 minutes post treatment than Game Ready®, though both maintained temperatures below baseline measurements.³²

Holwerda et al.³³ performed a similar study comparing an ice bag and ace wrap to Game Ready® at no compression, medium compression and high compression with temperatures measured in the quadriceps muscle. Temperatures were recorded at baseline, 30 minutes of treatment, and 30 minutes after treatment. The ice bag and ace wrap cooled muscle greater than Game Ready® at all pressures. Game Ready® with medium and high compression produced

lower intramuscular temperatures than the no compression setting, supporting previous studies stating the importance of ice paired with compression.

Both studies^{32,33} had issues with compression consistency in the ice and ace wrap groups. Holwerda et al.³³ used a blood pressure cuff inflated to about 30 mmHg placed between the ice bag and ace wrap to measure and ensure pressure consistency between subjects. Because the blood pressure cuff does not allow the cold from the modality to radiate into the air, data could be falsified by insulating the ice bag. A blood pressure cuff could exaggerate the insulating effect of an ace wrap. Hawkins et al.³² also used a blood pressure cuff, but placed it medial to the ice bag under the elastic wrap. This technique was only used during pilot testing because Hawkins et al. feared unfairly insulating the treatment. Not including the blood pressure cuff sacrifices treatment compression consistency. So, while one can be sure that ice and ace wrap data are not skewed by insulation, one cannot rely on the data because we cannot be certain compression was the same treatment by treatment and subject by subject. However, if the amount of compression (as long as compression is applied) truly plays no role in temperature decrease as Janwantanacal⁵ reported, then pressure consistency is irrelevant.

These studies raise the question of whether or not it is fair to compare static compression to intermittent compression. Static compression is constant throughout treatment while intermittent compression applies compression at intervals. While both studies attempted to control for pressure level, pressure is not the same at all times for the Game Ready® groups. Cold modalities paired with compression decrease tissue temperature more effectively than cold modalities alone because compression increased modality contact with the skin.^{5,27} Ice paired with an ace wrap may more effectively decrease temperature than intermittent compression because of constant maximum contact with the skin.

Summary

Cryotherapy is the use of ice or any other cooling agents to remove heat from the body.^{1,12} It is used to treat a variety of acute injuries including ligament sprains, muscle strains, and contusions.¹³⁻¹⁸ Several factors affect how efficiently cryotherapy removes heat from the body: size of energy gradients, surface area of the modality, modality contact with the skin, depth of treatment site, thermal conductance of the modality and tissues treated, and distance of the modality from the body.^{1,4,12,19} Common forms of cryotherapy include: ice massage, cold water immersion, crushed ice, cubed ice, wetted ice, gel pack, and frozen peas.^{1,3,4,9,12}

The two main effects of cryotherapy are decreased tissue temperature and pain reduction. Decreased tissue temperature causes vasoconstriction, which is vital to reducing blood flow and managing inflammation.^{1,12} Of all the common cold modalities, an ice bag causes the greatest decreases in skin and intramuscular temperatures.^{3,4,9} Researchers believe ice's success is due to a phase change.^{4,9} Ice undergoes a phase change from ice to water during treatment, which requires a lot of energy (heat). The increased amount of energy increases the energy gradient, increasing the rate and magnitude of tissue cooling.¹ Cryotherapy reduces pain by slowing nerve conduction velocity.²²⁻²⁴

Several factors must be taken into consideration when determining treatment duration for cryotherapy. These factors include adipose tissue thickness, treatment depth, and exercise.²⁵⁻²⁷ Sites with greater adipose thicknesses take longer to cool than sites with less adipose thickness.²⁵ Deeper treatment sites should have longer durations so energy has time to reach the tissue. Exercise before cryotherapy increases the rate of energy transfer by increasing the energy gradient.²⁷ Treatment durations should be shorter for individuals who have just completed exercise. Compression also affects the rate of cooling and treatment duration. An ice bag

paired with an ace wrap produces lower tissue temperatures than ice alone because the compression increases ice contact with the skin.^{5,28} Because of this, companies have been producing devices such as the Game Ready® system that combine cryotherapy and compression. Researchers suggested Game Ready® does not decrease intramuscular temperatures as low as traditional ice and elastic wrap treatments,^{32,33} but there are some flaws in these studies that could have affected data. It is important to understand the effectiveness of different cold modalities to ensure patients are receiving the best care possible.

CHAPTER 3. METHODOLOGY AND PROCEDURES

The purpose of this study was to determine if Game Ready® decreases quadriceps temperatures as much as or more than ice paired with an ace wrap. This knowledge allows clinicians to decide which treatment to use to ensure patients receive optimal recovery. The hypotheses were ice and static compression will induce a greater decrease in quadriceps intramuscular temperature than the Game Ready system and that the high pressure setting will induce the greatest temperature decreases of all the Game Ready® settings. This chapter focuses on the experimental design, population, procedures, instrumentation, and data analysis of this study.

Experimental Design

A 6 x 7 factorial crossover design with repeated measures on time guided data collection for decreases in intramuscular quadriceps temperature. Independent variables were cooling modality: ice bag, ice bag and ace wrap (six inch double), Game Ready® at no compression, low compression, medium compression, and high compression and time (recorded at 0, 1, 5, 10, 15, 20 and 30 minutes of treatment). The dependent variable was intramuscular quadriceps temperature.

Population of the Study

Fifteen healthy male and female subjects between the ages of 18 and 30 years old with no history of quadriceps injury in the last year were recruited by university email to participate in this study. The university list serve was only emailed once to reach all 15 subjects. Individuals for whom cryotherapy was contraindicated were excluded from this study. Contraindications for cryotherapy included: cold hypersensitivity, cardiac disorders, open wounds or active infections over the area of treatment, or Raynaud's phenomenon. Individuals who had participated in physical activity 24 hours before testing were excluded from this study. Individuals with

allergies or sensitivities to betadine were also excluded from this study. All procedures in this study obtained approval from the Institutional Review Board and all subjects signed an informed consent form prior to testing.

Instruments for Data Collection

A Game Ready® device (CoolSystems, Inc., Alameda CA) with standard knee sleeve (71 x 43 cm) was used to apply cold and intermittent compression to the dominant leg (leg used to kick a ball) for 30 minutes at four pressure settings: no compression, low (5 to 15 mmHg), medium (5 to 50 mmHg), and high (5 to 75 mmHg). A 1 kg ice bag was secured to the leg with a six inch double elastic wrap for the ice and ace wrap condition. A blood pressure cuff (American Diagnostic Corporation, Hauppauge NY) partially inflated to ~40 mmHg was placed between the ice bag and the ace wrap.

Intramuscular temperature was recorded using a calibrated 16-lead 256 Iso-Thermex electro thermometer (Columbus Instruments, Columbus OH). Temperatures were measured using IT-21 intramuscular-implantable thermocouples (Physitemp Inc, Clinton NJ). The thermocouples were sterilized in Cidex Plus™ 24 hours before testing. A 20-gauge x 1.16 needle catheter (Cardinal Health) was inserted into the quadriceps, the needle was retracted and the thermocouple was threaded through the remaining catheter. The skin surface and modalities were assessed using surface thermocouples (Physitemp Inc NJ). Adipose thickness was assessed at the treatment area using a Terason 3200™ Diagnostic Ultrasound machine with 15L4 linear transducer (4.0-15.0 MHz) (MedCorp, LLC., Tampa FL).

Procedures

Subjects reported to the test area on seven different days: one instructional day and six testing days. On the first day, subjects were instructed not to participate in physical activity that

would cause them to break a sweat 24 hours before testing. Subjects were also tested for a cold allergy. A cold allergy was assessed by placing a 1 kg ice bag on the treatment area for 20 minutes and then checking for a reaction. Symptoms of cold allergy were: whitening of the skin, raised skin and warmth over area of treatment. Subjects reported to testing on the remaining six days within at least 48 hours, but no more than two weeks between sessions. Treatment for each subject on each particular day was determined by Latin square to prevent order effects.

Upon arrival, the treatment area was determined by measuring the distance from the Anterior Superior Iliac Spin (ASIS) to the superior border of the patella and marking with a sharpie at two-thirds of that distance from the ASIS. With subjects lying supine, adipose thickness at the treatment site was assessed using a diagnostic ultrasound. The treatment depth was determined by adding the adipose thickness and 1.5 cm. This depth was selected because it is commonly used the literature. A thermocouple was removed from the CidexPlus™ 28 day solution, wiped dry and marked at the determined treatment depth and 5 cm. Then, the thermocouple section to be inserted into the quadriceps was sterilized with alcohol. The insertion area was prepared with betadine and alcohol. A 20 gauge x 1.16 needle catheter was inserted at the designated site, the needle was retracted leaving a flexible catheter in place. An IT-21 intramuscular thermocouple was inserted through the catheter to a depth of 1.5 cm plus adipose thickness, the catheter was removed and the thermocouple was secured to the leg with medical tape. The thermocouple was attached to a calibrated 16-lead Iso-Thermex electro thermometer. A surface thermocouple was placed on the skin 1 cm superior to the intramuscular thermocouple. A second surface thermocouple was placed on the outside of the cold modality to measure modality insulation by determining how much heat is radiated into the air. A third surface thermocouple was placed inside the bag for the ice and ice/ace wrap groups to measure

change in inner modality temperature. Game Ready® chamber temperatures were measured before and after treatment by placing a thermocouple in the chamber.

Subjects laid stationary in a supine position until a baseline temperature was stable for 5 minutes. The predetermined modality was applied over the insertion area at the proper settings. For the ice bag treatments, the bag was placed on the treatment area and secured using a single layer of Power-flex tape with no compression. In the ice and ace wrap treatments, a partially inflated blood pressure cuff was placed between the ice bag and the ace wrap to ensure consistent pressure (~40 mmHg) among subjects. Temperatures were recorded at 0, 1, 5, 10, 15, 20 and 30 minutes of treatment. After testing, the modality and instruments were removed and the insertion site was cleaned with alcohol and covered with a Band-Aid. Subjects were given instructions for care of the insertion site and signs of infection. The subjects returned for the next testing session no earlier than 48 hours after the previous testing, and no later than two weeks for the next testing session to give the tissue time to recover. Subjects were paid \$60 after completing the final session.

Data Analysis Procedures

A one-way repeated measures ANOVA was conducted at each of the seven time points where type of treatment was the independent variable and absolute intramuscular temperature was the dependent variable. Two additional ANOVAs were conducted with change in intramuscular temperature after 30 minutes and change in skin temperature after 30 minutes as the dependent variables, respectively. Seven more ANOVAs were conducted with absolute skin temperature as the dependent variable. The ANOVAs were conducted separately because there were too many cells and not enough subjects.

A one-way ANOVA was conducted at 0, 1 and 30 minutes with type of treatment as the independent variable and outer modality air temperature as the dependent variable. An ANOVA was conducted for each of the treatments with time as the independent variable and outer modality air temperature as the dependent variable. To assess inner modality temperature, an ANOVA was conducted for 0 and 30 minutes with type of treatment as the independent variable and inner modality temperature as the dependent variable. ANOVAs were also run to assess change in inner modality temperature over time for each treatment. A two-way repeated measures ANOVA was performed to determine any differences in intramuscular and skin temperature changes for the between subject factor of adipose tissue thickness < 1.0 cm and > 1.0 cm. Bonferroni adjustments were performed to determine significant differences between variables. SPSS version 21 was used for all statistical analyses. Significance was set a priori at $p \leq 0.05$.

CHAPTER 4. JOURNAL OF SPORT REHABILITATION MANUSCRIPT

Cryotherapy, “cold therapy,” is the use of ice or any cooling agent to remove heat from the body.¹ Clinicians use cryotherapy most commonly during immediate and acute injury care, but it also can be used during rehabilitation after the acute stage is complete. Cryotherapy is used primarily because it decreases tissue temperature. Benefits of tissue temperature decrease include: minimized signs of inflammation, decreased pain, decreased muscle spasm, decreased nerve conduction, and decreased cell metabolism.² A decrease in cell metabolism is the most important of these effects during immediate care because it reduces the amount of cell death caused by hypoxia.¹ Common forms of cryotherapy include: ice pack (filled with crushed, cubed or ice with water), chemical pack, and cold water immersion. Much research has been performed to determine which forms of cryotherapy most effectively decrease tissue temperature. Ice has been shown to decrease skin and intramuscular temperatures more effectively than gel packs, frozen peas, and cold water immersion.^{3,4}

Clinicians frequently pair cryotherapy with compression to minimize signs of inflammation, prevent swelling, and decrease blood flow. Research supports cryotherapy and compression from an ace wrap causes greater decreases in tissue temperature.^{5,6,7} Because cryotherapy and compression have shown to be effective in decreasing tissue temperature, companies have begun to market devices such as Game Ready® that combine cold with intermittent compression. Game Ready® pumps ice water through a sleeve that encompasses the injured body part while applying compression at three possible settings in 3-minute cycles: low (5 to 15 mmHg), medium (5 to 50 mmHg), and high (5 to 75 mmHg).⁸ Treatment duration can be as long as 90 minutes. Intermittent compression is used to reduce swelling and edema through a pumping effect.^{1,12} The device is portable and has sleeves for the ankle, knee, lower

back, wrist, and shoulder. Although Game Ready® is growing more popular in the clinical setting, it may not decrease tissue temperature as greatly as a traditional ice bag and ace wrap. Little is known about which pressure settings on the Game Ready® are appropriate to decrease tissue temperature enough to achieve the benefits of cryotherapy. Since no data exist at this time about the most beneficial amount of tissue temperature decrease, it is assumed the colder, the better.⁹ The purpose of this study was to determine if Game Ready® decreases quadriceps temperatures as much as or more than an ice bag paired with an ace wrap. This knowledge will allow clinicians to decide which treatment to use to ensure patients achieve optimal treatment. The hypotheses were 1) Ice bag and ace wrap will cause a greater decrease in quadriceps intramuscular temperature than ice bag and all the Game Ready® system treatment settings and; 2) of all the Game Ready® settings, the high pressure will cause the greatest decrease in quadriceps intramuscular temperature.

Methods

Design

We performed a 6x7 factorial crossover study with repeated measures on time. One independent variable was cooling modality (6): ice, ice and ace wrap, Game Ready® no compression, Game Ready® low compression, Game Ready® medium compression and Game Ready® high compression. The other independent variable was time (7), measured at 0, 1, 5, 10, 15, 20 and 30 minutes. The dependent variable was intramuscular quadriceps temperature.

Participants

Fifteen healthy volunteers (11 males, 4 females, age 20.87 ± 2.29 years, adipose thickness 1.03 ± 0.29 cm) with no history of a thigh injury in the last six months participated in this study. We recruited subjects by university email. The university list serve was only emailed

once to reach all 15 subjects. We excluded subjects if they had a history of cold allergy, were sensitive to betadine, were pregnant, had an adipose thickness greater than 1.5 cm or had any contraindications for cryotherapy. Contraindications for cryotherapy included active infections, cold allergy, open wounds, cardiac or circulatory disorders, and Raynaud's Phenomenon.

Subjects did not perform vigorous exercise 24 hours prior to testing. The University Institutional Review Board approved this study prior to subject recruitment.

Procedures

Subjects reported to the research laboratory on seven different days: one instructional day and six testing days. On the first day, subjects were instructed not to participate in physical activity that would cause them to break a sweat 24 hours before testing. Subjects were also tested for a cold allergy. We assessed a cold allergy by placing a 1 kg ice bag on the treatment area for 20 minutes and then checking for a reaction. Symptoms of a cold allergy were: whitening of the skin, raised skin, and warmth over the area of treatment. No subjects displayed cold allergy symptoms. Subjects reported to testing on the remaining six days with at least 48 hours, but no more than two weeks between sessions. The treatment for each subject on each particular day was determined by Latin square to prevent order effects.

Upon arrival, the treatment area was assessed by measuring the distance from the ASIS to the superior border of the patella and marking with a sharpie at two-thirds of that distance from the ASIS. With subjects lying supine, adipose thickness at the treatment site was assessed using a Terason 3200™ Diagnostic Ultrasound machine with 15L4 linear transducer (MedCorp. LLC., Tampa FL) and recorded. The treatment depth was determined by adding the adipose thickness and 1.5 cm. We selected this depth because it is commonly used in the literature. A thermocouple was removed from the CidexPlus™ 28 day solution, wiped dry and marked at the

determined treatment depth and 5cm. Then, the thermocouple section to be inserted into the quadriceps was sterilized with alcohol. The insertion area was prepared with betadine and alcohol. A 20 gauge x 1.16 needle catheter (Cardinal Health) was inserted at the designated site; the needle was retracted leaving a flexible catheter in place. An IT-21 intramuscular thermocouple (Physitemp Inc, Clinton NJ) was inserted through the catheter to a depth of 1.5 cm plus adipose thickness, the catheter was removed and the thermocouple was secured to the leg with medical tape. The thermocouple was attached to a calibrated 16-lead Iso-Thermex electro thermometer (Columbus Instruments, Columbus OH). A surface thermocouple (Physitemp Inc, Clinton NJ) was placed on the skin 1 cm superior to the intramuscular thermocouple. A second surface thermocouple was placed on the outside of the cold modality to measure modality insulation by determining how much cold is radiated into the air. A third surface thermocouple was placed inside the ice bags of the ice and ice and ace wrap groups. The Game Ready® chamber temperatures were recorded before and after treatments.

The subjects laid in a supine position on the treatment table until a baseline intramuscular temperature was stable for 5 minutes. The predetermined modality was applied over the insertion area at the proper settings. In the ice and ace wrap treatments, a partially inflated blood pressure cuff (American Diagnostic Corporation, Hauppauge NY) was placed between the ice bag and the ace wrap to ensure consistent pressure (~40 mmHg) among subjects. The Game Ready® device (CoolSystems Inc., Alameda CA) was applied using a standard knee sleeve (71 x 43 cm). Temperatures were recorded at 0, 1, 5, 10, 15, 20 and 30 minutes of treatment. After testing, the modality and instruments were removed and the insertion site was cleaned with alcohol and covered with a band-aid. Subjects were given instructions for care of the insertion site and signs of infection. The subjects returned for the next testing session no earlier than 48 hours after the

previous testing, and no later than two weeks for the next testing session. No subjects withdrew from the study and all subjects met the inclusion criteria. We paid each subject \$60 dollars after their final session was completed.

Statistical Analyses

We conducted a one-way repeated measures ANOVA at each of the seven time points where type of treatment was the independent variable and absolute intramuscular temperature was the dependent variable. Two additional ANOVAs were conducted with change in intramuscular temperature after 30 minutes and change in skin temperature after 30 minutes as the dependent variables, respectively. Seven more ANOVAs were conducted with absolute skin temperature as the dependent variable. We conducted the ANOVAs separately because there were too many cells and not enough subjects.

We conducted a one-way ANOVA at 0, 1 and 30 minutes with type of treatment as the independent variable and outer modality air temperature as the dependent variable. An ANOVA was conducted for each of the treatments with time as the independent variable and outer modality air temperature as the dependent variable. To assess inner modality temperature, an ANOVA was conducted for 0 and 30 minutes with type of treatment as the independent variable and inner modality temperature as the dependent variable. ANOVAs were also run to assess change in inner modality temperature over time for each treatment. A two-way repeated measures ANOVA was performed to determine any differences in intramuscular and skin temperature changes for the between subject factor of adipose tissue thickness < 1.0 cm and > 1.0 cm. Bonferroni adjustments were performed to determine significant differences between variables. SPSS version 21 was used for all statistical analyses. Significance was set a priori at $p \leq 0.05$.

Results

Intramuscular Temperature

There was a significant treatment effect for absolute intramuscular temperature at 10 ($F_{5,70} = 3.79, P = 0.004$), 15 ($F_{5,70} = 4.02, P = 0.003$), 20 ($F_{5,70} = 4.04, P = 0.003$) and 30 minutes ($F_{5,70} = 4.66, P = 0.001$). There was not a significant treatment effect for absolute intramuscular temperature at 0 ($F_{5,70} = 1.97, P = 0.093$), 1 ($F_{5,70} = 0.76, P = 0.582$) and 5 minutes ($F_{5,70} = 2.09, P = 0.077$). Ice and ace wrap caused the coldest intramuscular temperature at $24.76 \pm 4.53^{\circ}\text{C}$. Game Ready® no caused the warmest intramuscular temperature at $29.24 \pm 3.96^{\circ}\text{C}$. Ice, Game Ready® low, Game Ready® medium and Game Ready® high reached temperatures of $26.32 \pm 4.53^{\circ}\text{C}$, $28.96 \pm 3.66^{\circ}\text{C}$, $26.33 \pm 3.61^{\circ}\text{C}$ and $27.71^{\circ}\text{C} \pm 3.20$, respectively (Table 1). Ice and ace wrap was significantly lower than Game Ready® low at 5, 10, 15, 20 and 30 minutes. There were no significant differences in absolute temperature at any of the time points for any of the other conditions (Figure 1) (Table 2).

Table 1. Peak absolute intramuscular temperature and treatment ($^{\circ}\text{C}$)

Ice	Ice/ace wrap	GR no	GR low	GR medium	GR high
26.32 ± 4.53	24.76 ± 5.18	29.24 ± 3.96	28.98 ± 3.66	26.33 ± 3.61	27.71 ± 3.20

Table 2. Significant differences in absolute intramuscular temperature between Ice and ace wrap and Game Ready® low

Time (minutes)	Mean Difference ($^{\circ}\text{C}$)	Significance (P)
5	-1.917	0.048
10	-3.289	0.008
15	-3.957	0.002
20	-4.162	0.001
30	-4.216	0.001

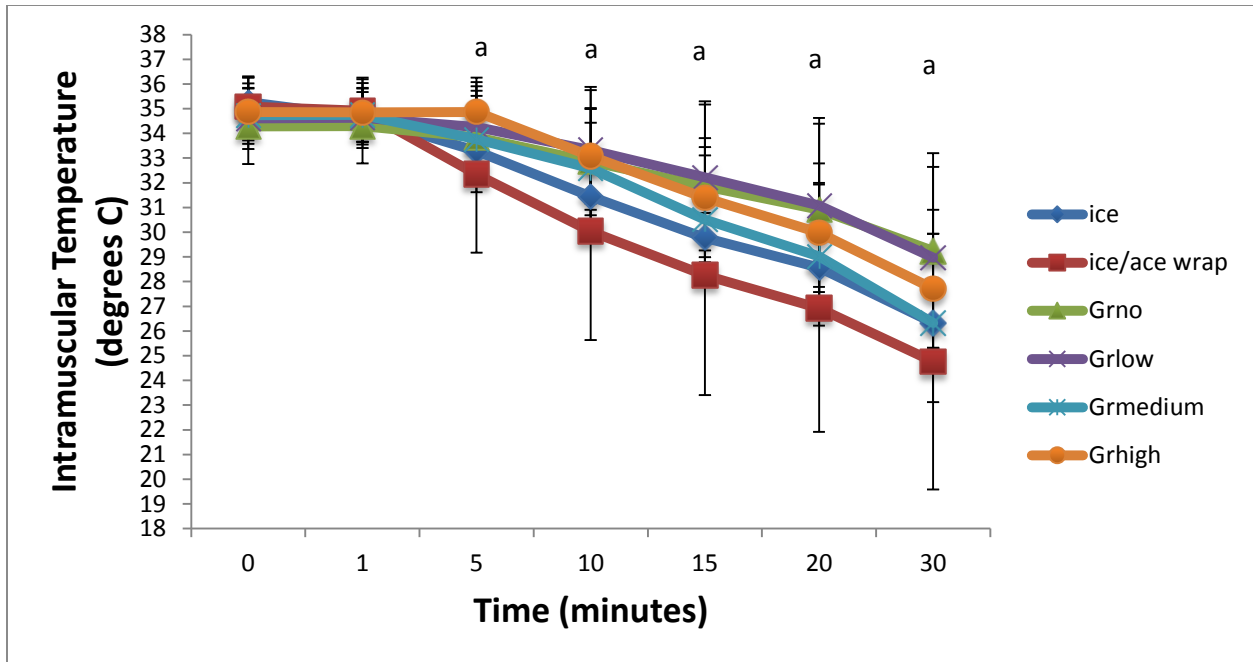


Figure 1. Absolute intramuscular temperature over time

a: Ice and ace wrap produced significantly greater muscle cooling than Game Ready® low. There were no other significant differences between treatments.

There was a significant treatment effect on the mean change in intramuscular temperature from 0 to 30 minutes ($F_{5,70} = 9.29$, $P < 0.0001$) at the ≤ 0.05 significance level. Ice produced a mean change in intramuscular temperature of $-8.95^{\circ}\text{C} \pm 4.19$ after 30 minutes. Ice and ace wrap produced a mean change in intramuscular temperature of $-10.76^{\circ}\text{C} \pm 4.71$. Game Ready® no caused a mean change of $-5.03^{\circ}\text{C} \pm 2.57$ and Game Ready® low caused a mean change of $-5.63^{\circ}\text{C} \pm 2.69$. Game Ready® medium produced a mean change of $-8.39^{\circ}\text{C} \pm 2.74$ and Game Ready® high produced a mean change of $-7.00^{\circ}\text{C} \pm 2.80$. Ice induced significantly lower temperatures than Game Ready® no. Ice and ace wrap was significantly lower from Game Ready® no and Game Ready® low. Game Ready® medium was significantly lower from Game Ready® no and Game Ready® low (Table 3). There were no significant differences in mean change intramuscular temperature between the following treatment pairs: ice and ice and ace wrap, ice and Game Ready® low, ice and Game Ready® medium, ice and Game Ready®

high, ice and ace wrap and Game Ready® medium, ice and ace wrap and Game Ready® high, Game Ready® no and Game Ready® low, Game Ready® no and Game Ready® high, Game Ready® low and Game Ready® high, and Game Ready® medium and Game Ready® high.

Table 3. Mean change in intramuscular temperature from 0 to 30 minutes (°C)

Ice	Ice/ace wrap	GR no	GR low	GR medium	GR high
-8.95 ± 4.19	-10.76 ± 4.70	-5.03 ± 2.57	-5.63 ± 2.69	-8.39 ± 2.74	-7.00 ± 2.80

Skin Temperature

There was a significant treatment effect for absolute skin temperature at 1 ($F_{5,70} = 11.29$, $P < 0.0001$), 5 ($F_{5,70} = 38.74$, $P < 0.0001$), 10 ($F_{5,70} = 41.17$, $P < 0.0001$), 15 ($F_{5,70} = 38.21$, $P < 0.0001$), 20 ($F_{5,70} = 33.35$, $P < 0.0001$) and 30 minutes ($F_{5,70} = 34.50$, $P < 0.0001$). There was not a significant treatment effect at 0 minutes ($F_{5,70} = 1.67$, $P = 0.154$). Ice and ace wrap reached the coldest skin temperature of $12.16 \pm 2.05^\circ\text{C}$. Game Ready® no reached the least cold skin temperature of $19.72 \pm 2.53^\circ\text{C}$. Ice, Game Ready® low, Game Ready® medium and Game Ready® high reached skin temperatures of $13.17 \pm 2.12^\circ\text{C}$, $18.77 \pm 2.48^\circ\text{C}$, $15.92 \pm 2.41^\circ\text{C}$ and $16.34 \pm 1.74^\circ\text{C}$, respectively (Table 4). There were no significant differences at 0 minutes between treatments.

Table 4. Peak absolute skin temperature and treatment (°C)

Ice	Ice/ace wrap	GR no	GR low	GR medium	GR high
13.17 ± 2.12	12.16 ± 2.05	19.72 ± 2.53	18.77 ± 2.48	15.92 ± 2.41	16.34 ± 1.74

At 1 minute, ice had significantly lower skin temperatures than the Game Ready® settings. Ice and ace wrap had significantly lower temperatures than Game Ready® low (Table 5). At 5 minutes, both ice and ice and ace wrap had significantly lower temperatures than all the Game Ready® settings (Table 6). At 10 minutes, both ice and ice and ace wrap had significantly

lower temperatures than all the Game Ready® settings. Game Ready® high had significantly lower temperatures than Game Ready® no (Table 7).

Table 5. Pairwise comparison of absolute skin temperatures at 1 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Game Ready® no	-2.218	0.006
Ice	Game Ready® low	-2.719	0.0001
Ice	Game Ready® medium	-2.524	0.004
Ice	Game Ready® high	-2.291	0.025
Ice and ace wrap	Game Ready® low	-2.125	0.017

Table 6. Pairwise comparison of absolute skin temperatures at 5 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Game Ready® no	-5.037	0.0001
Ice	Game Ready® low	-5.495	0.0001
Ice	Game Ready® medium	-4.370	0.0001
Ice	Game Ready® high	-3.874	0.0001
Ice and ace wrap	Game Ready® no	-5.800	0.0001
Ice and ace wrap	Game Ready® low	-6.257	0.0001
Ice and ace wrap	Game Ready® medium	-5.133	0.0001
Ice and ace wrap	Game Ready® high	-4.637	0.001

Table 7. Pairwise comparison of absolute skin temperatures at 10 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Game Ready® no	-6.031	0.0001
Ice	Game Ready® low	-6.169	0.0001
Ice	Game Ready® medium	-4.286	0.001
Ice	Game Ready® high	-3.583	0.003
Ice and ace wrap	Game Ready® no	-7.628	0.0001
Ice and ace wrap	Game Ready® low	-7.767	0.0001
Ice and ace wrap	Game Ready® medium	-5.883	0.0001
Ice and ace wrap	Game Ready® high	-5.180	0.0001
Game Ready® high	Game Ready® mo	-2.448	0.032

At 15 minutes, both ice and ice and ace wrap had significantly lower temperatures than all the Game Ready® settings. Game Ready® medium had significantly lower temperatures than Game Ready® no and low. Game Ready® high had significantly lower temperatures than Game Ready® no (Table 8). Similarly, at 20 minutes, both ice and ice and ace wrap had

significantly lower temperatures than all the Game Ready® settings. Game Ready® medium and Game Ready® high had significantly lower temperatures than Game Ready® no. Game Ready® medium had significantly lower temperatures than Game Ready® low (Table 9). At 30 minutes, ice had significantly lower skin temperatures than Game Ready® no, low and high. Ice and ace wrap had significantly lower temperatures than all the Game Ready® settings. Game Ready® medium had significantly lower temperatures than Game Ready® no and low. Game Ready® high had significantly lower temperatures than Game Ready® no (Table 10) (Figure 2).

Table 8. Pairwise comparison of absolute skin temperatures at 15 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Game Ready® no	-6.291	0.0001
Ice	Game Ready® low	-6.062	0.0001
Ice	Game Ready® medium	-3.536	0.005
Ice	Game Ready® high	-3.309	0.004
Ice and ace wrap	Game Ready® no	-7.675	0.0001
Ice and ace wrap	Game Ready® low	-7.447	0.0001
Ice and ace wrap	Game Ready® medium	-4.921	0.0001
Ice and ace wrap	Game Ready® high	-4.694	0.0001
Game Ready® medium	Game Ready® no	-2.755	0.021
Game Ready® high	Game Ready® no	-2.981	0.016
Game Ready® medium	Game Ready® low	-2.526	0.010

Table 9. Pairwise comparison of skin temperatures at 20 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Game Ready® no	-6.279	0.0001
Ice	Game Ready® low	-5.760	0.0001
Ice	Game Ready® medium	-3.247	0.020
Ice	Game Ready® high	-3.111	0.005
Ice and ace wrap	Game Ready® no	-7.575	0.0001
Ice and ace wrap	Game Ready® low	-7.057	0.0001
Ice and ace wrap	Game Ready® medium	-4.543	0.001
Ice and ace wrap	Game Ready® high	-4.407	0.0001
Game Ready® medium	Game Ready® no	-3.032	0.025
Game Ready® high	Game Ready® no	-3.168	0.013
Game Ready® medium	Game Ready® low	-2.513	0.015

Table 10. Pairwise comparison of skin temperatures at 30 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Game Ready® no	-6.552	0.0001
Ice	Game Ready® low	-5.607	0.0001
Ice	Game Ready® high	-3.173	0.002
Ice and ace wrap	Game Ready® no	-7.557	0.0001
Ice and ace wrap	Game Ready® low	-6.612	0.0001
Ice and ace wrap	Game Ready® medium	-3.758	0.003
Ice and ace wrap	Game Ready® high	-4.178	0.0001
Game Ready® medium	Game Ready® no	-3.799	0.004
Game Ready® high	Game Ready® no	-3.379	0.006
Game Ready® medium	Game Ready® low	-2.854	0.008

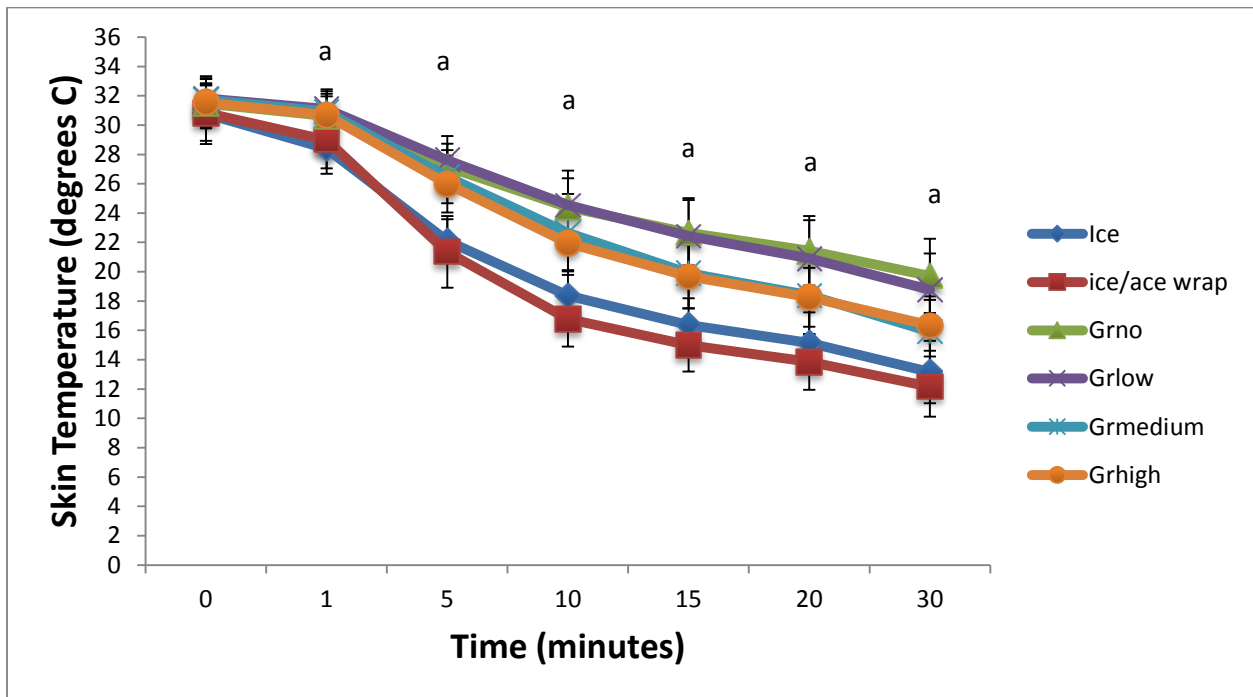


Figure 2. Absolute skin temperature over time

a: There was a significant treatment effect. See Tables 5-10 for significant differences between treatments.

There was a significant treatment effect for mean change in skin temperature from 0 to 30 minutes ($F_{5,70} = 25.99, P < 0.0001$). The mean change in skin temperature over 30 minutes for ice was $-17.47 \pm 1.74^{\circ}\text{C}$. Ice and ace wrap caused a mean temperature change of $-19.34 \pm 2.34^{\circ}\text{C}$. Game Ready® no produced a mean change of $-11.75 \pm 2.76^{\circ}\text{C}$. Game Ready® low caused a mean change of $-13.04 \pm 2.53^{\circ}\text{C}$. Game Ready® medium and Game Ready® high

produced mean changes in skin temperature of $-15.97 \pm 2.40^{\circ}\text{C}$ and $-15.14 \pm 1.74^{\circ}\text{C}$, respectively (Table 11). Ice induced significantly lower temperatures than Game Ready® no and Game Ready® low. Ice and ace wrap was significantly different from Game Ready® no, Game Ready® low, Game Ready® medium and Game Ready® high. Game Ready® medium was significantly different from Game Ready® no and Game Ready® low. Game Ready® high was significantly different from Game Ready® no (Table 12). There were no significant differences in mean change in skin temperature between the following groups: ice and ice and ace wrap, ice and Game Ready® medium, ice and Game Ready® high, ice and ace wrap and Game Ready® medium, Game Ready® no and Game Ready® low, Game Ready® no and Game Ready® high, Game Ready® low and Game Ready® high and Game Ready® medium and Game Ready® high.

Table 11. Mean change in skin temperature from 0 to 30 minutes ($^{\circ}\text{C}$)

Ice	Ice/ace wrap	GR no	GR low	GR medium	GR high
-17.47 ± 1.74	-19.34 ± 2.34	-11.74 ± 2.76	-13.04 ± 2.53	-15.97 ± 2.40	-15.14 ± 1.73

Table 12. Pairwise comparison of significant differences in change in mean skin temperature between treatments after 30 minutes

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (<i>P</i>)
Ice	Game Ready® no	5.721°	0.0001
Ice	Game Ready® low	4.427°	0.0001
Ice and Ace Wrap	Game Ready® no	7.593°	0.0001
Ice and Ace Wrap	Game Ready® low	6.299°	0.0001
Ice and Ace Wrap	Game Ready® high	4.205°	0.0001
Game Ready® medium	Game Ready® no	4.219°	0.0001
Game Ready® medium	Game Ready® low	2.925°	0.008

Change in Intramuscular Temperature and Adipose Tissue Thickness

There was a significant effect of adipose thickness on mean change in intramuscular temperature ($F_{1,13} = 459.45$, $P < 0.0001$). Subjects with less than 1 cm of adipose tissue had a

greater mean intramuscular temperature change than subjects with an adipose thickness greater than 1 cm (mean difference=3.609°, $P < 0.0001$).

Outer Modality Air Temperatures

There was a significant treatment effect for outer modality air temperature at 0 ($F_{5,70} = 12.40, P < 0.0001$), 1 ($F_{5,70} = 20.04, P < 0.0001$) and 30 minutes ($F_{5,70} = 92.59, P < 0.0001$). At 0 minutes of treatment, ice had significantly lower outer modality air temperatures than all Game Ready® treatments. Ice and ace wrap had significantly lower outer modality air temperatures than all the Game Ready® treatments (Table 13). Ice and ice and ace wrap were not statistically different at 0 min. None of the Game Ready® settings were statistically different. In contrast, at 1 minute, ice had a significantly lower outer modality air temperature than other treatments. Ice and ace wrap had higher outer modality air temperatures than Game Ready® no (Table 14). There were no statistical differences between any of the Game Ready® settings at 1 minute of treatment.

Table 13. Pairwise comparison of outer modality temperatures at 0 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Game Ready® no	-3.649	0.043
Ice	Game Ready® low	-4.253	0.029
Ice	Game Ready® medium	-4.487	0.015
Ice	Game Ready® high	-4.214	0.049
Ice and ace wrap	Game Ready® no	-2.923	0.019
Ice and ace wrap	Game Ready® low	-3.427	0.0001
Ice and ace wrap	Game Ready® medium	-3.661	0.0001
Ice and ace wrap	Game Ready® high	-3.388	0.022

Table 14. Pairwise comparison of outer modality temperatures at 1 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Ice and ace wrap	-10.425	0.0001
Ice	Game Ready® no	-6.065	0.041
Ice	Game Ready® low	-7.553	0.004
Ice	Game Ready® medium	-7.881	0.003
Ice	Game Ready® high	-8.547	0.001
Ice and ace wrap	Game Ready® no	4.359	0.002

At 30 minutes, ice had significantly colder outer air temperatures than all other treatments. Ice and ace wrap had significantly warmer air temperatures than all other treatments. Game Ready® no was significantly warmer than ice, colder than ice and ace wrap, colder than Game Ready® low, colder than Game Ready® medium and colder than Game Ready® high. Game Ready® low produced significantly warmer air temperatures than ice and Game Ready® no and colder air temperatures than Game Ready® high. Game Ready® medium produced significantly warmer air temperatures than ice, colder air temperatures than ice and ace wrap and warmer air temperatures than Game Ready® no. Game Ready® high produced significantly warmer air temperatures than ice, colder air temperatures than ice and ace wrap, warmer air temperatures than Game Ready® no and warmer temperatures than Game Ready® low (Table 15).

Table 15. Pairwise comparison of outer modality temperatures at 30 min and treatment (°C)

Treatment (I)	Treatment (J)	Mean Difference (I-J)	Sig. (P)
Ice	Ice and ace wrap	-14.168	0.0001
Ice	Game Ready® no	-3.187	0.009
Ice	Game Ready® low	-5.579	0.0001
Ice	Game Ready® medium	-7.581	0.0001
Ice	Game Ready® high	-9.636	0.0001
Ice and ace wrap	Game Ready® no	10.981	0.0001
Ice and ace wrap	Game Ready® low	8.589	0.0001
Ice and ace wrap	Game Ready® medium	6.587	0.0001
Ice and ace wrap	Game Ready® high	4.532	0.007
Game Ready® no	Game Ready® low	-2.391	0.005
Game Ready® no	Game Ready® medium	-4.394	0.0001
Game Ready® no	Game Ready® high	-6.449	0.0001
Game Ready® low	Game Ready® high	-4.057	0.0001

There was a significant time effect for all treatments at 0, 1 and 30 minutes (ice: $F_{2,28} = 67.96, P < 0.0001$; ice and ace wrap: $F_{2,28} = 36.74, P < 0.0001$; no: $F_{2,28} = 505.84, P < 0.0001$); low: $F_{2,28} = .15, P < 0.0001$); medium: $F_{2,28} = 199.10, P < 0.0001$); high: $F_{2,28} = 290.99, P <$

0.0001). For all treatments except ice and ace wrap, outer air temperature decreased significantly from 0 to 1 minute. For all treatments, outer air temperature decreased from 1 to 30 minutes. For all treatments, outer air temperature decreased significantly from 0 to 30 minutes. However, ice and ace wrap produced the least amount of cold into the air (Table 16) (Table 17).

Table 16. Absolute air temperature outside of modality and time (°C)

Time	Ice	Ice/ace wrap	GR no	GR low	GR medium	GR high
0 min	20.90° ± 4.02	21.72° ± 2.00	24.55° ± 1.58	25.15° ± 0.96	25.39 ± 1.22	25.11° ± 1.81
1 min	11.36° ± 6.27	21.79° ± 2.02	17.43° ± 2.38	18.92 ± 2.67	19.25 ± 2.45	19.91° ± 1.51
30 min	3.66° ± 1.73	17.83° ± 2.58	6.85° ± 1.78	9.24 ± 1.43	11.24 ± 2.66	13.29° ± 2.13

Table 17. Mean differences in outer modality over time (°C)

	0 to 1 min	1 to 30 min	0 to 30 min
Ice	-9.635, p<0.0001	-7.707, p<0.0001	-17.241, p<0.0001
Ice and ace wrap	0.064, p=0.999	-3.963, p<0.0001	-3.899, p<0.0001
GR no	-7.188, p<0.0001	-10.585, p<0.0001	-17.703, p<0.0001
GR low	-6.235, p<0.0001	-9.681, p<0.0001	-15.916, p<0.0001
GR medium	-6.141, p<0.0001	-8.006, p<0.0001	-14.147, p<0.0001

Inner Modality Temperature

Inner modality temperature was defined as the temperature inside the ice bags and inside the Game Ready® chamber. There was no significant treatment effect for inner modality temperature at 0 ($F_{5,65} = 1.08$, $P=0.383$) and 30 minutes ($F_{5,65} = 0.88$, $P = 0.501$). There was no significant time effect from 0 to 30 minutes for ice ($F_{1,14} = 0.03$, $P = 0.74$), ice and ace wrap ($F_{1,14} = 2.01$, $P = 0.178$), Game Ready® no ($F_{1,13} = 0.58$, $P = 0.459$) and Game Ready® high ($F_{1,13} = 4.36$, $P = 0.057$). There was a significant time effect from 0 to 30 minutes for Game Ready® low ($F_{1,13} = 6.88$, $P = 0.021$) and medium Game Ready® ($F_{1,13} = 4.94$, $P = 0.045$). For Game Ready® low, chamber temperature was colder at 0 minutes than at 30 minutes. For Game Ready® medium, chamber temperature was colder at 0 minutes than at 30 minutes (Table 18).

Table 18. Change in inner modality temperature (in ice bags and GR chamber) and time (°C)

Time	Ice	Ice/ace wrap	GR no	GR low ^b	GR medium ^c	GR high
0 min ^a	0.50° ± 0.15	0.82° ± 1.25	1.74° ± 0.49	1.21° ± 0.90	0.88° ± 0.92	0.90° ± 0.82
30 min ^a	0.60° ± 0.56	1.13° ± 1.87	-1.45° ± 3.59	-0.56° ± 0.32	-0.40° ± 0.20	-0.43° ± 0.18

a: There were no significant differences in inner modality temperature between all treatments.

b: Game Ready® low inner modality temperature is significantly colder at 0 minutes than 30 minutes (mean difference=0.645°, p=0.021).

c: Game Ready® medium inner modality temperature is significantly colder at 0 minutes than 30 minutes (mean difference=0.474, p=0.045)

Discussion

Intramuscular Temperature

Researchers have established in previous studies that ice applied with compression decreases intramuscular temperatures more than ice without compression.^{3,7,28} Merrick et al.²⁸ found ice bag and compression with an ace wrap caused greater decreases in absolute tissue temperature for skin and muscle at depths of 1 cm and 2 cm than ice bag alone. While our study may not statistically support these findings, our results are very similar. Merrick et al.²⁸ reported absolute values for tissue temperature at 2 cm below adipose (mean adipose thickness ~0.79 cm) as 26.46°C ± 3.04 and 28.21°C ± 2.34 after 30 minutes for ice and compression and ice bag only, respectively. We reported values at a slightly more shallow depth of 2.5 cm (mean adipose thickness 1.03 ± 0.29 cm) after 30 minutes of 24.76°C ± 5.18 and 26.32°C ± 4.53 for ice and ace wrap and ice bag alone, respectively. While our study found no statistical significant differences between these values, the difference may be clinically relevant and supports Merrick et al.'s findings. Compression increases skin surface area and modality contact. The more of the modality in contact with the skin, the greater the transfer of energy, and the greater the decrease in intramuscular temperature. This accounts for the ice and ace wrap's high change in intramuscular temperature and why Game Ready® medium and Game Ready® high decreased tissue temperature more than Game Ready® no and Game Ready® low.

This does not explain why all the Game Ready® settings, except no and low, were the statistical equivalence of ice with no compression. This can be contributed to phase change. In order to understand phase change, we must understand a basic law of energy transfer: energy transfers from levels of high concentration to low concentration. The greater the difference in concentration, the lower the decrease in temperature and the faster the rate of cooling. Substances that freeze completely solid, such as ice, undergo a phase change from ice to water. To change ice to water, a large amount of energy (heat) is needed. Therefore, more energy is transferred from the body to the ice bag.^{1,4} This is why ice bags decrease tissue temperature more than chemical packs despite chemical packs' lower modality temperature and larger energy gradient. Both Game Ready® and ice bags use ice and water and phase changes take place in both groups. The difference in change in intramuscular temperature results comes from the location in which the phase change takes place. For the ice bag groups (ice without compression and ice and ace wrap), the phase change takes place on the body, making the energy required for the change directly available from the body. In the Game Ready® groups, the phase change takes place in the chamber, away from the body and unavailable to impact the skin and muscle temperatures. Our data of the change in inner modality temperature supports this idea. The temperatures inside the ice bags and in the Game Ready® chamber were the same for each treatment and did not change as treatment progressed and the ice melted. Low and medium got warmer by 0.364°C and 0.474°C respectively as treatment progressed; however, this may be because of inaccurate thermocouple placement in the Game Ready® chamber. Therefore, we suggest weighting the thermocouple so it stays submerged in the chamber. This implies all treatments applied the same degree of cold to the body when compared to each other. The differences in intramuscular temperature we observed between treatments can be contributed to

the location of the phase change, rather than an energy gradient difference. Another difference between the ice bag and Game Ready® groups is the type of compression applied during treatment. The ice and ace wrap applies static compression while Game Ready® uses intermittent compression in 3 minute cycles. Hawkins et al.³² suggest this lack of constant pressure does not facilitate temperature decrease as well as static pressure. Our results are consistent with this idea. Because we do not know the ideal temperature from which to gain optimal benefits from cryotherapy, all treatments may be beneficial cooling modalities.

However, we must take insulation into consideration. The blood pressure cuff and ace wrap itself insulated the ice bag, not allowing the cold to escape into the environment causing the lower intramuscular temperature results. Our outer modality air temperature results suggest the ice and ace wrap treatment was insulated because it released the least amount of cold into the air. Ice, which had no insulating barrier, released the most cold into the air. If we were to rank our treatments in order of poor to excellent insulators, the order would be ice, Game Ready® no, low, medium, high and ice and ace wrap. This suggests insulation increases as level of compression increases. However, we cannot determine if the insulation of the ice and ace wrap treatment was exaggerated by the blood pressure cuff. Based on results of other studies, we can assume the insulation comes from the ace wrap itself and that the role of the blood pressure cuff as an insulator is minimal. Merrick et al.²⁸ used a manometer and bladder in their study to measure pressure consistency for the ice and compression treatment. According to Merrick et al.²⁸ and Tomchuk et al.⁷, ace wraps produce an insulating effect by reducing the amount of heat gained from the environment, which causes lower tissue temperatures. This is an important advantage for using this modality clinically. However, Merrick et al.²⁸ did not discuss the possible insulation effect of the manometer and bladder. In a study examining Game Ready®,

ice and ace wrap and cold water immersion, Hawkins et al.³² only used a blood pressure cuff during pilot testing, not during actual data collection. Hawkins et al.³² concluded ice and ace wrap produced greater decreases in ankle intramuscular temperature than both cold water immersion and Game Ready® at medium, regardless of possible pressure inconsistency. This suggests the blood pressure cuff may play a minimal role in modality insulation and that the level of compression itself does not play a large role in overall tissue cooling as long as some compression is applied. With that said, for the ice and ace wrap group in our study, we had to pump air into the blood pressure cuff throughout treatment to ensure that the pressure stayed consistently at 40 mmHg. This suggests either the blood pressure cuff itself could not hold air, the deformation of the ice bag as the ice melted changed the pressure of the ace wrap or the ace wrap itself lost its elasticity over time. The latter two options must be considered when selecting a cooling modality clinically. Are patients using ice and ace wrap getting constant static compression throughout treatment?

Our intramuscular temperature results are consistent with a study on Game Ready® by Holwerda et al.³³ Holwerda et al.³³ found significant differences in peak intramuscular temperature change between ice and ace wrap and Game Ready® no, but no differences in peak temperature change between ice and elastic wrap and Game Ready® medium or Game Ready® high (Game Ready® low was not studied). Also, there were no differences in peak change in temperature between any of the Game Ready® settings after 30 minutes. Both studies were performed on the quadriceps and used similar treatment depths and the same treatment duration. Again, though our results for absolute tissue cooling may not be statistically different, they are very similar to those of Holwerda et al. Holwerda et al.³³ found ice and ace wrap produced significantly lower tissue temperatures than both Game Ready® medium and high (ice and ace

wrap $\sim 23^{\circ}\text{C}$, medium $\sim 26^{\circ}\text{C}$ and high $\sim 25^{\circ}\text{C}$). Our study found also ice and ace wrap produced lower tissue temperatures than both Game Ready[®] medium and high, but these differences were not found to be statistically different (ice and ace wrap $24.75^{\circ}\text{C} \pm 5.18$, medium $26.33^{\circ}\text{C} \pm 3.61$ and high $27.71^{\circ}\text{C} \pm 3.20$). These findings are almost identical. We take Holwerda et al.'s findings further by adding ice with no compression as a treatment. Ice only produced temperatures similar to those of both Game Ready[®] medium and high found in both studies (ice $26.32^{\circ}\text{C} \pm 4.53$). Clinically, this means Game Ready[®] may not be the modality of choice for the immediate care of injuries. Under the assumption that colder tissue temperatures produce higher benefits of cryotherapy, an ice bag with an ace wrap should be the modality of choice because both cause a greater magnitude of cooling than the Game Ready[®] system. Using Game Ready[®] during post-acute injury may be more appropriate because during post-acute injury, decreasing cell death due to hypoxia is no longer the primary goal of cryotherapy. After the immediate stage of injury is over, decreasing muscle spasm, pain and nerve conduction are the goals for using cryotherapy and all three can be gained without reaching the lowest possible intramuscular temperature.

We might have found more statistically different findings if our treatment duration had been longer. Long et al.²⁷ performed a study on how long it took two different depths, 1 cm and 2cm below the adipose layer, to decrease 10°C after an ice bag had been applied. They found it took tissues at 1 cm below the adipose layer (~ 2.54 cm for a total depth of ~ 3.54 cm) 45 ± 9.4 minutes and tissue at 2 cm below the adipose layer (~ 4.54 cm total depth) 53.6 ± 11.3 minutes to decrease 10°C . Long et al.'s treatment time for 1 cm below the adipose layer, which is ~ 0.5 cm deeper than our treatment depth, was approximately 15 minutes longer than our treatment time.

This implies we may have needed more time to see greater differences in intramuscular temperature between groups, especially for the Game Ready® treatments.

Skin Temperature

Change in skin temperature results can be attributed to many of the same causes as change in intramuscular temperature results. Groups with higher levels of compression (ice and ace wrap, Game Ready® medium and Game Ready® high) produced lower absolute temperatures and greater changes in skin temperature because the cooling modality was in closer contact with the skin. This supports findings in previous literature. Janwantanakul⁵ found ice bag with compression from an ace wrap at 14, 24, 34 and 44 mmHg decreased skin temperature more than ice with no compression. However, Janwantanakul⁵ found there were no significant differences in skin temperature change between levels of compression. Our study refutes this finding. We found the degree of compression did affect the magnitude of skin cooling. Higher levels of compression decreased skin temperature more than lower levels of compression. This could be caused by even further modality contact with the skin as compression increases. This also could explain why as compression increased, modality insulation increased as well. Merrick et al.²⁸ also found ice and ace wrap decreased skin temperature more than ice with no compression, though only one level of compression was used (~42-48 mmHg). In contrast, our study found no statistical difference in skin temperature between ice bag only and ice and ace wrap. Ice and ace wrap's greater decrease in skin temperature than the Game Ready®, again, could be contributed to insulation from the blood pressure cuff and ace wrap. Phase change also accounts for the ice groups' greater changes in skin temperature, though the differences between groups are less prominent than in the changes in intramuscular temperature. Again, our results are similar to those found by Holwerda et al.³³, who found ice and ace wrap caused significantly

greater peak change in skin temperature and colder absolute skin temperature than all of the Game Ready® settings. In contrast to our study, Holwerda et al.³³ found Game Ready® high had a significantly greater peak change in skin temperature than Game Ready® no compression. This could be due to wide variances in our data in our statistical analyses. Our statistical model did not pool the data variances, so each mean had a different standard error, which affected how the Bonferroni adjustments determined significant values. Future studies should use a mixed model for their statistical analyses.

Changes in Intramuscular Temperature and Adipose Tissue Thickness

After data were collected, we divided subjects into two groups, adipose thickness < 1.0 cm (6 subjects) and adipose thickness > 1.0 cm (9 subjects), to determine if adipose thickness affected the change in intramuscular temperature over time. The thickness of the adipose layer over the muscle clearly affects the amount of temperature decrease that occurs in the underlying muscle. Our data support results found in a study by Myrer et al.²⁵ This study examined intramuscular temperatures over 20 minutes at 1 cm and 3 cm below the adipose layer on the thigh for three different adipose thicknesses: < 8 mm, 10-18 mm and > 20 mm. They found subjects with < 8 mm of adipose tissue reached lower absolute muscle temperatures at faster rates than subjects with both 10-18 mm and > 20 mm adipose tissue at depths of both 1 and 3 cm below the adipose layer. The temperatures at 3 cm were not as cold as their counterparts at 1 cm for all adipose thickness groups. This is explained by two laws of energy transfer: the Inverse Square Law and the Law of Grothus-Draper. The Inverse Square Law states the intensity (I) of the energy going to the tissue is inversely proportional to the square of the distance (d) between the source and the tissue receiving the energy ($I=1/d^2$).¹² As the distance between the tissue and the source increases, the intensity of the energy reaching the tissue decreases by a law of squares.

Thicker adipose tissue creates a greater distance for the energy to travel between the cooling modality and the underlying muscle, therefore, more time is needed to reach lower intramuscular temperatures. Otte et al.³⁴ support this idea by finding a direct relationship between adipose thickness and treatment time: as adipose thickness increases, treatment duration must increase in order to reach the desired intramuscular temperature.¹² The Law of Grothus-Draper states the depth of penetration and the amount of energy absorbed by the tissues are inversely related; as treatment depth increases, the amount of energy absorbed by the tissues at that depth decreases because it is being absorbed by the tissues closer to the energy source.¹² So, in patients with greater adipose levels, not only does the energy have a greater distance to travel, not all of the energy gets to the desired tissue. Clinically, we should apply cryotherapy treatments for longer than 30 minutes on the quadriceps if the adipose thickness exceeds 1.0 cm in order for the treatment to be effective, assuming the colder the tissue temperature, the better. Though no single predictor can predict intramuscular temperature, Jutte et al.³⁵ suggests time is the strongest predictor in intramuscular temperature. Longer treatment times will result in lower intramuscular temperatures. Starkey¹² suggests 25 minute treatments for patients with a skinfold measurement of < 20 mm, 40 minutes for 20-30 mm and 60 minutes for 30-40 mm. Our study did not follow these guidelines. We studied subjects with adipose thicknesses no greater 1.5 cm for 30 minutes and still saw mixed results for intramuscular temperature decrease. The treatment duration should also depend on the modality applied, as well the patient's adipose thickness. Game Ready® treatment durations should be longer than ice treatment durations because it takes more time for Game Ready® to reach lower temperatures than it does for an ice bag. Future studies should be performed to test treatment times greater than 30 minutes, as they may produce

greater significant differences that were not observed in our study because there was not enough time for the cold to completely penetrate the desired tissue.

Conclusions

Because we do not know the ideal temperature at which the maximum benefits of cryotherapy are achieved, all the modalities in this study could be adequate cooling modalities. However, under the assumption that the colder the tissue temperature reached, the more effective the treatment, we suggest using an ice bag and ace wrap or the medium and high settings when using the Game Ready® system. Because of its ability to produce the coldest intramuscular temperatures, an ice bag and ace wrap should be used in the immediate care of injuries instead of the Game Ready® system in order to achieve optimal benefits of cryotherapy. Game Ready® should be used in the post-acute stage of the injury process. Patients with greater adipose tissue thickness should apply cryotherapy treatments longer than those with thinner adipose thickness. We suggest longer than 30 minutes over the quadriceps for patients with adipose tissue thicknesses greater than 1.0 cm, but not greater than 60 minutes.¹²

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to determine if Game Ready® decreases quadriceps temperatures as much as or more than an ice bag paired with an ace wrap. There were two hypotheses: 1) ice and static compression (ace wrap) will cause a greater decrease in quadriceps intramuscular temperature than all the settings of the Game Ready® system and 2) of all the Game Ready® settings, the high pressure will cause the greatest decrease in intramuscular temperature. Cryotherapy is the use of ice or any other cooling agent to remove heat from the body.^{1,12} It is used to treat a variety of acute injuries including ligament sprains, muscle strains, and contusions.¹³⁻¹⁸ Several factors affect how efficiently cryotherapy removes heat from the body: size of energy gradients, surface area of the modality, modality contact with the skin, depth of treatment site, thermal conductance of the modality and tissues treated, and distance of the modality from the body.^{1,4,12,19}

Of all the common cold modalities, an ice bag causes the greatest decreases in skin and intramuscular temperatures.^{3,4,9} Researchers believe ice's success is due to a phase change.^{4,9} Ice undergoes a phase change from ice to water during treatment, which requires a lot of energy (heat). The increased amount of energy enlarges the energy gradient, increasing the rate and magnitude of tissue cooling.¹ An ice bag paired with an ace wrap produces lower tissue temperatures than ice alone because the compression increases ice contact with the skin.^{5,28} Because of this, companies have been producing devices such as the Game Ready® system that combine cryotherapy and compression. Researchers suggest Game Ready® does not decrease intramuscular temperatures as low as traditional ice bag and ace wrap treatments,^{32,33} but there are some flaws in these studies that could affect data.

Fifteen subjects (9 male, 4 female) received all of six possible treatments on six separate days: ice, ice and ace wrap, Game Ready® no compression, Game Ready® low, Game Ready® medium and Game Ready® high. During each session, an intramuscular thermocouple was inserted to a depth of 1.5 cm plus adipose thickness to measure change in quadriceps temperature. A surface thermocouple was placed 1 cm superior to the intramuscular insertion to measure changes in skin temperature. Another surface thermocouple was placed face down on the outside of the modality. For the ice groups another surface thermocouple was placed inside the ice bags. Game Ready® chamber temperatures were taken before and after the treatment. Temperatures were recorded at 0, 1, 5, 10, 15, 20 and 30 minutes.

Discussion

Change in Intramuscular Temperature

Researchers have established in previous studies that ice applied with compression decreases intramuscular temperatures more than ice without compression.^{3,7,28} Merrick et al.²⁸ found ice bag and compression with an ace wrap caused greater decreases in absolute tissue temperature for skin and muscle at depths of 1 cm and 2 cm than ice bag alone. While the current study may not statistically support these findings, results of both studies are very similar. Merrick et al.²⁸ reported absolute values for tissue temperature at 2 cm below adipose (mean adipose thickness ~0.79 cm for a mean treatment depth ~2.79 cm) as $26.46 \pm 3.04^{\circ}\text{C}$ and $28.21 \pm 2.34^{\circ}\text{C}$ after 30 minutes for ice and ace wrap and ice bag only, respectively. The current study reported values at a slightly more shallow depth of 2.5 cm (mean adipose tissue thickness 1.03 ± 0.29 cm) after 30 minutes of $24.76 \pm 5.18^{\circ}\text{C}$ and $26.32 \pm 4.53^{\circ}\text{C}$ for ice and ace wrap and ice bag alone, respectively. While this study found no statistical significant differences between these values, the difference may be clinically relevant and supports Merrick et al.'s findings.

Compression increases skin surface area and modality contact. The more of the modality in contact with the skin, the greater the transfer of energy, and the greater the decrease in intramuscular temperature. This accounts for the ice and ace wrap's high change in intramuscular temperature and why Game Ready® medium and Game Ready® high decreased tissue temperature more than Game Ready® no and Game Ready® low.

This does not explain why all the Game Ready® settings, except no and low, were the statistical equivalence of ice with no compression. This can be contributed to phase change. In order to understand phase change, one must understand a basic law of energy transfer: energy transfers from levels of high concentration to low concentration. The greater the difference in concentration, the lower the decrease in temperature and the faster the rate of cooling.

Substances that freeze completely solid, such as ice, undergo a phase change from ice to water.

To change ice to water, a large amount of energy (heat) is needed. Therefore, more energy is transferred from the body to the ice bag.^{1,4} This is why ice bags decrease tissue temperature

more than chemical packs despite chemical packs' lower modality temperature and larger energy gradient. Both Game Ready® and ice bags use ice and water and phase changes take place in both groups. However, the difference in change in intramuscular temperature results comes from the location in which the phase change takes place. For the ice bag groups (ice without compression and ice and ace wrap), the phase change takes place on the body, making the energy required for the change directly available from the body. In the Game Ready® groups, the phase change takes place in the chamber, away from the body and unavailable to impact the skin and muscle temperatures. The data of the change in inner modality temperature support this idea.

The temperatures inside the ice bags and Game Ready® no and high were same for each treatment and did not change as treatment progressed and the ice melted. Low and medium got

significantly warmer, by 0.364°C and 0.474°C respectively, as treatment progressed. This may be because of inaccurate thermocouple placement in the Game Ready® chamber. Future researchers should consider weighting the thermocouple so it stays submerged in the chamber. This implies all treatments, except medium and low, applied the same degree of cold to body when compared to each other. The differences in intramuscular temperature observed between treatments can be contributed to the location of the phase change.

Another difference between the ice bag and Game Ready® groups is the type of compression applied during treatment. Ice and ace wrap applies static compression while Game Ready® uses intermittent compression in 3 minute cycles. Even though Game Ready® at its highest setting applied almost double the amount of pressure that ice and ace wrap applied, Game Ready® did not decrease the intramuscular muscle as much as ice and ace wrap because the pressure was not constantly at that highest pressure for the entire 30 minutes. Hawkins et al.³² suggest this lack of constant pressure does not facilitate temperature decrease as well as static pressure because the modality is not in constant contact with skin to the same degree throughout treatment. The current study's results are consistent with this idea. Because the ideal temperature at which optimal benefits of cryotherapy are gained is unknown, all treatments may be beneficial cooling modalities.

However, insulation must be taken into consideration. The blood pressure cuff and ace wrap insulated the ice bag, not allowing the cold to escape into the environment causing the lower intramuscular temperature results. The outer modality air temperature results suggest the ice bag and ace wrap treatment was insulated because it released the least amount of cold into the air. The ice treatment, which had no insulating barrier, released the most cold into the air. If the treatments were ranked in order of poor to excellent insulators, the order would be ice, Game

Ready® no, low, medium, high and ice and ace wrap. This suggests insulation increases as level of compression increases. However, it cannot be determined if the insulation of the ice and ace wrap treatment was exaggerated by the blood pressure cuff. Based on results of other studies, it can be assumed the insulation comes from the ace wrap itself and that the role of the blood pressure cuff as an insulator is minimal. Merrick et al.²⁸ used a manometer and bladder in their study to measure pressure consistency for the ice and ace wrap treatment. According to Merrick et al.²⁸ and Tomchuk et al.⁷, ace wraps are shown to produce an insulating effect by reducing the amount of heat gained from the environment, which causes lower tissue temperatures. This is an important advantage for using this modality clinically. However, Merrick et al.²⁸ did not discuss the possible insulation effect of the manometer and bladder. There are no studies in the literature that examine the effect of insulation caused by a manometer and bladder. Hawkins et al.³² examined Game Ready® medium, ice bag and ace wrap and cold water immersion and only used a blood pressure cuff during pilot testing, not during actual data collection. Hawkins et al.³² concluded the ice and ace wrap produced greater decreases in ankle intramuscular temperature than both cold water immersion and Game Ready® at medium, regardless of possible pressure inconsistency. This suggests the blood pressure cuff may play a minimal role in modality insulation and that the level of compression itself does not play a large role in overall tissue cooling as long as some compression is applied. With that said, for the ice and ace wrap group in this study, the blood pressure cuff had to be pumped throughout treatment to ensure that the pressure stayed consistently at 40mmHg. This suggests either the blood pressure cuff itself could not hold air, the deformation of the ice bag as the ice melted changed the pressure of the ace wrap or the ace wrap itself lost its elasticity over time. The latter two options must be

considered when selecting a cooling modality clinically. Are patients using ice and ace wrap getting constant static compression throughout treatment?

The current study's results are consistent with a study on Game Ready® by Holwerda et al.³³ Holwerda et al.³³ found significant differences in peak intramuscular temperature change between ice and ace wrap and Game Ready® no, but no significant differences in peak temperature change between ice and ace wrap and Game Ready® medium or Game Ready® high (Game Ready® low was not studied). Also, there were no significant differences in peak change in temperature between any of the Game Ready® settings after 30 minutes. Both studies were performed on the quadriceps and used the same treatment duration. Again, though the results for absolute tissue cooling were not statistically different in the current study, they are very similar to those of Holwerda et al. Holwerda et al.³³ found ice and ace wrap produced significantly lower tissue temperatures than both Game Ready® medium and high (ice and ace wrap ~23°C, medium ~26°C and high ~25°C). The current study also found ice and ace wrap produced lower tissue temperatures than both Game Ready® medium and high, but these differences were not found to be statistically different (ice and ace wrap 24.75°C ± 5.18, medium 26.33°C ± 3.61 and high 27.71°C ± 3.20). These findings are very similar, yet Holwerda et al.'s are significant and the ones in the current study are not. This could be because Holwerda et al. treated at a shallower depth than this study (~2.0 cm). Shallower depths require less time to reach lower intramuscular temperatures than deeper depths. The current study may have seen more significant differences between treatments if the treatment duration had been longer. Long et al.²⁷ performed a study on how long it took two different depths, 1 cm and 2 cm below the adipose layer, to decrease 10°C after an ice bag had been applied. They found it took tissues at 1 cm below the adipose layer (~2.54 cm skinfold for a total depth of ~2.27 cm) 45 ± 9.4 minutes

and tissue at 2 cm below the adipose layer (~3.27 cm total depth) 53.6 ± 11.3 minutes to decrease 10°C . The treatment depth for this study fits between Long et al.'s treatment depths and it took a 15 minutes longer to cool 1 cm in Long et al.'s study. This implies we may have needed more time to see greater significant differences in intramuscular temperature between groups, especially for the Game Ready® treatments. The current study takes Holwerda et al.'s findings further by adding ice with no compression as a treatment. Ice only produced temperatures similar to those of both Game Ready® medium and high found in both studies (ice $26.32 \pm 4.53^{\circ}\text{C}$). Clinically, this means Game Ready® may not be the modality of choice for the immediate care of injuries. Under the assumption that colder tissue temperatures produce higher benefits of cryotherapy, ice bag with an ace wrap should be the modality of choice because both cause a greater magnitude of cooling than the Game Ready® system. Using Game Ready® during post-acute injury may be more appropriate because during post-acute injury decreasing cell death due to hypoxia is no longer the primary goal of cryotherapy. After the immediate stage of injury is over, decreasing muscle spasm, pain and nerve conduction velocity are the goals for using cryotherapy and all three can be gained without reaching the lowest possible intramuscular temperature.

Change in Skin Temperature

Change in skin temperature results can be attributed to many of the same causes as change in intramuscular temperature results. Groups with higher levels of compression (ice and ace wrap, Game Ready® medium and Game Ready® high) produced greater absolute temperatures and changes in skin temperature because the cooling modality was in closer contact with the skin. This supports findings in previous literature. Janwantanakul⁵ found ice bag with compression from an ace wrap at 14, 24, 34 and 44 mmHg decreased skin temperature more than

ice with no compression. There were no significant differences in skin temperature change between levels of compression. Merrick et al.²⁸ also found ice bag and ace wrap decreased skin temperature more than ice bag with no compression, though only one level of compression was used (~42-48 mmHg). In contrast, the current study found no statistical difference in skin temperature between ice bag only and ice bag and ace wrap, although the absolute temperature was lower in the ice bag and ace wrap group. This could be the pressure applied by the ace wrap decreased during treatment and air had to be pumped regularly into the blood pressure cuff to keep the compression at ~40 mmHg. The pressure in the current study may not have been as constant as it was in the studies by Janwantanakul and Merrick et al. However, the current study did find significant differences in intramuscular temperature between levels of compression. Game Ready® medium induced significantly lower temperatures than Game Ready® low. This supports results found by Janwantanakul. The low setting applies less compression than the 14 mmHg compression group in Janwantanakul's study. Clinically, clinicians should apply at least 15 mmHg of pressure in order for the treatment to be effective. Ice and ace wrap's greater decrease in skin temperature, again, could be attributed to insulation from the blood pressure cuff and ace wrap. Phase change also accounts for the ice groups' greater changes in skin temperature, though the differences between groups are less prominent than in the changes in intramuscular temperature. Again, the current study's results are similar to those found by Holwerda et al.³³, who found ice and ace wrap caused significantly greater peak change in skin temperature and colder absolute skin temperature than all of the Game Ready® settings. In contrast to the current study, Holwerda et al.³³ found Game Ready® high had a significantly greater peak change in skin temperature than Game Ready® no compression. This could be due to wide variances in our data in our statistical analyses. Our statistical model did not pool the

data variances, so each mean had a different standard error, which affected how the Bonferroni adjustments determined significant values. Future studies should use a mixed model for their statistical analyses.

Change in Intramuscular Temperature related to Adipose Tissue Thickness

After data were collected, subjects were divided into two groups, adipose thickness < 1.0 cm (6 subjects) and adipose thickness > 1.0 cm (9 subjects), to determine if adipose thickness affected the change in intramuscular temperature over time. The thickness of the adipose layer over the muscle clearly affects the amount of temperature decrease that occurs in the underlying muscle. The current study supports results found in a study by Myrer et al.²⁵ Myrer et al. found subjects with shallower adipose thicknesses reached lower absolute muscle temperatures at faster rates than subjects with thicker adipose tissue at depths of both 1 and 3 cm below the adipose layer. This is explained by two laws of energy transfer: the Inverse Square Law and the Law of Grothus-Draper. The Inverse Square Law states the intensity (I) of the energy going to the tissue is inversely proportional to the square of the distance (d) between the source and the tissue receiving the energy ($I=1/d^2$).¹² As the distance between the tissue and the source increases, the intensity of the energy reaching the tissue decreases by a law of squares. Thicker adipose tissue creates a greater distance for the energy to travel between the cooling modality and the underlying muscle, therefore, more time is needed to reach lower intramuscular temperatures. Otte et al.³⁴ support this idea by finding a direct relationship between adipose thickness and treatment time: as adipose thickness increases, treatment duration must increase in order to reach the desired intramuscular temperature. The Law of Grothus-Draper states the depth of penetration and the amount of energy absorbed by the tissues are inversely related; as treatment depth increases, the amount of energy absorbed by the tissues at that depth decreases because it

is being absorbed by the tissues closer to the energy source.¹² So, in patients with greater adipose levels, not only does the energy have a greater distance to travel, not all of the energy gets to the desired tissue. Otte et al.³⁴ studied intramuscular temperature decreases at a treatment depth of 1 cm below the adipose layer for four different adipose thicknesses. The skinfold measurements for the four groups were 0-10 mm, 11-20 mm, 21-30 mm and 31-40 mm. Each measurement was divided by two to determine the treatment depth. It took the 21-30 mm group 37.8 ± 9.6 minutes to decrease intramuscular temperatures 7°C. The treatment depth in the current study falls into the range of this group (absolute depth 2.05-2.5 cm). There were not significant differences between groups in the current study because the treatment duration was not longer. If the treatment duration was closer to 40 minutes, there may have been more significant differences. Clinically, cryotherapy treatments should be applied for longer than 30 minutes on the quadriceps if the adipose thickness exceeds 1.0 cm in order for the treatment to be effective, assuming the colder the tissue temperature, the better. Jutte et al.³⁵ examined the relationships among intramuscular temperature, skin temperature, adipose thickness, room temperature and core temperature during cryotherapy, in order to see if any of those factors can be used to predict intramuscular temperature. Subjects were treated with an ice bag over the thigh for 30 minutes at a depth of 2.0 cm below the adipose layer (~3 cm total). The researchers used two equations incorporating all the factors to attempt to predict intramuscular temperature. Though none of these factors can singly predict intramuscular temperature, Jutte et al.³⁵ suggests time is strongest predictor in intramuscular temperature. Longer treatment times will result in lower intramuscular temperatures. With all the factors combined, Jutte et al.³⁵ were able to predict intramuscular cooling up to 76%. This is clinically relevant because it exemplifies how complex it is to determine cryotherapy parameters. One cannot simply rely on one factor when

choosing treatment parameters, but must consider several factors such as time, target tissue depth and adipose thickness together. Jutte et al.³⁵ found a weak singular correlation between adipose thickness and intramuscular cooling, which the current study refutes. This could be because of procedural limitations in the Jutte et al. study that did not allow the treatment depth standard to be met for subjects with large adipose thicknesses. Subjects with larger adipose thicknesses were unable have their intramuscular temperatures recorded at the desired treatment depth, but rather at a shallower depth due to the use of hypodermic needles. This created a lot of variability in the intramuscular temperature data, which affected the prediction equation results.

Clinical Relevance

The current study is important because cryotherapy is used daily in athletic training rooms all over the world and there are so many different cooling modalities to choose from. Among ice bags, chemical packs, gel packs, cold water immersion and cold and compression devices like the Game Ready® system, this choice can be an overwhelming one. Previous literature provides athletic trainers with a solid foundation on which to base their decisions, but most of the research is limited to validating the use of ice bags. Little is known about up and coming cryotherapy devices like the Game Ready® system, which are gaining more popularity in clinical use. This study gives athletic trainers clearer criteria for selecting cryotherapy treatments. The most important effect of cryotherapy during the immediate care stage of injury is reduced cell death due to hypoxia.¹ Because the ideal tissue temperature for optimal cryotherapy effects is unknown, it is assumed the colder the tissue is, the more effective the treatment is. Ice bag and ace wrap reduced tissue temperature better than the Game Ready® device. Therefore, ice and ace wrap is a more appropriate treatment for the immediate care of acute injuries. Game Ready® is more appropriate for post-acute injury. The medium and high

settings on the Game Ready® should be used because they reached the lowest intramuscular temperatures of all the Game Ready® settings. One of the reasons ice and ace wrap is an effective treatment is that the ace wrap serves as an insulator. Before the current study, only a few studies existed that suggested an ace wrap may be a modality insulator and now this study adds to and supports those studies. This promotes the use of an ice and ace wrap as the immediate care modality of choice. When applying an ice treatment without an ace wrap, clinicians should cover the bag with a towel to give the treatment an insulating barrier. The results for inner modality temperature suggest that ice bag and Game Ready® chamber temperatures are the same and do not change as the ice melts, providing the same level of cold throughout the entire treatment. It is already established that cooling modalities that undergo a complete phase change (i.e. ice bag) decrease tissue temperature better than those that undergo partial phase change (i.e. frozen peas).³ This study takes those findings further by showing that the location in which the phase change takes place matters. The phase change must take place on the body in order for the energy to be available to decrease the tissue temperature.

Once one has selected an appropriate cooling modality, one must select the appropriate treatment parameters, which can be very complex and many factors must be taken into consideration in order for the treatment to be effective. These factors include target tissue depth, duration and patient adipose thickness. Again the previous literature has provided a solid foundation for selecting the criteria and this study adds to and supports the literature. This study also helps athletic trainers determine appropriate cryotherapy treatment durations. Adipose tissue thickness has an effect on intramuscular cooling. Since the energy from the modality has a greater distance to travel and requires more time, patients with adipose tissue thicknesses greater than 1 cm over the target tissue should have cryotherapy treatments for longer than 30 minutes in

order for the treatment to be effective. Level of compression is also important when selecting a modality during immediate care. Static compression should be applied, instead of intermittent compression, at least 15 mmHg in order for the treatment to be effective during immediate care.

Recommendations for Future Research

Research needs to be performed to determine the ideal tissue temperature at which optimal benefits of cryotherapy occur. If other researchers are interested in performing a study similar to this one, they should consider using a different technique to regulate compression in the ice bag and ace wrap treatments to determine if the ace wrap's insulation effects are exaggerated. When using a blood pressure cuff, it should be placed to the side of ice bag instead of directly on top of it. They should also consider weighting the thermocouple when measuring the Game Ready® chamber temperatures so it stays submerged in the chamber. Researchers should consider using a mixed model for their statistical analysis in order to pool the data variances and get more accurate significant differences between treatments. The Game Ready® system's true merit may be its ability to reduce swelling, rather than its ability to reduce tissue temperature. Research should be performed on this capability of the device. Studies should be performed with longer treatment durations to see if tissue temperatures plateau and if more significant differences between treatments and adipose thicknesses can be found that were not seen with this study.

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