

1-1-2005

## Tissue cooling during cryotherapy with varied types of compression

David Tomchuk  
*University of Nevada, Las Vegas*

Follow this and additional works at: <https://digitalscholarship.unlv.edu/rtds>

---

### Repository Citation

Tomchuk, David, "Tissue cooling during cryotherapy with varied types of compression" (2005). *UNLV Retrospective Theses & Dissertations*. 1808.  
<http://dx.doi.org/10.25669/j6oz-kr4r>

This Thesis is protected by copyright and/or related rights. It has been brought to you by Digital Scholarship@UNLV with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Thesis has been accepted for inclusion in UNLV Retrospective Theses & Dissertations by an authorized administrator of Digital Scholarship@UNLV. For more information, please contact [digitalscholarship@unlv.edu](mailto:digitalscholarship@unlv.edu).

TISSUE COOLING DURING CRYOTHERAPY WITH VARIED TYPES OF  
COMPRESSION

by

David Tomchuk

Bachelor of Science  
Southern Oregon University  
2002

Master of Science  
University of Nevada, Las Vegas  
2005

A thesis submitted in partial fulfillment  
of the requirements for the

**Master of Science in Kinesiology**  
**Department of Kinesiology**  
**School of Health and Human Sciences**  
**Division of Health Sciences**

**Graduate College**  
**University of Nevada, Las Vegas**  
**May 2005**

UMI Number: 1428595

Copyright 2005 by  
Tomchuk, David

All rights reserved.

#### INFORMATION TO USERS

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleed-through, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

**UMI<sup>®</sup>**

---

UMI Microform 1428595

Copyright 2005 by ProQuest Information and Learning Company.

All rights reserved. This microform edition is protected against  
unauthorized copying under Title 17, United States Code.

ProQuest Information and Learning Company  
300 North Zeeb Road  
P.O. Box 1346  
Ann Arbor, MI 48106-1346

Copyright by David Tomchuk 2005  
All Rights Reserved



## Thesis Approval

The Graduate College  
University of Nevada, Las Vegas

April 12, 2005

The Thesis prepared by  
David Tomchuk

### Entitled

The Rate of Tissue Cooling During Cryotherapy With Varried Types  
of Compression

is approved in partial fulfillment of the requirements for the degree of

Master of Science in Kinesiology

Examination Committee Chair

Dean of the Graduate College

Examination Committee Member

Examination Committee Member

## ABSTRACT

### **Tissue Cooling During Cryotherapy with Varied Types of Compression**

by

David Tomchuk

Dr. Mack D. Rubley, Examination Committee Chair  
Assistant Professor of Kinesiology  
University of Nevada, Las Vegas

This study was performed to examine the effects of varied types of external compression on surface and intramuscular temperature. Fourteen university students volunteered for this study; each subject received all 3 treatment conditions: ice compressed with an elastic wrap, ice compressed with Flex-i-Wrap™, and ice with no compression. Subjects were asked to lie prone on a standard treatment table during the 30-minute ice application and the 60-minute post-application durations. Surface and intramuscular temperatures were recorded every 30 seconds throughout the experiment. The results revealed a significant difference in surface temperature between compression and no compression, but no difference between forms of compression. Intramuscular temperature was significantly colder between compression and no compression and between an elastic wrap and Flex-i-Wrap™ where an elastic wrap was significantly colder than Flex-i-Wrap™. Externally compressing an ice bag with an elastic wrap generates a greater rate and magnitude of intramuscular tissue cooling than external compression with Flex-i-Wrap™.

## TABLE OF CONTENTS

ABSTRACT .....	iii
CHAPTER 1 INTRODUCTION .....	1
Statement of the Problem .....	2
Purpose of the Study .....	2
Statement of Hypothesis .....	3
Limitations of Study .....	4
CHAPTER 2 LITERATURE REVIEW .....	5
Sports Injury Model—Primary Injury .....	5
Sports Injury Model—Secondary Injury .....	6
Secondary Hypoxic Injury .....	7
Secondary Enzymatic Injury .....	8
Inflammatory Response .....	9
Normal Fluid Exchange .....	11
Fluid Exchange Subsequent to Injury .....	12
Preventing Secondary Hypoxic and Enzymatic Injury .....	12
Pathophysiological Effects of Cold .....	13
Cryotherapy Types and Applications .....	14
Cryotherapy Application Times .....	17
Heat Conduction .....	20
Contraindications to Cryotherapy .....	22
Tissue Cooling on Blood Flow Rates .....	24
Adipose Tissue Thickness on Tissue Cooling .....	30
Ice and Comfort Barriers .....	32
Physiological Effects of Compression .....	35
Compression and Cryotherapy .....	36
Activity and Cryotherapy .....	40
Cryotherapy Immediately Post-Surgery .....	43
Predicting Intramuscular Temperature .....	48
Intramuscular Thermocouple Sterilization .....	50
IM Implantation Techniques .....	50
CHAPTER 3 METHODS .....	53
Description of Subjects .....	53

Design .....	54
Treatment .....	54
Instrumentation .....	54
Procedures.....	55
Statistical Analysis.....	58
CHAPTER 4 RESULTS .....	59
CHAPTER 5 DISCUSSION.....	64
Conclusions.....	79
Practical Recommendations.....	80
Future Study Considerations.....	80
APPENDIX I PICTURES OF THERMOCOUPLE AND ICE APPLICATION TECHNIQUES.....	81
APPENDIX II BIOMEDICAL SCIENCES INSTITUTIONAL REVIEW BOARD APPROVAL AND SUBJECT FORMS .....	88
Informed Consent to be a Research Subject .....	89
Subject Information and Injury History Questionnaire .....	92
Subject Information Take-Home Sheet on Infection.....	93
APPENDIX III PROCEDURE FOR IMPLANTING INTRAMUSCULAR THERMOCOUPLE .....	94
APPENDIX IV RAW TEMPERATURE DATA.....	98
REFERENCES .....	106
VITA.....	111



## LIST OF TABLES

Table 1	Surface Temperatures (°C, Mean $\pm$ St Dev) with Three Compression Types.....	60
Table 2.	Intramuscular Temperature (°C, Mean $\pm$ St Dev) with Three Compression Types.....	63
Table 3.	Comparison of the Research on Surface Temperature Changes in Human Tissue After Applications of Cryotherapy.....	65
Table 4.	Comparison of the Research on Intramuscular Temperature Changes in Human Tissue After Applications of Cryotherapy .....	67
Table 5.	Interface Temperature Between the Wrap and the Atmosphere with Three Compression Types .....	76

## ACKNOWLEDGEMENTS

First, my father who has sacrificed his life for the betterment of others and these past 3 years are just one example out of countless selfless acts he has done. My committee members: Drs. Rubley, Holcomb, Guadagnoli, and Prof. Altenburger, for helping me with this work. I will remember your patience and kindness and hope to work with each of you in the future. Dr. Jason Tarno for allowing me to borrow his medical expertise and being available for questions during data collection. Dr. Rick Lippmann who initially assisted me with his medical knowledge. Dr. Richard Tandy for his always-informative statistical expertise. Dr. Brent Mangus, who offered me a position for my 3<sup>rd</sup> year at UNLV and allowed me plenty of hands on experience that will help me in the future; I hope I have helped you half as much as you have helped me. All 14 of my subjects; unfortunately, I cannot print your names. All my athletes; I wish each of you the best in your athletic career and in life. All of my students who have helped me grow as both an ATC and an instructor; hopefully, a few of you will use what I have taught. All my colleagues and friends: Crager, Leland, Joe (geeeeeeeek), AJ Jayhawk, Rock, Heather and John, The Scumbag, Baca, Ernst, Ann, Bern-Dog, Kyle, Kylee, Nichole T, Adam and Stephanie and the Kid, Yvette, Amaris, Jerry, Kristy J, Kelly M, Natalie, Katie O, Tiff Z, Dave D, Janet and Monty G, Angie & Andy B, MF Courtland, Mike S #1, Ty, Jacob, Jen B, Mayumi, Kris B, Erica, Mindy R, Fumi, Gus, Jose B, Blake, Darlene, Plaster, Jeff D, Donny, Jung-Gi, Nichole VDB, Phil P, Mike S #2, Sara S, Scooter. If I have forgotten you please accept my most sincere and heartfelt apology.

## CHAPTER 1

### INTRODUCTION

Cryotherapy, the application of ice to an injured area, is a basic treatment protocol used to reduce the magnitude of the inflammatory process,<sup>1-9</sup> blood flow,<sup>10-14</sup> initial swelling,<sup>1-6, 9, 15</sup> secondary injury,<sup>1, 3-9, 16, 17</sup> and pain.<sup>1-3, 5-9</sup> It is often assumed that the cooler the tissue becomes following injury, the greater benefit of the treatment. However, to date the appropriate rate and magnitude of temperature decrease for ideal tissue healing remains unknown. Additionally, it is unknown if the differing methods of compression used in conjunction with an ice bag application provide differing rates of cooling in muscle tissue. Yet, cryotherapy is still known to speed the rate of recovery from injury, making it the treatment of choice following acute injury.<sup>1</sup>

Clinicians have several cryotherapy options available to aid tissue healing and facilitate rehabilitative exercise. Traditional cryotherapy treatments include: cold whirlpools, cold-gel packs, ice massage, and ice bags.<sup>1</sup> While each cryotherapy application is used for a variety of situations, all forms of cryotherapy have the potential to reduce tissue temperature and speed recovery, if used properly.

Traditionally, an ice bag with some form of compression is the most commonly used modality to treat acute injuries as part of rest, ice, compression, elevation, and support (RICES).<sup>1, 6, 7</sup> Tissue cooling is augmented by the compressive wrap which

provides insulation to area and reduces energy exchange between the ice bag and the atmosphere.<sup>1, 11, 17</sup> The combination of ice and external compression causes a greater rate and magnitude of cooling than an ice bag application alone.<sup>17</sup> The rate and magnitude of tissue temperature decrease may depend on the type of external compression utilized. However, it remains unknown if different types of compression make a difference in the rate and magnitude of tissue cooling

### Statement of the Problem

Commonly, clinicians use one of two options when compressing an ice bag to the body, either an elastic wrap (Ace Wrap) or Flex-i-Wrap™. Elastic wraps are the most commonly used external compression; but Flex-i-Wrap™ has become a popular mode of compression during the past decade.<sup>1, 18</sup> This disposable plastic wrap, much like strong saran wrap, has made the application of ice bags more convenient than elastic wraps. Flex-i-Wrap™ has allowed a clinician to apply cryotherapy to an individual after activity and the individual can subsequently leave the treatment area. The ice can be removed and the wrap discarded without having to return the wrap to the treatment facility. However, it is unknown if the combination of ice compressed with Flex-i-Wrap™ is as effective as the combination of ice compressed with an elastic wrap in generating tissue cooling, or greater than no compression alone.

### Purpose of the Study

To date, no study has directly compared the rate and magnitude of tissue cooling between differing forms of external compression (elastic wrap and Flex-i-Wrap™)

verses icing without compression. Therefore, it is our intention to determine which method of ice application and external compression results in the greatest rate and magnitude of tissue temperature cooling. The purpose of this study is to compare two methods of external compression on surface and intramuscular temperatures during and following a 30-minute ice bag application to the gastrocnemius muscle. This study will assist in determining the most effective treatment method for reducing tissue temperature. Secondly, this study will examine if the relationship of compression and cooling are consistent on the skin's surface and within the muscle.

#### Statement of Hypothesis

##### Null-

1. There is no difference in tissue temperature 2 cm below the surface between no compression, Flex-i-Wrap™, and elastic wrap.
2. There is no difference in surface temperature between no compression, Flex-i-Wrap™, and elastic wrap.
3. The rate of rewarming will not be different no compression, Flex-i-Wrap™, and elastic wrap.

##### Alternate-

1. There is a significant difference in tissue temperature 2 cm below the surface between no compression, Flex-i-Wrap™, and elastic wrap.
2. There is a significant difference in surface temperature no compression, Flex-i-Wrap™, and elastic wrap.

3. The rate of rewarming will be different between no compression, Flex-i-Wrap™, and elastic wrap.

#### Limitations of Study

1. Amount of compression was not measured.
2. No exercise will be performed during the study. Flex-i-Wrap™ is commonly used on individuals who leave the treatment facility once the ice bag is externally compressed.
3. The data collection area is relatively small compared to treatment area; the effect that is measured may not be constant across the entire treatment area.

## CHAPTER 2

### LITERATURE REVIEW

#### Sports Injury Model—Primary Injury

An injury sustained to the body can be caused by stretching forces (sprains or sprains) or direct compressive forces (contusions).<sup>1, 4, 7, 19</sup> Either mechanism of injury damages nerves and blood vessels.<sup>1, 4, 7, 19, 20</sup> Any damage caused by a direct and specific trauma is a primary injury.<sup>1, 4, 7, 19</sup> The damaged nerves send impulses to the brain, and pain is perceived.<sup>1</sup> The ruptured vasculature allows their contents to spill into the interstitial area.<sup>1</sup> Subsequently, the contents must be removed before new cells can replace damaged ones.<sup>1, 21</sup>

Blood which hemorrhages from broken vessels enters into the extravascular space, resulting in swelling.<sup>1, 7, 19</sup> Fibrin and blood platelets close the damaged vessels.<sup>1</sup> The fibrin forms into strands, which develop into a net-type structure.<sup>1</sup> This structure captures circulating platelets, sealing the damaged vessels.<sup>1, 21</sup> A hematoma, consisting of whole blood and cellular debris, is formed.<sup>1</sup> The individual perceives additional pain when the hematoma exerts pressure on undamaged pain neurons.<sup>1</sup> The body responds with muscle spasm, inhibition of muscular strength, and decreased range of motion to protect the area from injury aggravation.<sup>1</sup> The body removes the hematoma by the

inflammatory response so that once the hematoma is removed, wound healing and repair can begin.<sup>1, 21</sup>

### Sports Injury Model—Secondary Injury

Secondary injury occurs after primary injury.<sup>1, 4</sup> Knight<sup>4</sup> published the first article directly discussing secondary injury. The edema, which is caused by the original mechanism of injury, causes a lack of blood flow to the undamaged surrounding tissue.<sup>1, 4, 6, 7, 19</sup> The lack of blood flow causes the undamaged cells to transfer from an aerobic to an anaerobic state.<sup>4, 22</sup> Resulting in a fall in adenosine triphosphate (ATP) production, metabolic acidosis, decreased pH, membrane failure, and finally cell necrosis and lysing.<sup>4</sup> The area which is damaged increases from the original injury to include surrounding (uninjured) tissues.<sup>1, 7, 19, 22</sup> Knight<sup>4</sup> cited several studies where injuries treated with ice allowed cells to survive longer than no treatment or treatment with thermotherapy as initial evidence demonstrating the existence of secondary injury.<sup>23-25</sup>

Secondary injury results in greater edema, which results in greater secondary injury.<sup>1</sup> Two mechanisms are involved in increasing secondary hypoxia, distance and compression.<sup>1</sup> As edema develops, the distance between the blood vessels and tissue cells increases.<sup>1, 22</sup> Increased distance between these structures makes it increasingly difficult for oxygen and nutrients to diffuse from the circulatory system to the tissue.<sup>1</sup> Second, edema may compress blood vessels, decreasing circulation to the area.<sup>1, 22</sup>

Since secondary injury was first described,<sup>4</sup> cryotherapy has been the modality of choice for treating acute injuries; but few controlled studies examined the role of cryotherapy on reducing secondary injury or whether secondary injury actually occurred.<sup>7, 19, 22</sup> It was believed that by using ice, the reduced temperature would lower



the metabolic rate, thus the demand for ATP; resulting in less need for oxygen.<sup>19, 22</sup>

This potentially lengthens the survival of cells surrounding the area of injury during a hypoxic state.<sup>19, 22</sup> Merrick et al.<sup>7</sup> attempted to document the presence of secondary injury in skeletal muscle, to quantify it, and to determine whether it is altered by cryotherapy. Their findings suggested that something subsequent to the primary injury caused the difference in triphenyltetazolium chloride (TCC) reduction between injured groups.<sup>7</sup> Therefore, secondary injury must have occurred explaining the difference in TCC reduction between groups.<sup>7</sup>

With these results it can be concluded that: continuous cryotherapy application for 5 hours retarded injury and secondary injury occurred after primary injury.<sup>7</sup> Merrick et al.<sup>7</sup> suggest two mechanisms of secondary injury, secondary hypoxic injury and secondary enzymatic injury.

#### Secondary Hypoxic Injury

In secondary hypoxia, the lack of blood flow causes undamaged cells, on the periphery of the primary injury, to transfer from an aerobic state to an anaerobic state; resulting in post-injury ischemia.<sup>1, 4, 7</sup> Secondary hypoxia results in greater edema; further increasing secondary hypoxic injury.<sup>1</sup> As edema develops, the distance between the blood vessels and the tissue increase, compressing blood vessels and decreasing circulation to the area.<sup>1, 22</sup> Increased distance between the vasculature and the tissue make it difficult for oxygen and nutrients to diffuse from the circulatory system to the tissue.<sup>1, 22</sup> The ischemia results in a hypoxic period; preventing the use of oxygen as the terminal electron acceptor in oxidative phosphorylation. This leads to a dependence on

the glycolytic pathways for ATP production.<sup>7, 19</sup> The inefficiency of glycolysis, coupled with the low availability of fuel substrates, prevents an adequate production of ATP for a limited time.<sup>7, 19</sup> This period of ischemia may last from minutes to hours, depending on the tissue involved.<sup>7, 19</sup> When the glycolytic pathway can no longer provide adequate ATP, membrane ion pumps (ATPase pump), and other homeostatic mechanisms fail, resulting in necrosis and eventually cellular death.<sup>19</sup>

### Secondary Enzymatic Injury

Secondary enzymatic injury occurs when enzymes designed to digest cellular debris are activated and released from the lysosomes of dead cells.<sup>1</sup> The enzymes come into contact with nearby live cells damaging the cell membranes.<sup>1, 22</sup> The enzymes thought to cause subsequent injury include: acid hydrolases, phospholipases, various proteases, and any of a number of human neutrophil proteins.<sup>7, 19</sup>

Acid hydrolases and phospholipases lyse the membranes of nearby cells by cleaving hydrocarbon chains from the lipid portion of membrane phospholipids.<sup>1, 7, 19, 21</sup> Proteases cleave the peptide bonds of proteins (inactivating the proteins), leading to additional cellular death.<sup>1, 7, 19</sup> Changing the structure of the membrane phospholipids leads to the loss of membrane polarity, fluidity, and integrity.<sup>19</sup> Changes in the structure of membrane phospholipids lead to the loss of resting membrane potential and increased hydropic swelling, resulting in cellular death.<sup>7, 19, 22</sup>

## Inflammatory Response

Acute musculoskeletal trauma triggers the inflammatory response and its five cardinal signs: swelling, heat, redness, pain, and loss of function.<sup>1, 21, 26</sup> Inflammation plays three primary functions in the body: 1) defend against alien substances, 2) disposal of dead and dying tissue so that repair can take place, and 3) promote regeneration of normal tissue.<sup>1</sup> The inflammatory process involves vascular, hemostatic, and cellular responses which are all mediated by a complex interaction of neural and hormonal regulations still being researched.<sup>26, 27</sup> Chemical messengers allow the progression of the inflammatory process and are activated with each injury.<sup>1</sup>

The vascular response is characterized by an initial vasoconstriction of local blood vessels, lasting several minutes, followed by a vasodilation of the same local blood vessels.<sup>22, 26, 27</sup> Local chemical mediators including: histamine, bradykinin, prostaglandins, leukotrienes, and serotonin are released.<sup>1, 26, 27</sup> Histamine is released by blood platelets, basophil leukocytes, and mast cells; increasing arterial dilation and microvessel permeability.<sup>1, 4, 26, 27</sup> Bradykinin, a plasma protease, increases microvessel permeability and causes pain.<sup>1, 26, 27</sup> Prostaglandin and leukotrienes are released from damaged cell membranes cause vasodilation and pain.<sup>21, 26, 27</sup> Serotonin, found in platelets and mast cells, is a powerful vasoconstrictor.<sup>27</sup> Histamines, bradykinin, prostaglandin, and leukotrienes increase blood flow to an injured area.<sup>1, 27</sup>

The hemostatic response is a function to control local blood flow by dilating local vasculature.<sup>1, 26</sup> These combined actions cause an increase in blood flow, but a decrease in the blood flow rate.<sup>1</sup> The decreased blood flow rate allows leukocytes to fall from the blood towards the capillary walls.<sup>1</sup> The leukocytes adhere themselves to the vessel walls

and pass through because the capillary walls become porous by a process known as margination.<sup>1, 26, 27</sup>

The cellular response is characterized by the interaction of leukocytes, tissue, and interstitial fluid.<sup>26, 27</sup> After margination, leukocytes diffuse through the endothelial walls and are directed to the injury site by chemotaxis; a cellular function in which phagocytic activity is influenced by the chemical factors released by invading microorganisms.<sup>27</sup> Leukocytes migrate towards the injured site; attracted by the concentration of chemical mediators in the area.<sup>1</sup> An injured area with a high concentration of chemical mediators will attract a large amount of leukocytes, likewise an injury site with a low concentration of chemical mediators will attract a low amount of leukocytes; forming a concentration-limited relationship.<sup>1</sup>

Once the leukocytes enter the interstitial area, their primary function is to cleanse the injured area of microorganisms; preparing the area for tissue repair.<sup>1, 26, 27</sup> Neutrophils, the type of leukocyte most dominant in the blood, arrive at the injury site first and in the greatest numbers, being attracted by chemotaxtic agents released at the time of injury. Neutrophils have a life span of approximately 7 hours and are incapable of reproduction.<sup>1, 27</sup> The primary responsibility of neutrophils is to remove bacteria and small debris by phagocytosis.<sup>1, 21, 27</sup> Phagocytosis breaks down the damaged tissue, allowing it to be removed by the lymph system.<sup>1</sup> The byproducts of phagocytosis are released into the intracellular space, increasing tissue oncotic pressure and causes edema formation.<sup>1, 21</sup> Bacteria is usually not present in athletic injuries. As neutrophils die, their digestive enzymes are released, causing subsequent chemical reactions; adding to the amount of chemical messengers already present.<sup>1, 4, 26, 27</sup> Macrophages, the

principle scavengers, are attracted to the area.<sup>1, 4, 26, 27</sup> Macrophages live for several months and are capable of reproduction, resulting in an increased capacity to decrease inflammation and remove damaged cells.<sup>1</sup> Macrophages remove unwanted cellular debris (fibrin, red cells, and bacteria) by phagocytosis.<sup>1, 4, 21, 26</sup>

There are drawbacks to the inflammatory response.<sup>1</sup> Vascular blood flow on the periphery of the primary injury site decreases; less oxygen is delivered to the undamaged cells on the periphery of the primary injury site.<sup>1</sup> If this hypoxic state continues metabolic changes occur and the area of the injury expands, leading to secondary injury.<sup>1</sup>

The inflammatory process is a natural process with vascular, hemostatic, and cellular responses. Chemical mediators, and their concentrations, propagate the inflammatory process. Secondary injury is the primary side effect of the inflammatory process.

### Normal Fluid Exchange

In the body, blood flow is regulated by the constant exchange of blood entering and leaving an area.<sup>1, 26</sup> Physiologically, edema is formed when the flow of fluid entering an area is greater than the flow exiting the area.<sup>1</sup> The formula to describe this interaction between fluids, Starling's hypothesis, is:  $CFP = (CHP + TOP) - (COP + THP + EFP)$ .<sup>1, 26</sup> The components of Starling's hypothesis are: CHP (capillary hydrostatic pressure), TOP (tissue oncotic pressure), COP (capillary oncotic pressure), THP (tissue hydrostatic pressure), and EFP (external force pressures).<sup>1, 26</sup> CFP (capillary filtration pressure) is the sum of the five pressures.<sup>1</sup>

CHP forces fluid out of capillaries.<sup>1, 26</sup> TOP tends to pull fluid out of the capillary.<sup>1, 26</sup> COP tends to pull fluid back into the capillary.<sup>1, 26</sup> THP forces fluid back into the capillary.<sup>1, 26</sup> EFP does not occur in normal circumstances and results from the external force pressures resulting from tissue elasticity and bandages.<sup>1, 26</sup> The average normal pressure (mm Hg) for these pressures are: CHP 23, TOP 10, COP 25, THP 1 to 4, and EFP 0.<sup>1</sup> Under normal circumstances, CFP is slightly positive, between 4 and 7 mm Hg, meaning that more fluid leaves the capillaries from the arterioles than enters the venules.<sup>1</sup> The fluid that does not return to the veins is removed via the lymphatic system.<sup>1</sup>

#### Fluid Exchange Subsequent to Injury

When an injury is sustained, the amount of fluid leaving the vessels and entering the tissue is greater due mostly to an increase in TOP.<sup>1, 22</sup> TOP rises because of an increase in free proteins in the injured area as a result of phagocytosis occurring in the area.<sup>1</sup> More fluids pass out of the capillaries in the vicinity of the injury and less fluid is absorbed, resulting in increased edema.<sup>1</sup> A greater severity of injury causes more free protein and eventually more edema.<sup>1</sup> This process accounts for the delayed onset of most swelling.<sup>1</sup>

#### Preventing Secondary Hypoxic and Enzymatic Injury

As previously stated, it is believed that cryotherapy assists in preventing secondary injury from occurring; but few direct laboratory evaluations have occurred.<sup>1, 7, 22</sup> Evidence does exist that metabolic enzymatic activity is decreased by approximately

50% when the local temperature is lowered by 10°C.<sup>22, 28</sup> Normal venous blood is 70% oxygen saturated; but venous blood from areas exposed to cold is 80% oxygen saturated.<sup>28</sup> This indicates that cooled tissues require less oxygen to survive than tissues at normal body temperatures.<sup>28</sup> Merrick et al.<sup>7</sup> determined that cooling tissues with ice caused a mechanism by which mitochondrial damage is retarded. It is likely this mechanism is a reduction in the metabolic demand of the tissue, although the physiological mechanisms for the retarding of mitochondrial damage was not examined in this study.

Secondary hypoxic and enzymatic injury may be reduced by slowing cellular metabolism in the area surrounding the injury site.<sup>1, 4, 6, 7, 19, 22</sup> If local metabolism can be reduced, cellular respiration will be reduced, which decreases oxygen demand and ATP production, leading to a reduction in the proliferation of secondary hypoxic and enzymatic injury.<sup>1, 4, 6, 7, 19</sup> Recent cryotherapy research suggests that a tissue temperature decrease of 5°C at depths of 2 to 3 cm below the adipose tissue is needed to reduce the risk of secondary hypoxic and enzymatic injury.<sup>1, 5-7, 19</sup>

### Pathophysiological Effects of Cold

When cold is applied to the body many pathophysiological affects occur.<sup>1, 27</sup> The affects can be grouped into seven primary categories: 1) decreased temperature, 2) decreased metabolism, 3) inflammatory effects (decreased or increased), 4) circulatory effects (decreased or increased), 5) decreased pain, 6) decreased muscular spasm, and 7) increased tissue stiffness.<sup>1, 27</sup> Immediately upon cold application, tissue cools. The temperature may be severe enough to destroy tissue (-20°C to -70°C), however ATCs do

not use temperatures this low.<sup>1</sup> Tissue is usually cooled to a surface temperature between 1°C and 10°C; with intramuscular and intra-articular temperatures being higher than surface temperature.<sup>1</sup> Decreased pain, muscle spasm, metabolism, and inflammation are universally accepted.<sup>1</sup> The circulation effects of cold application is more complex; with some authors believing that cold will actually result in cold-induced vasodilation (CIVD) and increasing blood flow,<sup>29-35</sup> while others<sup>1, 10, 12-14, 36, 37</sup> demonstrate that cold does not cause reflex vasodilation and CIVD does not occur. A clinician must understand cold in its entirety and how it affects the body in order to utilize it correctly to return an individual to participation quickly and safely.<sup>1</sup>

### Cryotherapy Types and Applications

A clinician has several cryotherapy options available to aid in the tissue healing process. Traditional cryotherapy treatments include: ice bags, cold gel-packs, ice massage, cold whirlpools, and commercial cold machines.<sup>1, 5, 26, 27</sup> Each form of cryotherapy is used in certain situations; with specific advantages and disadvantages.<sup>1, 5, 26, 27</sup> All forms of cryotherapy have the potential to reduce tissue temperature. The type of cryotherapy used will affect the rate of cooling.<sup>1, 6</sup> Ice bags with external compression are the most commonly used and most effective at removing heat from the body.<sup>1, 5, 26, 27</sup>

Ice bags are either cubed, crushed, shaved, or chipped ice that is placed in a plastic bag and applied to the body.<sup>1</sup> Ice bags are popular amongst certified athletic trainers (ATCs). They cool the body more than cold gel-packs and can last longer outside a freezer. This difference makes ice bags economical, easily to transported, and can be stored to be used in first aid situations.<sup>1, 5, 6, 38</sup>



Cold gel-packs are usually utilized in physical therapy clinics and are marketed for home use, having a mean temperature of approximately  $-17^{\circ}\text{C}$ .<sup>1, 6</sup> Cold gel-packs are less messy and can be used numerous times when the vinyl enclosure remains intact and chilled for at least 2 to 3 hours between applications.<sup>1, 38</sup> However, cold gel-packs begin to re-warm immediately upon removal from the freezer, they can not be effectively removed for use at a practice site or stored, for later use, in anything except a freezer.<sup>1</sup>

Since cold gel-packs are below freezing when utilized, layers of toweling must be used to protect the skin from frostbite.<sup>1, 6, 39</sup> This added barrier greatly decreases the efficiency of the treatment by decreasing the modalities' ability to lower temperature.<sup>39</sup> Compressing a cold gel-pack to the body should be closely monitored to prevent frostbite.<sup>1</sup>

Cold gel-packs have the capacity to absorb 92,092 J/kg as they increase in temperature from  $-17^{\circ}\text{C}$  to  $5^{\circ}\text{C}$ ; compared to an ice pack which absorbs 356,022 J/kg when increasing from  $-1^{\circ}\text{C}$  to  $5^{\circ}\text{C}$ .<sup>1, 6</sup> As ice melts, from  $0^{\circ}\text{C}$  ice to  $0^{\circ}\text{C}$  water, it requires 333,000 J/kg of energy.<sup>6, 40</sup> This phase change absorbs approximately four times more heat from the tissue.<sup>6</sup> Cold gel-packs do not have the cooling ability to prevent secondary injury, before being wrapped in toweling.<sup>1, 5, 6</sup>

Merrick et al.<sup>40</sup> investigated the statement that natural ice absorbs more heat than cold-gel packs. The authors examined natural ice, a cold-gel pack, and a hybrid product that combined the two, measuring temperature at skin, 1, and 2 cm below adipose for 30 minutes. Results showed that all three cryotherapy treatments produced colder intramuscular temperatures at all depths than the no-ice condition. The ice-based treatments produced significantly lower skin and 1 cm deep temperature than the cold-

gel pack; the 2-cm depth was not significant at the conclusion of the 30-minute treatment. Cold modalities, which go through a phase change, are preferred to cold modalities, which do not change physical states, to reduce tissue temperatures.

McMaster et al.<sup>38</sup> examined the application of four different cooling modalities (ice, cold gel-packs, instant cold pack, and refrigerant-inflated bladders) on intramuscular temperature. Each cooling device was applied with a standard method used in clinical practice using the thigh of a dog for 1 hour. Results showed that the refrigerant-inflated bladders decreased intramuscular temperature less than 2°C, instant cold packs reduced intramuscular temperature 3.5°C, and cold gel-packs decreased intramuscular temperature by 8.4°C, while ice application resulted in an 11.3°C decrease in intramuscular temperature. No statistical analysis was used in this publication, but the temperature decreases were plotted against time to develop a linear trend.

Belitsky et al.<sup>2</sup> examined the effectiveness of wet ice, dry ice, and cryogen (cold-gel) packs on the reduction of surface temperature. All ten subjects received each cryotherapy source for 15 minutes to the posterior gastrocnemius muscle. Upon removal of the cryotherapy source, the area was allowed to re-warm for 15 minutes. Results demonstrated that wet ice cooled surface temperature significantly more than both dry ice and cryogen packs. The wet ice application reduced skin temperature to 17.9°C after 15 minutes, dry ice reduced surface temperature to 20.1°C, and cryogen packs reduced surface temperature to 22.1°C. No difference between groups during post-application re-warming was observed.

A recent study by Zemke et al.<sup>41</sup> examined how quickly ice bags cool the body. Intramuscular temperature probes were placed under the overlying tissue mass and the

ice bag were applied to the gastrocnemius complex for 15 minutes. The authors did not state if the ice bag was compressed. There was no difference between treatment groups when analyzed for lowest intramuscular temperature, duration of lowest intramuscular temperature, and absolute temperature decrease. There was a difference between groups when the time to lowest intramuscular temperature was compared. At 10 minutes, the absolute temperature difference between resting and intramuscular temperature was the only other significant difference between the groups. A correlation analysis revealed a weak correlation between subcutaneous fat and lowest intramuscular temperature, duration of lowest intramuscular temperature, absolute temperature decrease, and time to temperature decrease at specific times. Zemke et al.<sup>41</sup> concluded that ice bags are effective in decreasing intramuscular temperature and maintaining the duration of temperature depression.

There are several different cryotherapy sources clinicians have to choose from. Ice requires more energy input (to change physical states) than cold-gel packs can absorb.<sup>1, 6, 40</sup> Ice bags have been shown to decrease skin and intramuscular temperature significantly more than cold-gel packs and is a more effective treatment when compared to cold-gel packs.<sup>2, 38</sup>

### Cryotherapy Application Times

Different individuals require different treatment protocols and application times. Clinicians typically apply ice for approximately 15 to 20 minutes per treatment; however several studies have shown that a minimum of 30 minutes of cryotherapy is needed to reduce deep tissue (1 cm or greater below adipose) temperature and local

metabolic rates.<sup>7, 15, 42, 43</sup> A lightweight wrestler should not be treated in the same manner as a football offensive guard. Some individuals have deeper muscle tissue and thicker layers of adipose than others. Also, the amount of tissue varies between body parts on every person. Ice bags are typically recommended to be applied between 15 and 20 minutes; however most recent studies and recommendations are that ice bags should be applied for at least 30 minutes.<sup>5-9, 17, 19, 40, 42</sup> Cold gel-packs can safely be applied for up to 30 minutes, when appropriate barriers are used, but do not have the cooling ability of ice.<sup>1, 6, 40</sup> A “magic number” of 15 to 20 minutes of ice application will not create the same temperature change at the cellular level for different people and body areas.<sup>6</sup>

The exact cryotherapy duration is not known.<sup>1, 6</sup> Instead, the clinician must consider several aspects to determine the length of cryotherapy application: comfort barriers (towels and elastic wraps), natural barriers (adipose and tissue depth), and activity level prior and subsequent to the cryotherapy application.<sup>1, 6</sup>

Several authors<sup>44-46</sup> have evaluated the effectiveness of different comfort barriers and their affect on skin temperature. LaVelle and Snyder<sup>44</sup> used a dry washcloth, an elastic wrap, and a padded elastic wrap; using ice directly to the skin only when no frostbite was observed under any previous barrier condition. Tsang et al.<sup>45</sup> examined a dry towel, dry elastic wraps, and ice with no barrier. Urban<sup>46</sup> examined wet, frozen, and dry elastic wraps to the direct application of an ice bag upon the skin. All authors determined that ice with no barriers is superior in reducing skin temperature than any barrier studied.<sup>44-46</sup> Tsang et al.<sup>45</sup> stated that in order to obtain the same skin temperature observed with a no barrier condition (13°C), the ice would need to be applied for 151 minutes over a dry elastic wrap and 109 minutes over a dry towel. Metzman et al.<sup>47</sup> reported similar results

when the authors investigated the effect of applying ice over plaster and synthetic casts. Metzman et al.<sup>47</sup> observed that it took between 56 and 63.8 minutes to reduce surface temperature under synthetic and plaster casts to 18.7°C.<sup>47</sup>

Frostbite should not be a concern when applying an ice bag directly to the skin 20 minutes; as many authors apply ice bags directly to the skin for 30 minutes with no frostbite reported.<sup>8, 9, 42, 44-46, 48</sup> If any barriers are going to be utilized between the cryotherapy source and the skin, the treatment time should be extended.<sup>1, 6, 45, 46</sup> The only cryotherapy treatment which absolutely needs a barrier between the cryotherapy source and the skin, to prevent frostbite, is a cold gel-pack.<sup>1, 6</sup>

Adipose and tissue thickness should be considered before cryotherapy is applied to an injured area; being the largest predictor of intramuscular temperature change.<sup>1, 6, 8, 9, 42</sup> Adipose tissue thickness and tissue depth affects intramuscular temperature and blood flow rates because of its thermodynamic properties.<sup>8, 41, 49</sup> The thermal conductivity of adipose tissue is low when compared with other biologic tissues (skin and muscles); suggesting that heat does not transfer well through adipose tissue.<sup>8, 41, 49</sup> When the thickness of adipose is great, heat must be conducted an increased distance; prolonging the necessary time to affect intramuscular temperatures.<sup>1, 6, 8, 9, 41, 42</sup> In order to affect a sufficient temperature decrease at 3 cm below adipose depth, preventing secondary injury, it takes at least 30 minutes of ice application.<sup>1, 6, 9, 42</sup>

Exercising increases metabolism.<sup>1, 6</sup> Activity prior to the application of ice will increase skin temperature by approximately 3°C<sup>39, 50</sup> and intramuscular temperature by 2.2°C.<sup>51</sup> Activity after ice removal will result in an increased intramuscular temperature re-warming rate.<sup>50</sup> Mild activity, such as changing clothes or showering, will result in

rapid re-warming to the area, and it is recommended that the area be subsequently cooled to decrease metabolic activity.<sup>1,6</sup>

MacAuley<sup>52</sup> examined 45 common sports medicine text books to determine if there is consistent advice on the use of ice. Seventeen textbooks gave no specific guidance on the duration, frequency, or length of ice treatment. Recommendations on treatment duration were given in 28 textbooks and many of the recommendations differed depending on the particular ice therapy, injury location, or severity. Twenty-one textbooks gave advice on treatment frequency, while 22 advised specific treatment lengths. MacAuley<sup>52</sup> concluded that there is little consistency in guidance given in common textbooks on how ice should be applied and advice varies greatly.

The exact “magic number” for icing time is not known and utilizing cryotherapy based on a one-fits-all treatment idea is not appropriate.<sup>1,6</sup> An ATC needs to understand that many different factors affect how the cold modality reduces tissue cooling: comfort barriers, natural barriers, and previous activity levels.<sup>1,6</sup> The treatment time may need to be increased or decreased from individual to individual based on the above factors and no common cryotherapy application time should be used on every patient.<sup>1,6</sup>

### Heat Conduction

During cryotherapy, tissue temperature is decreased via conduction.<sup>1, 27, 40</sup>

Conduction is the exchange of heat between two substances that are in direct contact with each other; the heat always moving from the body of higher energy (heat) to the body of lower energy (heat) because cold is non-transferable.<sup>1, 40</sup>

When a cold source is applied to the body, the tissue at the surface cools first (losing energy directly to the modality through conduction); because of its proximity to the cryotherapy source.<sup>40</sup> This leads to a rather large decrease in surface temperature. As the superficial layers cool, they begin to absorb heat from underlying tissues, 1 cm deep to the cold source. As the tissue at 1 cm cools through conduction, it absorbs temperature from underlying tissues (2 cm). This procedure results in the warmer body cooling and the cooler body warming until equilibrium is reached.<sup>1, 40</sup> Overlying tissues are always colder than the underlying tissue. This ongoing gradient demonstrates why the magnitude of temperature change is considerably smaller at deeper tissue depths, but still prominent enough that heat exchange occurs to cool deep tissue.<sup>40</sup>

The rate of conduction depends on seven factors.<sup>1</sup> 1) The temperature difference between the tissue and the cold modality; the colder the modality is the cooler the tissue will be.<sup>1, 40, 53</sup> 2) Regeneration of body heat and modality cooling; as tissue gives up heat to the modality, heat is replaced by circulating blood and conduction from surrounding tissues.<sup>1, 40, 53</sup> 3) The heat storage capacity of the cold modality; the structure of the modality affects how much heat can be absorbed and stored by the modality (heat capacity).<sup>1, 40</sup> 4) The size of the cold modality; a larger cold modality application will have a greater storage capacity.<sup>1</sup> 5) The area of the body in contact with the cold modality; a greater heat loss will occur to a body which has a larger cold modality applied to it, a larger cold pack, will cool a body part more than a smaller one because a larger body area is covered.<sup>1</sup> 6) The duration of the application; a longer application time will result in more heat removed from the body because more time is available for

heat exchange.<sup>1</sup> 7) Individual variability; people will react differently to cold applications.<sup>1</sup>

Heat conduction is the process by which temperature decreases occurs in the human body. Surface areas of the body cool faster and have a lower final temperature than deep tissues. The rate of conduction is an interaction between seven factors.

### Contraindications to Cryotherapy

As with most therapies and remedies, cryotherapy has its own specific contraindications; situations in which a given treatment is not advisable.<sup>1</sup> Cryotherapy of any source should not be applied directly to the skin for longer than one continuous hour; as the risk of frostbite increases at this point.<sup>1</sup> A cold gel-pack should not be applied under a compression wrap; as the risk of frostbite increases because the initial temperature of a cold gel-pack is typically -17°C.<sup>1</sup> The individual receiving the cryotherapy treatment should be asked if they have any of the following conditions: cold-induced urticaria, cryoglobulinemia, Raynaud's phenomenon, paroxysmal cold hemoglobinuria, or compromised local circulation.<sup>1, 20, 22, 26, 54, 55</sup>

Cold-induced urticaria can result in both local and systemic reactions.<sup>26</sup> Patients with this condition develop wheals, which are characterized by raised borders and blanched centers.<sup>26, 56, 57</sup> The hives typically appear during warm-up and resolve within hours after the athlete removes the cryotherapy source.<sup>55, 56</sup> Histamine is released by mast-cell degranulation, and leads to redness, swelling, and wheal formation.<sup>26, 28, 55, 56</sup> A systemic reaction includes flushing of the face, a sharp drop in blood pressure, increased heart rate, and syncope.<sup>58</sup> Patients with severe cases develop generalized



swelling involving mucus membranes and viscera.<sup>26</sup> Cold-induced urticaria may also occur with exercise-induced asthma.<sup>56</sup>

Cryoglobulinemia is a disorder characterized by the presence of an abnormal blood protein that forms a gel when exposed to low temperatures.<sup>20, 26</sup> This gel formation can lead to ischemia or gangrene. Multiple myeloma, certain types of viral and bacterial infections, chronic liver disease, systemic lupus erythematosus, and other rheumatic diseases are associated with cryoglobulinemia.

Raynaud's phenomenon is a vasospastic disorder, which is either idiopathic or associated with systemic scleroderma, systemic lupus erythematosus, thoracic outlet syndrome, trauma, emotional change, or other disorders.<sup>20, 26, 55, 56</sup> Raynaud's phenomenon is more common in women.<sup>55, 56</sup> During the first phase (ischemic phase) of Raynaud's phenomenon, the digits first become cold, pale, and numb.<sup>55, 56</sup> The second phase, hyperemic phase, results from rebound vessel dilation and eventually the digits turn red, throb, and swell.<sup>55, 56</sup> Approximately 50% of individuals with Buerger's disease also experience Raynaud's phenomenon.<sup>26</sup> Attacks are precipitated by exposure to cold (or emotional stress) and are evident by cycles of pallor, cyanosis, spasm, and rubor.<sup>20, 26, 55, 56</sup> Numbness, tingling, or burning may accompany the normal color of the digits.<sup>20, 26, 55, 56</sup>

Paroxysmal cold hemoglobinuria can occur following local or general exposure to cold and occurs when hemoglobin is released from lysed red blood cells and appears in the urine; leading to renal dysfunction.<sup>20, 26</sup>

Cold should not be applied over any area of the body which is known to have compromised circulation.<sup>1, 26</sup> The vasoconstrictive effects of cold could potentially

compromise an already nutritionally deprived area in patients with peripheral vascular disease.

Cryotherapy has specific contraindications. Individuals usually have applied ice to their body sometime during their lifetime and know if they have suffered any adverse side effects of cryotherapy application. ATCs should inquire about their patients' medical history to prevent adverse reactions to modalities and therapies.

### Tissue Cooling on Blood Flow Rates

A decrease in tissue temperature causes a decrease in blood flow; likewise an increase in tissue temperature increases tissue blood flow.<sup>26</sup> However, it is not a completely linear relationship.<sup>1, 26</sup> Applying ice to a body part will first reduce blood flow and temperature at the surface.<sup>17, 36, 42, 59</sup> Slowly, the cooling penetrates the epidermis and adipose, entering the deeper layers of the body.<sup>8, 9, 17, 42, 50, 60</sup>

The regulation of body temperature is controlled by the hypothalamus.<sup>41, 61</sup> This organ, located in the brain, regulates body temperature by controlling the diameter of peripheral blood vessels.<sup>61</sup> Counter current blood flow controls the rate of tissue cooling and heating in the body.<sup>26</sup> Arteries and veins lie juxtaposition to one another; allowing heat to be removed from the arterial blood by venous blood as the two flow by each other.<sup>26</sup> Cooler blood returning to the body's core passes warmer blood moving towards the periphery.<sup>26</sup> Heat is exchanged between the two blood sources.<sup>26</sup> Applying cryotherapy has the further affect of constricting blood vessels.<sup>26</sup> This reduces the total amount of blood entering a cooled area.<sup>26</sup> The combination of these physiological effects keeps an area cooler for a longer period of time than if heat was applied.<sup>26</sup>

Recent cryotherapy research suggests that a tissue temperature decrease of 5°C at depths of 2 to 3 cm is needed to reduce the risk of secondary hypoxia and enzymatic injury.<sup>5-7, 17, 19</sup> Other studies have attempted to discover how this cooling translates to blood flow reductions.<sup>10-14</sup>

Knight and Londeree<sup>11</sup> examined how therapeutic applications of heat and cold combined with exercise affects blood flow. Over a 55-minute period, blood flow measurements were obtained by strain gauge plethysmography. Twelve males completed each of the 6 treatment conditions 1 day apart: control, heat, cold, control-exercise, heat-exercise, and cold-exercise. Results showed that during control conditions, blood flow decreased gradually. Blood flow increased with heat application and began to decrease 4.5 minutes after removal of heat; returning to pre-heating conditions within 20 minutes after heat removal. Cold therapy decreased blood flow, and remained decreased during the 20-minute post-treatment observation time. These results were significant. Blood flow was significantly reduced when ice was applied when compared to control conditions. When all three exercise conditions were analyzed, there was no significant difference between the groups. Ice application resulted in decreased blood flow for longer periods than heat application, and exercise increased blood flow with all conditions (control, heat, and ice).

Knight and Londeree<sup>11</sup> discussed a major flaw in their study. Blood flow during exercise could not be measured; it had to be estimated. The authors believed that their measurement equipment resulted in a gross underestimation of total blood flow. The actual blood flow measurement was taken 4 seconds after cessation of exercise. Knight and Londeree<sup>11</sup> wrote that caution is advised in drawing conclusions from these blood

flow comparisons because there was no way of knowing whether the estimated blood flow was the same percentage of actual total blood flow in each experimental exercise conditions. Since the publication of this article in 1980, other authors have performed similar studies examining how cold application affects intramuscular and intra-articular blood flow rates.<sup>10, 12-14</sup>

Thorsson et al.<sup>10</sup> examined the effect of local cold application on intramuscular blood flow at rest and after running. Eight male middle distance runners went through the testing procedure. Blood flow and surface temperature of the quadriceps muscle was tested after a 20-minute application of activated instant cold-packs and another identical treatment after 15 minutes of treadmill running. To control for the effect of compression, the investigators applied “dummy packs” to the control leg, which were not activated. Results demonstrated a significant decrease in blood flow in the cooled quadriceps while resting with instant cold packs before and after exercise. Maximum reduction of blood flow occurred 10 minutes after the conclusion of the cooling period. A blood flow reduction of 66% and 69% were observed after rest and running when compared to the control leg.

The blood flow measuring instrumentation used in this investigation was only inserted at a depth of 20 to 25 mm and instant cold packs were utilized.<sup>10</sup> The authors acknowledged that instant cold packs are not the most effective method to reduce intramuscular temperature and may explain why most of their intramuscular blood flow reduction was observed during the initial 15 minutes of cold application, when the cooling ability of the instant cold-packs is similar to that of cold gel-packs and ice bags.

Ho et al.<sup>12, 13</sup> performed two studies examining ice application and blood flow rates in the knee. The authors did not use strain gauge plethysmography<sup>11</sup> or the <sup>133</sup>Xe clearance technique;<sup>10</sup> instead using triple-phase technetium scintigraphy (bone scan).<sup>12, 13</sup> The technique used by Ho et al. was not invasive and allowed both knees to be evaluated simultaneously. The initial investigation<sup>12</sup> examined how 20 minutes of ice application, using a commercially available circumferential ice wrap, affects blood flow and bone metabolism of the knee. An identical, thawed, ice wrap was used on the contralateral knee to control for the influence of compression on knee blood flow and bone metabolism. Upon ice wrap removal, the patient immediately underwent the aforementioned bone scan. Statistical analysis revealed a mean decrease in arterial blood flow by 38.4%, soft tissue blood flow by 25.8%, and bone uptake by 19.3% in the iced knees compared to the control knee. Ho et al.<sup>12</sup> found no significant correlation between the “ice effect” and age, knee circumference, or skin-ice interface temperature. “Ice effect” was a term used by this research group meaning: ice demonstrated a decreased blood flow and bone metabolism in large joints (such as the knee). A major unanswered research question surfaced after the conclusion of this study; how do different ice application durations affect blood flow and bone metabolism? This question would be considered in a follow-up study.<sup>13</sup>

Ho et al.<sup>13</sup> published a subsequent article examining the effects of differing cryotherapy application times on blood flow and bone metabolism rates. The authors used the same cryotherapy application and bone scan techniques as the initial study, however icing times of 5, 10, 15, 20, and 25 minutes were examined. The results of this study showed that only 5 minutes of ice wrap application was needed to produce a

small, but significant, decrease in blood flow and bone metabolism. The decrease became progressively profound with increased icing times up to the maximum ice application time of 25 minutes. Arterial and soft tissue blood flow revealed a similar trend, but with a slightly decreased magnitude. As discovered in the first study,<sup>12</sup> there was no significant correlation between knee circumference, age, and temperature difference on blood flow or bone metabolism.<sup>13</sup> However, there was a difference between temperature and ice application time. Ho et al.<sup>12, 13</sup> concluded it only took 5 minutes to observe a significant decrease in blood flow and bone metabolism and the decrease would quadruple as the time increase to 25 minutes.

In both studies,<sup>12, 13</sup> groups demonstrated decreased blood flow and bone metabolism with ice application; but an older population was utilized as subjects and ice was not applied for longer than 25 minutes. The initial study,<sup>12</sup> contained 21 subjects (6 men, 15 women) with a mean age of 45 years (the range being from 29 and 63 years). Subjects over 65 were not included in the study to reduce the influence of age-related vessel wall changes on blood flow.<sup>12</sup> The second publication,<sup>13</sup> utilized 38 subjects (21 men, 17 women) with the mean age of 51.7 years and a median of 53 (the range being from 28 to 65). Since the population utilized was an relatively old; a majority of the subjects are not in an age category that would participate in competitive athletics, the youngest being 29<sup>12</sup> and 28<sup>13</sup> years old. A younger population may result in different blood flow and bone metabolism rates, however the rates may be reduced even more because younger individuals may have more drastic physiological changes during cryotherapy application that presently are not known.

The ice application time in the first study was 20 minutes, while the longest ice duration in the second study was 25 minutes.<sup>12, 13</sup> This time limit was based on an article published by Drez et al.,<sup>62</sup> concluding that ice application for longer than 30 minutes is associated with peroneal nerve dysfunction. Drez et al.<sup>62</sup> does not recommend applying cryotherapy to the knees for longer than 30 minutes.<sup>12, 13</sup> The 20 minute cryotherapy application used in the first study was used because 20 minutes is a commonly used icing time for musculoskeletal injuries.<sup>12</sup> Maximal ice application time was extended to 25 minutes for the second publication.<sup>13</sup> Ho et al.<sup>12, 13</sup> used the study by Drez et al.,<sup>62</sup> thus not applying ice for longer than 25 minutes to ensure the safety of their subjects; but still used a common treatment time in both studies. Several authors apply ice for periods longer than 25 minutes.<sup>8, 9, 11, 19, 42, 50, 60</sup> Extending the ice application duration or applying intermittent cryotherapy over time may further assist in reducing blood flow rates.

One research group published a study examining intermittent ice application times and the affect on blood flow.<sup>14</sup> Intermittent icing allows the clinician to protect against possible frostbite, and other complications due to cold, while essentially extending the ice application time during a single treatment.

Karunakara et al.<sup>14</sup> examined forearm blood flow during single and intermittent cold application. The authors mentioned the article by Drez et al.,<sup>62</sup> thus studying intermittent ice application to guard again superficial nerve damage. Procedure one (experimental) consisted of prolonged intermittent cold application with 20 minutes of continuous ice application, 10 minutes with no ice, 10 minutes of ice re-application, 10 minutes of ice removal, and 10 minutes of ice re-application totaling 60 minutes.

Procedure two (control) also required 60 minutes to complete; but consisted of 20 minutes of continuous ice application, 10 minutes of ice removal, 10 minutes room-temperature pack applied, 10 minutes of room temperature pack removal, ending with 10 minutes of room-temperature pack application. A significant time main effect resulted as blood flow decreased during both conditions. A significant treatment by time interaction was detected, specifically at 35 vs. 40 minutes, 50 vs. 55 minutes, and 55 vs. 60 minutes, as the intermittent cold application condition produced a greater reduction in blood flow than the control condition. Once the ice was removed, blood flow increased and decreased subsequent to the re-application of ice. Blood flow decreased significantly following the initial 20-minute cold application and intermittent cold re-application every 10 minutes maintained the decrease for an additional 35 minutes. Karunakara et al.<sup>14</sup> suggest that blood flow increases 35 minutes after a 20-minute ice application to the forearm and that intermittent ice application retards the rebound, or increase, in blood flow.

Applying ice to the body decreases arterial and soft tissue blood flow and bone uptake rates. A decrease in blood flow will prevent secondary injury from occurring. The intermittent application of ice results in a significant decrease in blood flow when compared to not re-applying ice.

#### Adipose Tissue Thickness on Tissue Cooling

Adipose tissue thickness affects intramuscular temperature and blood flow rates.<sup>1, 8, 9,</sup>

<sup>42</sup> Adipose thickness affects cooling time because of its thermodynamic properties.<sup>8, 41, 49</sup>

The thermal conductivity of adipose tissue is low when compared with other biologic



tissues (skin and muscles).<sup>8, 41, 49</sup> Thermal diffusivity, the ability of thermal energy to disperse through a substance, is also relatively low for adipose tissue, particularly when compared with muscle tissue.<sup>8, 41, 49</sup> Since the thermodynamic properties are relatively low, it suggests that heat does not transfer well through adipose tissue because the insulating affect of adipose is somewhat greater than other tissues. When the thickness of adipose is great, heat must be conducted a greater distance; prolonging the necessary cryotherapy application time to affect IM cooling temperature.<sup>8, 41</sup>

Adipose tissue thickness is the largest predictor of intramuscular temperature change.<sup>8, 42</sup> Temperatures at depths of 3 cm below the adipose require at least 30 minutes to reach temperatures where local metabolism is sufficiently decreased to prevent secondary injury.<sup>1, 6, 9, 42</sup> Intramuscular temperatures continue to decrease when the cryotherapy modality is removed and tend to cool for several additional minutes before slowly rising towards baseline temperatures.<sup>22, 42, 54</sup> Consequently, surface temperature increases immediately after the removal of the cryotherapy source and returns to baseline quicker.<sup>1, 9, 42</sup>

Jutte et al.<sup>9</sup> described the need to ice for 30 minutes to decrease intramuscular temperature 8°C 2 cm under the adipose level in the anterior thigh. The same study found skin temperature decreased 27°C in the same time frame. Myrer et al.<sup>42</sup> had similar conclusions. Finding a significant difference between the temperature decrease at 1 and 3 cm of tissue depths. A 3 cm depth was significantly warmer than the 1 cm depth; but the 3 cm depth warmed slower than the 1 cm depth. Tissue at depth warms slowly after the removal of the ice modality, whereas surface temperature increases rapidly after the removal of the cryotherapy source.

Otte et al.<sup>8</sup> performed a study to determine the effect that adipose tissue thickness has on intramuscular temperatures. Four groups were created, each group contained individuals with adipose tissue thickness, about the anterior thigh, within pre-determined ranges: 0-10 mm, 11-20 mm, 21-30 mm, and 31-40 mm. The authors wanted intramuscular tissue temperature to decrease by 7°C or more 1 cm below adipose depth for 60 seconds before the ice was removed. The use of 7°C was determined by the authors as a typical affect for intramuscular temperature decrease in the literature and was used to standardize a temperature goal. The results showed that as the thickness of adipose tissue increased, the cryotherapy treatment time to achieve a 7°C tissue temperature increased. On average, it took a person with an adipose thickness between 31 to 40 mm 58.6 minutes to decrease in temperature 7°C 1 cm under the adipose tissue. Individuals with adipose thickness of 21 to 30 mm, 11 to 20 mm, and 0 to 10 mm took 37.8, 23.3, and 8.0 minutes respectively for the same effect to occur.

Adipose tissue and the depth of the injury need to be considered before a treatment protocol begins. An injury located at a deep tissue depth (3 cm) or with an increased adipose content (greater than 40 mm) should be treated for at least 30 minutes before removal of the modality.<sup>6, 8, 9, 15, 17, 42</sup> This increased time is needed to reduce secondary injury.

### Ice and Comfort Barriers

Several studies have specifically examined whether placing a comfort barrier between the ice and the treatment area assisted or reduced the cooling effect of ice.<sup>1, 44, 45</sup>

The reasons for a comfort barrier is to reduce risk of frostbite to the patient, and to increase patient compliance with the treatment.<sup>1</sup>

LaVelle and Snyder<sup>44</sup> analyzed the effectiveness of a dry washcloth, damp washcloth, elastic wrap, and a padded elastic wrap when compared to an ice bag alone on surface temperature. The original design of this study did not include an ice only group. An ice with no barrier group was only added after it was determined that no frostbite was noted under any other experimental conditions. However, the ice only group had the ice applied for 30 minutes compared to 45 minutes for all other groups. The authors determined that ice with no barrier had the highest penetration ratio (of the skin) followed by the damp washcloth. There was no significant difference between no barrier and a damp washcloth with regards to skin temperature at 30 minutes of ice application.

Tsang et al.<sup>45</sup> analyzed the use of a dry towel and a dry elastic wrap to the direct application of ice on the skin. The authors did not say on which body part the ice was applied, just that it was on the skin. Ice application resulted in a significant decrease in surface temperature during all conditions with the ice only group resulting in the greatest decrease in surface temperature during treatment and had the lowest post-application temperature 20 minutes after ice removal. Tsang et al.<sup>45</sup> determined that in order to obtain the same surface temperature (13°C), as obtained during directly icing with no barriers, the ice would need to be applied over a dry towel for 109 minutes and a dry elastic wrap for 151 minutes.

The effectiveness of placing bags of ice over casts have also been examined.<sup>47</sup> Four pounds of crushed ice was applied over plaster and synthetic casts of the leg. After an

average of 56 minutes, surface temperatures under the synthetic cast were cooled to an average of 19.7°C. Likewise, it took an average of 63.8 minutes for the skin under a plaster cast to be reduced to 18.7°C. For both conditions it took approximately 1 hour for the skin to return to baseline. This study determined that there was no difference between a group of uninjured individuals and individuals who presently wore casts for a closed lower-leg fracture.

Urban<sup>46</sup> studied the effects of barriers on skin cooling, examining: wet, frozen, and dry elastic wraps as barriers to directly icing the skin.<sup>1</sup> This study determined that frozen and wet elastic wrap decrease surface temperature significantly more than a dry elastic wrap and that applying an ice bag directly to the skin resulted in greater cooling of all conditions.<sup>1, 46</sup>

Perhaps some of the confusion over the need to use protective barriers between cryotherapy sources and the skin is that barriers need to be used between cold-gel packs and the skin.<sup>1, 6</sup> The temperature of these products is below zero (-17°C) and the risk of frostbite is greater unless a barrier is placed between the source and the treatment area.<sup>1,</sup>

6

These studies mention a concern and an interesting paradox about ice application. Ice applied directly to the skin, with no barriers, decreases surface temperature the greatest and is the easiest way to apply ice. Clinicians are concerned that their patients will not continue treating the area once they leave the rehabilitation facility. If a treatment is difficult to be applied by a patient, the chance that the protocol will be followed is decreased. LaVelle and Snyder<sup>44</sup> cited a survey where only 55% of patients continued to apply ice to their injured body part after discharge from the emergency department. The authors also wrote that several subjects stated they would not comply

with a home treatment protocol that consists of using a wet washcloth as a “comfort barrier” before the application of an ice bag.

When ice is applied to the body, no comfort barrier should be used. Comfort barriers limit the temperature-reducing capacity of the ice and the potential physiological effects of the ice application. If comfort barriers are used, the ATC must increase the ice application time to allow the modality to significantly reduce intramuscular temperature and blood flow rates.

### Physiological Effects of Compression

Differing amounts of external pressure affects blood flow;<sup>63</sup> which may lead to differing cooling rates.<sup>18</sup> Sabri et al.<sup>63</sup> examined how external pressure affects hemodynamics of the lower limb. Nine patients undergoing varicose vein surgery had external pressures applied to one limb during surgery with either a below-knee splint or a full-length leg and thigh splint. Inflatable splint pressures between 5 and 40 mm Hg were utilized. Although no formal statistical analysis was performed, the authors stated that it was quite clear that the full-length splint inflated to a pressure of 5 mm Hg produced an increase in femoral venous blood flow by 15%. Examining the graphs provided by the authors, it appears that, as pressure increased there was a gradual decrease in the femoral vein blood flow percentage with the below-knee splint. Contrastingly, the change in femoral vein blood flow percentage increased initially, then gradually decreased afterwards. The results of Sabri et al.<sup>63</sup> were based on patients who were completely at rest with no muscular contractions; they were under general

anesthesia during data collection. A trend was evident that as more external pressure was applied, blood flow gradually reduced.

These findings give a good basic understand of how much external pressure may be required to reduce blood flow. If blood flow is reduced with external compression, secondary injury may be retarded because less blood reaches the area. However, in the study, pressures were only applied for 3-minute intervals. When ATCs apply external compression the time would be a minimum of 20 to 30 minutes with the probability of compressing a body area for hours in an attempt to reduce vascular perfusion.

### Compression and Cryotherapy

The effects of a cryotherapy application can be increased with the application of a compressive wrap.<sup>1, 17, 64, 65</sup> The wrap insulates the area, increasing the effect of the ice application by aiding the prevention of secondary injury.<sup>1, 6, 11, 17</sup> Compression increases pressure outside of the vasculature, helping to control edema formation and reducing swelling by promoting reabsorption of fluid.<sup>1</sup> External pressure is most beneficial once edema begins to occur and is effective while edema is present.<sup>1</sup>

When treating the ankle, Wilkerson et al.<sup>66</sup> believed focused, and not generalized, compression was superior, reasoning that general compression allows excess edema to accumulate in the area of the anterior talofibular ligament of the ankle. This was determined by examining 3 methods of applying compression in the management of acute grade II inversion ankle sprains: 1) using elastic tape to provide uniform compression, 2) focal compression with a U-shaped horseshoe maintained at room temperature, and 3) compression utilizing a frozen U-shaped horseshoe.<sup>66</sup> Each

cryotherapy session was 20 to 30 minutes.<sup>26, 66</sup> The groups which received focal compression attained their functional goals in 25% fewer days than the group receiving uniform compression.<sup>66</sup>

Duffley and Knight<sup>67</sup> measured pressure, with a manometer placed over the anterior talofibular ligament of the ankle, observing no difference with or without focused compression (horseshoe pad under the elastic wrap). Research is still needed to determine how long after an injury is sustained edema develops. Knight<sup>1</sup> recommends that compression be applied within minutes of initial injury and remain in place for a minimum of 24 hours.

Barlas et al.<sup>65</sup> used dogs to compare the effectiveness of instant cold-packs with compression and instant cold-packs alone on intramuscular tissue temperature after a 60-minute application. The authors concluded that compression augments the tissue cooling effect of external cryotherapy reporting an additional 2.5°C temperature decrease when external compression was used with the instant cold-pack.

Merrick et al.<sup>17</sup> examined the effects of ice and compressive wraps on intramuscular temperature at the surface, 1 cm, and 2 cm below adipose tissue depth. Four groups were created: control, compression only, ice only, and ice with compression. The treatment time was 30 minutes. The pressures exerted by the compressive wraps were between 42 and 48 mm Hg. This study revealed several key results. As stated previously,<sup>1, 39</sup> surface temperature decreased significantly and rapidly when ice was applied and re-warmed quickly after ice bag removal.<sup>17</sup> It was also determined that ice with compression resulted in a significant decrease in temperature when compared to ice with no compression in regards to surface, 1 cm, and 2 cm below adipose.

Temperatures at 1 cm below adipose were 23.5°C during ice with compression application and only 26.58°C when ice with no compression was applied.<sup>17</sup> At 2 cm below adipose, ice with compression resulted in a temperature of 26.46°C while ice only resulted in a temperature of 28.21°C.<sup>17</sup>

Merrick et al.<sup>17</sup> explained several modes by which compressing ice to the body would result in a significant decrease in intramuscular temperature when compared to ice alone: 1) compression improves the contact between the skin and the ice bag, 2) compression greater than 30 to 40 mm Hg reduces blood flow, 3) insulation effects of the compressive wrap, and 4) compression may change the density of the tissue. Merrick et al.<sup>17</sup> first discussed that compression allows for improved contact between the skin and the ice bag, describing that merely placing an ice bag on a body part may result in pockets of air between the ice and the body part.<sup>17</sup> Compression may cause more ice to be in contact with the skin, resulting in improved cooling.<sup>17</sup> As described by Ashton<sup>68</sup> if external compression is greater than 30 to 40 mm Hg, blood flow will be reduced.<sup>17</sup> When blood flow is reduced, the inflow of heat from other body parts is restricted. Merrick et al.<sup>17</sup> determined that although blood flow may be obstructed, compression alone (with elastic wraps) significantly increased tissue temperature. Combining a reduction in blood flow (compression) with an external source of cold (ice) restricts the body's ability to re-warm the area being cooling; resulting in a significant decrease in tissue temperature when compared to an identical treatment with no compression. Urban<sup>46</sup> showed that elastic wraps provides insulating effect. Merrick et al.<sup>17</sup> used this as their third point; stating that placing elastic warps around the pack reduces heat gain from the environment, leading to colder tissue temperatures.



Compressive wraps allow the ice bag to interact more with the tissue than the atmosphere. Lastly, by compressing the tissue, the area occupied by the tissue may be decreased. However, the tissue's mass remains unchanged. If this belief holds true, then the density of the area will be increased resulting in greater conductive cooling.<sup>17</sup> Sloan et al.<sup>69</sup> came to the same conclusion when cold and cold with compression treatments were studied during artificially induced acute inflammatory edema.

Varpalotai and Knight<sup>70</sup> examined how beginning and advanced athletic training students apply elastic wraps to determine if a significant difference exists between several different variables. The variables examined were: gender, experience, body part, ice bag, and trial. The body parts used were the anterior tibiofibular ligament of the ankle and the thigh; each individual performed four trials. No significant difference existed between pressures exerted by beginning and advanced athletic training students, males and females, or treatments applied with and without an ice bag. Elastic wraps, which were applied to the thigh, exerted significantly more pressure than those applied to the ankle. By the fourth day of this study, the beginning athletic training students were applying the wraps quicker, neater, and with less attention than during the first trials. 47% of the subjects applied elastic wraps at pressures exceeding 40 mm Hg and 23% of total elastic wrap applications were at pressures over 50 mm Hg.

The results of compression variability reported by Varpalotai and Knight<sup>70</sup> were similar to what was reported by Duffley and Knight.<sup>67</sup> However, Duffley and Knight<sup>67</sup> used 2 individuals of each gender while Varpalotai and Knight<sup>70</sup> used 23 members of each gender.

Serwa et al.<sup>18</sup> examined the effects of varying external compression pressures on an ice bag have on surface and intramuscular temperature at 2 cm below adipose. Flex-i-Wrap™ was applied at pressures of 0, 10 to 15 mm Hg, 30 to 40 mm Hg, and 50 to 60 mm Hg. Results showed that the only significant difference between the trials was the 50 to 60 mm Hg group resulted in colder temperatures than the control (no wrap) condition. A typical compression application, 30 to 40 mm Hg, was not significantly different than an extremely tight wrap (50 to 60 mm Hg) or an extremely loose wrap (10 to 15 mm Hg).

Applying compression during a cryotherapy treatment increases the ability of the cold to penetrate the skin and allows the tissue to decrease in temperature significantly and rapidly. The wrap places the ice in closer proximity to the skin, restricts blood flow, and prevents the atmosphere from warming the ice. The assistance of a compressive wrap assists the ice cool the body part more affectively.

#### Activity and Cryotherapy

Exercise time and duration affect cryotherapy treatments.<sup>1, 6, 11, 39, 50</sup> An exercise bout will increase metabolism; consequently, an increase in secondary injury will occur.<sup>1, 6</sup> Wirth et al.<sup>51</sup> demonstrated that active exercise increases intramuscular temperature in working muscles, but not non-working muscles. The authors showed that 15 minutes of jogging at 70% VO<sub>2</sub> Max increased intramuscular temperature significantly, by 2.2°C, from 38.7°C to 36.5°C.

After an exercise bout of 30 minutes, skin temperature increased from a baseline of approximately 30°C to about 33°C.<sup>39, 50</sup> However, this increased skin temperature will

decrease at about the same rate when ice is applied to the skin when compared to not exercising prior to an ice application.<sup>50</sup> Activity following the conclusion of ice application will greatly increase the rewarming rate of both surface and intramuscular temperatures; when compared to groups that remain in a relaxed state.<sup>50</sup> Even mild activity, changing clothes or taking a shower, will result in rapid re-warming and the area should be cooled again to decrease metabolic activity.<sup>1, 6, 59</sup>

Mancuso and Knight<sup>39</sup> examined how previous physical activity effects surface temperature before and after a 30 minute ice bag application. Exercise was performed for 15 and 30 minutes between 60% and 80% of VO<sub>2</sub> Max on a treadmill. A control group also existed. Surface temperature over the anterior talofibular ligament was measured intermittently. Surface temperature increased 2.0°C and 2.3°C during the 15 and 30 minutes of exercise respectively. There was no significant difference between the two exercise groups with regards to temperature increase during exercise. There was a significant difference between all three groups when post application temperatures were analyzed; but no significant difference between groups during the ice application time frame.

Vigorous exercise immediately prior to ice application did not change how skin temperature responds to ice.<sup>39</sup> Mean surface temperature was slightly, though not significantly, higher following exercise than at rest. Prior exercise does not affect how skin temperature responds after ice removal.<sup>36, 39, 71, 72</sup> The skin re-warmed rapidly, followed by a more gradual increase in temperature towards pre-ice application temperatures.<sup>36, 39, 71, 73</sup> Mancuso and Knight<sup>39</sup> recommend that longer ice applications or shorter reapplication times may be necessary following exercise of at least 15 minutes.

Knight and Londoree<sup>11</sup> determined that blood flow was greater during a cryotherapy and exercise condition than during a heat-treatment condition. Concluding that during cryokinetics, exercise causes increased blood flow, and cold application functions only to allow active motion in a painful joint.<sup>11</sup> Other authors<sup>1, 50</sup> have found that an exercise bout, either before or after ice application, will increase intramuscular re-warming rates significantly.

Palmer and Knight<sup>59</sup> examined the effects of activity on subsequent ice pack applications and rewarming using standard acute care procedures; ankle and thigh surface temperature were measured. Subjects rode an exercise bike for 15 minutes, then an ice bag was applied, with a compressive wrap, for either 20, 30, or 40 minutes. After the initial ice treatment was completed, subjects simulated normal activity for the subsequent 20 minutes. The activity simulated showering and changing clothing. The subjects walked slowly on crutches for 5 minutes, then balanced on one leg for 5 minutes, followed by 5 minutes of minimal activity on one leg, and finally 5 minutes of slow crutch walking. After this activity, the elastic wrap was re-applied to the ankle and thigh for an additional 40 minutes. After the next 40 minutes, another ice bag was applied for the same duration as the initial treatment; upon removal, an elastic wrap was immediately re-applied for 60 minutes. The authors stated that the simulated activity associated with showering, changing clothes, and returning home on crutches cause the body parts to warm more quickly than previously thought. After the first re-warming, both the ankle and thigh skin temperatures regained the heat that had been absorbed by the ice. Palmer and Knight,<sup>59</sup> as well as other authors,<sup>6, 14, 50</sup> state that after light activity

(showering or changing clothes) the individual should apply additional cryotherapy to the tissue.

Physical activity increases metabolism and tissue temperatures. Applying ice to an athlete who just completed a workout, or was injured during a workout, will reduce surface and intramuscular temperature at approximately the same rate as applying ice to an area, which was not previously exercised. Light activity after the conclusion of a cryotherapy treatment increases tissue temperature rapidly and ice should be re-applied to reduce secondary injury.

#### Cryotherapy Immediately Post-Surgery

Several authors have evaluated the effectiveness of cryotherapy on post-surgical narcotic consumption, pain, swelling, inflammation, and joint range of motion.<sup>48, 74-77</sup> Authors have examined whether a Cryo-Cuff® (Aircast Inc., Summit, NJ) or traditional ice bags provided greater decreases in skin, intra-articular, and intramuscular temperatures post-surgery<sup>74-76</sup> and cryotherapy application compared to no cryotherapy post-surgery.<sup>48, 77</sup>

Konrath et al.<sup>74</sup> sought to determine the effectiveness of postoperative cold therapy in patients who underwent ACL reconstructive surgery. Four groups were created: group one received a Polar Care® (Breg Inc., Vista, CA) device filled with ice water between 40°F and 50°F, group two received a Polar Care® device filled with lukewarm water between 70°F and 80°F, group three received a 1.3 kg to 1.5 kg ice bag of crushed ice compressed to the knee, and group four received no cold therapy. Surface and oral temperatures, drain output, and pain medication were measured every 4 hours. Results

showed the mean temperatures of the knees in groups one and three were statistically lower than group two and four; but the difference between these two sets of groups was not significant. Mean oral temperatures, drain outputs, ROM at discharge, pain medication ingested, and length of hospital stay were not significant between any groups. These groups existed during the hospital stay only as all groups were given a Polar Care® to use at home per their standard protocol.

Warren et al.<sup>75</sup> compared a Cryo-Cuff® device to an ice bag compressed with plastic wrap on the knees of healthy patients. Surface and intramuscular temperatures were measured. The cryotherapy application time was 1 hour, with a 1-hour post-treatment measurement time. Ice application decreased the mean surface temperatures by 21.4°C, 26.2°C, 12.3°C, and 5.8°C after 30, 60, 90, and 120 minutes respectively; with the intra-articular temperatures decreasing by 3.3°C, 12.8°C, 15.2°C, and 11.2°C at the same times. Mean surface temperatures for the cryotherapy device at 30 minutes decreased 14.8°C, 16.7°C at 60 minutes, 8.2°C at 90 minutes, and 4.4°C at 120 minutes. Intra-articular decreases for the same device and time frame were 2.2°C, 7.1°C, 9.7°C, and 5.7°C. All mean surface temperature decreases for both groups were significant at each time. Ice lowered both surface and intra-articular temperatures significantly more than the cryotherapy device at 60, 90, and 120 minutes with skin only being significantly decreased at 30 minutes. During the study a VAS pain score was obtained, revealing that at 30 and 60 minutes the ice was more painful for the patients than the cryotherapy device. This study demonstrates that standard ice bags with compression lowered surface and intra-articular temperatures significantly when compared to a cryotherapy

device, over equal time frames. However, patients demonstrated less tolerance for the greater decrease in temperatures.

Whitelaw et al.<sup>76</sup> used a population of post-operative knee arthroscopy patients to test narcotic pain medication use, satisfaction in regards to effectiveness and convenience, pain reported, pre and post-operative ROM, and thigh circumference. After the completion of a standard knee arthroscopy patients were placed into either a Cryo-Cuff® group or an ice and elastic wrap group. The Cryo-Cuff® patients required significantly less pain medication. The authors also expressed that the Cryo-Cuff® was more convenient and thought the device was of more benefit than the ice and elastic wrap group declared. However, there was no statistical significance with regards to degree of pain, knee ROM, or thigh circumference from pre to post operative periods between groups.

Martin et al.<sup>48</sup> examined if delaying the application of cryotherapy, via a Polar Care® device, would impact intra-articular temperature. Routine, minor, knee arthroscopy surgery was performed and a Cryo-Cuff® applied post-surgery. The treatment group had the cryotherapy applied to their knee for two continuous hours, while the control group only had the Cryo-Cuff® active during the second hour. The water used by the Cryo-Cuff® was exchanged each 30 minutes. In the treatment group, the mean intra-articular temperature decreased by 2.2°C over the first hour and 0.79°C over the second hour, for a total mean decrease of 3.0°C. The temperature in the control group increased by 5.0°C during the first hour and decreased by 4.0°C at the conclusion of the second hour. An interaction between the groups was present. This study demonstrated that cryotherapy after knee arthroscopy decreases intra-articular

temperatures (whether begun immediately after surgery or postponed for an hour) significantly once cryotherapy is initiated. However, icing for two hours directly following knee arthroscopy, will result in a greater decrease in intra-articular temperature than delaying icing for one hour and icing for the following hour.

Ohkoshi et al.<sup>77</sup> examined the effect of another Cryo-Cuff® type device, an Icing System 2000® (Nippon Sigmax Co., Ltd., Tokyo, Japan). ACL reconstruction patients during the first 48 hours post-surgery were split into three groups. Besides a control group, receiving no cold therapy, there was a group whose cryotherapy system was set to 5°C and another set at 10°C. Both treatment groups demonstrated a decrease in intra-articular temperature compared to the control groups. There were differing clinical results between the two treatment groups. The 10°C cooling temperature showed a better effect in relationship to pain, while the 5°C cooling temperature was more effective in reducing the volume of post-operative blood loss.

With evidence that the application of cryotherapy of any form after surgery results in less pain, less narcotic medication ingestion, and cooler surface and intra-articular temperature,<sup>48, 74-77</sup> a question about using cryotherapy during surgery in order to decrease post-operative swelling was examined by Fincher et al.<sup>78</sup> The authors wanted to determine what effect using a cold irrigation solution during knee arthroscopy would have on post-operative pain intensity, pain-medication consumption, and knee joint swelling. Of the two groups created for this study, one group had a simple knee arthroscopy performed with saline chilled to 4°C while the control group had the identical surgery performed with the saline at room temperature (18°C). Results showed that although the intra-articular temperature between the two groups after



surgery completion was significant, the mean intra-articular knee temperature for the cold saline group being 12.1°C colder than the control, there was no difference between the two groups five days post-surgery in regards to post-operative pain, medication use, or swelling. The authors stated that a possible reason no difference between groups was seen is that most arthroscopic procedures performed were less than 30 minutes in duration and that in most cases the cold irrigation was performed for less than 10 minutes after the beginning of the surgical procedure.

The authors used a simple knee arthroscopy (partial meniscectomy) and not ACL reconstruction or lateral retinacular release.<sup>78</sup> The patients had limited exposure to the cold saline. The authors stated that perhaps irrigating the area for an additional 10 to 15 minutes after the procedure is completed might result in different results. However, Fincher et al.<sup>78</sup> also acknowledged that it would not be economically feasible to continue irrigating area after the procedure. The financial costs associated with further operating room time is likely to outweigh any potential benefit that may be attributed to the procedure. This adjustment in surgical procedure may be of benefit to orthopedic surgical procedures of longer duration and future research is needed to examine the effect of cold therapy on surgeries of longer duration (ACL reconstruction).

Several authors have demonstrated that applying cryotherapy post-operatively will result in decreased intra-articular temperatures and may result in less pain medication consumption and post-operative edema.<sup>48, 74-77</sup> Beginning cryotherapy after surgery will reduce surface and intra-articular temperature whether begun immediately, or postponed; but initiating cryotherapy immediately after surgery will result in a greater decrease in pain and secondary injury.

### Predicting Intramuscular Temperature

One of the basic assumptions in the surface temperature based cryotherapy literature is that changes in intramuscular temperature are strongly correlated to changes in surface temperature; that there is a way to measure surface temperature and accurately predict intramuscular temperature.<sup>9</sup> Authors<sup>9, 17, 79</sup> have shown that surface and intramuscular temperature may not have a strong relationship with Dahlstedt<sup>80</sup> stating that surface temperature had to be 20°C before any demonstrable intra-articular temperature decreases become evident. Jutte et al.<sup>9</sup> examined the relationship between surface and intramuscular temperature. In order to obtain a good prediction equation, the authors examined many separate factors in an attempt to predict intramuscular temperature: subcutaneous adipose thickness, average surface interface temperature, body core temperature, room temperature, and time. All variables were recorded during a 30-minute treatment time and 120-minute post-treatment rewarming period of anterior thigh.

The results demonstrated that during the cooling time there was no single predictor which adequately explained intramuscular temperature; but, when combined, all five variables explained 76% of the intramuscular temperature decrease.<sup>9</sup> Of the five predictive variables studied, time was the strongest single predictor ( $R^2=0.35$ ). Room temperature was the next strongest predictor at ( $R^2=0.23$ ), followed by surface temperature ( $R^2=0.21$ ), skinfold ( $R^2=0.14$ ), and lastly body core temperature ( $R^2=0.04$ ). When the actual intramuscular temperatures are compared to the predicted intramuscular temperature using the equation developed by Jutte et al.,<sup>9</sup> the difference

between the two temperatures is less than 1°C at each time point over the entire treatment time.

Intramuscular temperature predictors observed during 120 minutes of re-warming explained 81% of intramuscular temperature.<sup>9</sup> Time was once again the best single predictor of intramuscular temperature ( $R^2=0.58$ ), followed by surface temperature ( $R^2=0.5$ ). Skinfold ( $R^2=0.07$ ), room temperature ( $R^2=0.04$ ), and body core temperature ( $R^2=0.00$ ) were all extremely poor individual predictors of intramuscular temperature during re-warming. During the 120-minute re-warming, intramuscular temperature did not return to baseline. Jutte et al.<sup>9</sup> states the re-warming equation appears to be less accurate during the first 6 minutes, the period during which intramuscular temperature continues to decline after ice removal. However, after this 6-minute period, the predicted intramuscular temperatures differed by less than 1°C at each time point.

Jutte et al.<sup>9</sup> recommend that researchers measure intramuscular temperature directly whenever possible if an accurate measure of intramuscular temperature is required, stating that predicting intramuscular temperature is complex and probably not practical during most clinical treatments. If measuring intramuscular temperature directly is not an option for the research group then enough additional data should be collected to estimate intramuscular temperature using a predictive equation similar or identical to the ones published Jutte et al.<sup>9</sup> These equations should be limited to normal subjects and under thermoneutral environmental conditions. Jutte et al.<sup>9</sup> concluded that surface temperature is a poor single predictor and reminds the reader that the skin begins to warm immediately after cryotherapy is removed.

Intramuscular temperature is difficult to predict and researchers should measure intramuscular temperature directly whenever possible. If measuring intramuscular temperature directly is not feasible, the clinician should follow a valid prediction equation to estimate intramuscular temperature during the treatment.

### Intramuscular Thermocouple Sterilization

Recent intramuscular temperature research<sup>8, 9, 17, 42, 50, 60, 81, 82</sup> uses two primary methods to sterilize the intramuscular temperature probes; gas or chemical sterilization. Draper et al.,<sup>82</sup> Myrer et al.,<sup>60</sup> and Holcomb and Joyce<sup>81</sup> used gas sterilization with ethylene oxide. Other authors<sup>8, 9, 17, 42, 50</sup> used Cidex® (Johnson and Johnson, New Brunswick, NJ) to perform high-level chemical disinfection of the intramuscular thermocouples. Cidex® is typically used for at least 20 minutes<sup>8, 9, 40, 50</sup> with applications of 40 minutes<sup>42</sup> used as well. After the bath, the Cidex® is washed from the thermocouple with sterile water<sup>8, 9, 42, 50</sup> before being implanted.

### Intramuscular Implantation Techniques

An IM thermocouple can be implanted into the gastrocnemius either medially<sup>50, 81, 82</sup> or posteriorly.<sup>42</sup> To prepare the area, a great majority of authors, will shave an area of skin.<sup>8, 9, 17, 40, 42, 50, 60</sup> The skin is prepared similarly among authors, using a 10% povidone-iodine swab followed by a 70% isopropyl alcohol prep-pad.<sup>8, 9, 40, 42, 50, 60</sup> Some authors<sup>81, 82</sup> anesthetize the area with a 1-mL injection of 1% lidocaine (xylocaine) without epinephrine before the intramuscular thermocouple is implanted. More authors<sup>8, 9, 17, 40, 42, 50, 60</sup> do not use injections before intramuscular thermocouple implantation. Cutaneous

injections serve to numb the area prior to intramuscular thermocouple insertion and is done strictly for patient comfort, however the subject must still experience the needle stick of the anesthetizing agent. With placing two needles into an area, the miniscule chance of infection is theoretically doubled. Myrer et al.<sup>42, 50, 60</sup> administered 1 500-mg dose of an oral antibiotic (Keftab or cephalexin hydrochloride) immediately before the experiment and three similar doses at 6-hour intervals following the conclusion of the experiment. The medication is given as a precaution to minimize the risk of infection. Myrer et al.<sup>42, 50, 60</sup> does ask if the subjects have an allergy to the antibiotics; but the risk of an allergic reaction to the medication is higher than the possibility of infection.

Depending on the study design, the intramuscular thermocouple needs to be inserted into the body at a specific depth either below the adipose tissue<sup>8, 9, 17, 40, 42, 50, 60</sup> or below the skin surface at a set depth.<sup>43, 51, 71, 73, 83, 84</sup> To account for the thickness of the adipose tissue, a Lange® skinfold caliper (Beta Technology Incorporated, Cambridge, MD) measures the skinfold thickness of the posterior gastrocnemius.<sup>42, 50, 60</sup> Dividing this figure by two gives a good estimate of adipose thickness.<sup>42, 50, 60</sup> This number is added to the desired tissue depth, determining the depth the intramuscular thermocouple will be implanted into the body. Using this method, no single depth is used on every individual subject. This ensures that adipose is accounted for and that the intramuscular thermocouple is placed at the same depth below adipose amongst all subjects. A mark is simply put on the intramuscular thermocouple and the probe inserted the desired mark.

At the conclusion of the study, the area was cleansed with an alcohol pad, antibiotic ointment and a bandage applied to the insertion area, and the subject sent home with a sheet informing the subjects about the signs of infection.<sup>8, 9, 17, 42, 50, 60</sup>

There are several different protocols to implant an intramuscular thermocouple. The researchers should follow appropriate sterilization procedures. The intramuscular thermocouple can be applied several centimeters into the body; but adipose tissue depth should be considered to ensure accurate temperature readings.

## CHAPTER 3

### METHODS

#### Description of Subjects

Fourteen college students, (10 females, 4 males, age  $22.4 \pm 1.8$  years, height  $169.1 \pm 8.2$  cm, weight  $73.3 \pm 18.5$  kg, site skinfold  $13.14 \pm 1.61$  mm) volunteered and signed informed consent documents approved by the University of Nevada, Las Vegas Institutional Review Board. Each subject was healthy, with no history of heart disease, cardiovascular disorder, neurological disease or injury, latex or iodine allergy, current injury to the lower extremity, and not currently under the care of a physician for any illness or injury. Each subject had previous experience using cryotherapy, with no complications, and no fear of needles. To further limit the subject population, skinfold thickness of the right posterior calf was measured utilizing a Lange® skinfold caliper (Beta Technology Incorporated, Cambridge, MD). Subjects with a skinfold thickness greater than 15 mm were excused from the study in order to minimize the effects of differences in adipose thickness between subjects.<sup>8,9</sup>

### Design

Two separate 3 x 14 within subjects repeated measures designs were used. The independent variables being treatment type (ice bag compressed with Flex-i-Wrap™, ice bag compressed with elastic wrap, and ice only), and time (Pre 5, 0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, and 90 minutes). The dependent measure of interest was temperature at the surface and 2 cm below skin surface.

### Treatment

A total of three treatments were applied to each subject, one treatment per day, with each treatment separated by 24-48 hours. The treatment groups were randomized with a balanced Latin-square.

1. 30-minute ice bag application to the right gastrocnemius muscle compressed with Flex-i-Wrap™.
1. 30-minute ice bag application to the right gastrocnemius muscle compressed with an elastic wrap.
3. 30-minute ice bag application to the right gastrocnemius muscle with no additional compression.

### Instrumentation

Atmospheric temperature was measured using one PT-6 thermocouple (Columbus PT-6, Columbus Instruments International Corporation, Columbus, OH) secured to the cart beside the subject. Surface temperature was measured using two PT-6 non-



implantable thermocouples. Prior to each use, the non-implantable thermocouples were washed with soap and water.

Intramuscular temperature was measured using a sterile 23-gauge microprobe (Columbus IT-23, Columbus Instruments International Corporation, Columbus, OH). The intramuscular temperature probe was implanted with a 21-gauge sterile disposable needle, used and disposed of in accordance with OSHA standards. Prior to use, the intramuscular probe was sterilized and sealed in individual packages. Additionally, the intramuscular temperature probe underwent high-level disinfection by being placed in 10% povidone-iodine for 10 minutes then bathed in Cidexplus® (Johnson & Johnson, New Brunswick, NJ) for 40 minutes. Immediately prior to implantation the microprobe was rinsed with sterile water.<sup>8, 9, 42, 50</sup>

The non-implantable and intramuscular thermocouples were secured to the skin using Transpore® clear tape (3M Health Care, St. Paul, MN). An isothermex temperature measurement device (Model 256, Columbus Instruments International Corporation, Columbus, OH) sampled atmospheric, surface, and intramuscular temperatures at a rate of 60 Hz. The data was collected on an IBM laptop computer.

### Procedures

Subjects were asked to limit physical activity 2 hours prior to their appointment.<sup>42</sup> Local muscle temperature may have been elevated by previous activity such as walking to the laboratory,<sup>39, 50, 59</sup> therefore on each day, subjects began by lying prone on a padded treatment table for 15 minutes prior to instrument application allowing local tissue temperature to return to baseline.<sup>10, 17</sup> For added comfort, a Pron Pillo®

(Chattanooga Pharmacal Co., Chattanooga, TN) was available. Subjects were able to read, sleep, watch DVD's, and perform other tasks involving minimal movement of the lower extremities during the experiment.

On the first day of the study, the right posterior gastrocnemius of each subject was measured with a Lange® skinfold caliper (Beta Technology Incorporated, Cambridge, MD) to determine adipose tissue thickness before the area was cleansed or any thermocouples applied.<sup>85</sup> Individuals with a site skinfold greater than 15mm were excused from the study. Prior to the first treatment application, an area 4 X 4 in<sup>2</sup> of skin over the midportion of the right gastrocnemius muscle belly was shaved and thoroughly cleansed using 10% povidone-iodine; followed by a 70% isopropyl alcohol prep pad.<sup>8, 9, 17, 41, 42, 50, 60</sup> The center of the shaved area served as the site for intramuscular thermocouple implantation and the reference-point for surface temperature measurement.

Before the intramuscular thermocouple was disinfected, a black mark at 2 cm was placed on the thermocouple; this position represented a depth of 2 cm. The sterile needle was likewise marked with a strip of tape secured around the needle at 2 cm. The intramuscular thermocouple was implanted with the marked sterile needle from the posterior aspect of the right leg, perpendicular to the treatment table to the pre-determined depth of 2 cm.<sup>9, 17, 41, 43, 50, 60, 86</sup> To decrease the time the needle was in the body, the intramuscular thermocouple was fed through the needle before being implanted in the gastrocnemius. To decrease the risk of infection, the second implantation site was 1 cm medial and the third 1 cm lateral to the initial site. Once the intramuscular thermocouple was inserted to the 2 cm depth, the needle was removed from the

gastrocnemius muscle, exposing the intramuscular thermocouple to the muscle tissue. At this time, the mark on the intramuscular thermocouple was examined to determine how deep the intramuscular thermocouple was implanted. Any necessary changes to the intramuscular thermocouple depth were made at this time. The needle was wrapped in a sterile gauze pad and secured distal to the treatment site with a piece of Transpore® clear tape (2 cm). When the intramuscular thermocouple was secured, the surface non-implantable thermocouples were applied 1 cm superior and 1 cm inferior to the intramuscular implantation site. The non-implantable thermocouples were secured with a strip of Transpore® clear tape (2 cm). The thermocouples were then connected to an Isothermex temperature-measuring device. After 5 minutes, the baseline surface and intramuscular temperatures were recorded to the nearest 0.01°C. Temperature was measured every 30 seconds prior to, during the 30-minute treatment, and for the 60-minute post-treatment.<sup>7-9, 17, 43</sup> However, the data was analyzed at the specified times of 5 minutes prior to, 0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, and 90 minutes, with 0 minutes being the time of ice application and 30 minutes the time of ice removal.

Treatments were randomly assigned to a specific order using a balanced Latin-square, with each subject receiving all 3 treatments. The treatment phase consisted of placing an ice bag, with the air evacuated, containing 56 oz of crushed ice directly over the thermocouples.<sup>42, 50, 60</sup> The ice was then compressed with either an elastic wrap (Hartmann-Conco, Rock Hill, SC), Flex-i-Wrap™ (Cramer Products Inc., Gardner, KS), or no compression was applied. The wrap was applied circumferentially, from distal to proximal, around the limb so that 2 layers of the wrap completely covered the

ice. To maintain similar amounts of pressure applied per treatment, the same individual applied each treatment.<sup>70</sup> The ice-only treatment condition served as the control group.

The ice remained in place for 30 minutes.<sup>8, 9, 17, 42, 50, 60</sup> At the conclusion of the 30-minute treatment, the ice and wrap were removed, allowing the gastrocnemius to re-warm. The subject remained lying prone on the treatment table, preventing excess muscular activity for 60 an additional minutes.<sup>8, 9, 17, 50</sup> At the conclusion of 90 minutes, the surface and intramuscular thermocouples were removed. The calf was dried, the treatment site swabbed with a 70% isopropyl alcohol prep pad, and the implantation site covered with a Band-Aid® (Johnson and Johnson, New Brunswick, NJ).<sup>8, 9, 41, 42, 60, 86</sup> A wound-care informational sheet was given to each subject with instructions for contacting the principal investigator in the event of an infection. The subjects were scheduled to return 24-48 hours later for the second treatment condition and an additional 24-48 hours after for the third treatment condition.<sup>59</sup> On the subsequent days of the experiment, the same preparation and treatment protocols were followed.

### Statistical Analysis

Mean data were analyzed using two separate 3 x 14 analysis of variance (ANOVA) procedures with repeated measures on both factors. The independent variables of interest were treatment type (ice bag compressed with Flex-i-Wrap™, ice bag compressed with elastic wrap, and an ice bag with no compression), and time (Pre 5, 0, 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, and 90 minutes). The dependent measures of interest were temperature at the surface and temperature 2 cm below the skin. The statistics were calculated by SPSS Version 11 (SPSS Inc., Chicago, IL) for Windows.

## CHAPTER 4

### RESULTS

The analysis revealed no significant main effect for Treatment, ( $F(2,26) = 2.102$ ,  $p=0.148$ ). The analysis did reveal a significant main effect for Time, ( $F(13,169) = 99.562$ ,  $p<0.001$ ). Most importantly, the Treatment x Time interaction reached significance, ( $F(26,338) = 153.952$ ,  $p<0.001$ ) (Figure 1).

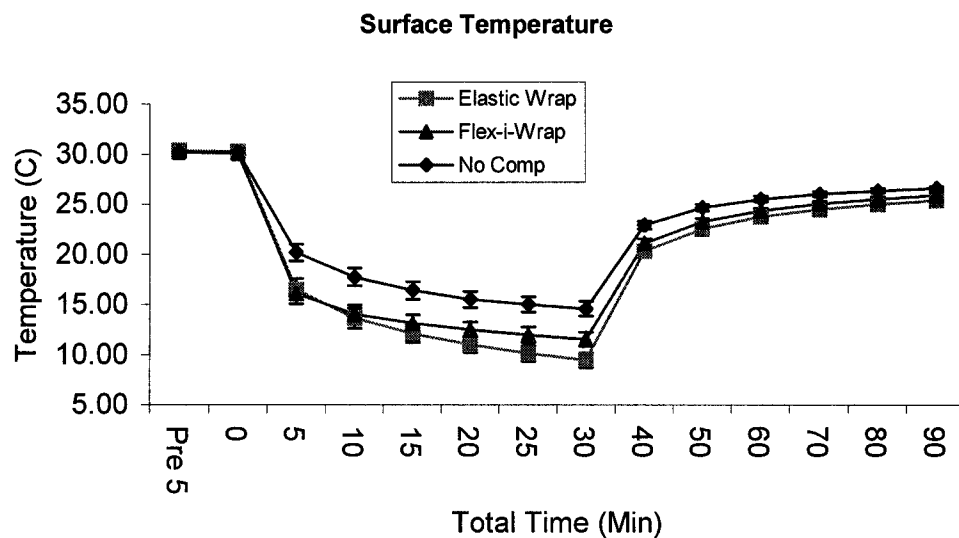


Figure 1. Graph of Surface Temperature Over Time (Temp°C Mean  $\pm$  St. Error)

As such, simple main effects were run on the interaction. After 5 minutes of ice bag application, there was a significant main effect between treatment types; Flex-i-Wrap™,

( $F(2,26) = 4.313$ ,  $p=0.045$ ) and the elastic wrap, ( $F(2,26) = 4.313$ ,  $p=0.007$ ), conditions were both significantly colder than no compression. At this time, Flex-i-Wrap™ decreased surface temperature by  $14.11^{\circ}\text{C}$  (46.72%) and elastic wrap decreased surface temperature by  $13.85^{\circ}\text{C}$  (45.59%). No compression decreased surface temperature by  $10.08^{\circ}\text{C}$  (33.33%) during the first 5 minutes (Table 1).

**Table 1. Surface Temperatures ( $^{\circ}\text{C}$ , Mean  $\pm$  St Dev) with Three Compression Types**

Time (Min)	Ice Application Technique					
	Ice Only		Elastic Wrap		Flex-i-Wrap™	
	Temp $^{\circ}\text{C}$	% Decrease	Temp $^{\circ}\text{C}$	%Decrease	Temp $^{\circ}\text{C}$	%Decrease
Pre	$30.24 \pm 1.13$	0%	$30.38 \pm 1.37$	0%	$30.20 \pm 1.19$	0%
0	$30.17 \pm 1.25$	0.23%	$30.28 \pm 1.28$	0.34%	$30.07 \pm 1.19$	0.43%
5	$20.16 \pm 4.39$	33.33%	$16.53 \pm 5.50$	45.59%	$16.09 \pm 5.12$	46.72%
10	$17.73 \pm 4.54$	41.37%	$13.67 \pm 5.27$	55%	$14.04 \pm 4.81$	53.51%
15	$16.42 \pm 4.50$	45.70%	$12.12 \pm 4.83$	60.11%	$13.13 \pm 4.41$	56.23%
20	$15.51 \pm 4.34$	48.71%	$11.02 \pm 4.39$	63.73%	$12.52 \pm 4.12$	58.54%
25	$15.03 \pm 4.14$	50.30%	$10.16 \pm 4.13$	66.56%	$12.01 \pm 3.92$	60.23%
30	$14.59 \pm 3.98$	52.08%	$9.49 \pm 3.95$	68.76%	$11.55 \pm 3.77$	61.75%
40	$22.86 \pm 2.02$	24.40%	$20.27 \pm 2.08$	33.28%	$21.09 \pm 2.20$	30.17%
50	$24.58 \pm 1.63$	18.72%	$22.45 \pm 1.56$	26.10%	$23.18 \pm 1.61$	23.25%
60	$25.45 \pm 1.40$	15.84%	$23.69 \pm 1.55$	22.02%	$24.25 \pm 1.42$	19.70%
70	$25.96 \pm 1.31$	14.15%	$24.41 \pm 1.50$	19.65%	$24.95 \pm 1.39$	17.38%
80	$26.28 \pm 1.24$	13.10%	$24.92 \pm 1.50$	17.97%	$25.40 \pm 1.40$	15.89%
90	$26.50 \pm 1.23$	12.37%	$25.30 \pm 1.37$	16.72%	$25.81 \pm 1.47$	14.54%

These significant differences were maintained throughout the remainder of the experiment (85 minutes). No significant difference occurred between Flex-i-Wrap™ and elastic wrap when surface temperature was examined. At the conclusion of the 30-minute treatment, no compression generated a 52.08% decrease in surface temperature. Flex-i-Wrap™ decreased surface temperature by  $18.65^{\circ}\text{C}$  (61.75%) and elastic wrap

decreased surface temperature by 20.89°C (68.76%) in surface temperature over the same time period.

The analysis revealed a significant main effect for both Treatment, ( $F(2,26) = 34.026, p < 0.001$ ) and Time, ( $F(13,169) = 431.655, p < 0.001$ ). Most importantly, the Treatment x Time interaction reached significance, ( $F(26,338) = 15.110, p < 0.001$ ) (Figure 2).

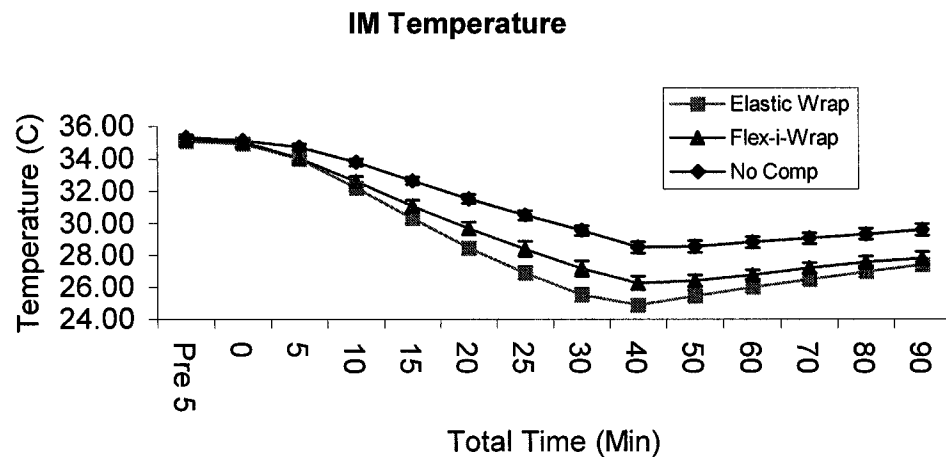


Figure 2. Graph of Intramuscular Temperature Over Time (Temp°C Mean  $\pm$  St. Error)

As such, simple main effects were run on the interaction. After 10 minutes of ice bag application, there was a significant main effect between treatment types; both Flex-i-Wrap™ ( $F(2,26) = 12.567, p = 0.002$ ) and elastic wrap, ( $F(2,26) = 12.567, p < 0.001$ ) were significantly colder than no compression. At this time, no compression decreased intramuscular temperature by 1.82°C (4.31%). Flex-i-Wrap™ and elastic wrap generated a intramuscular temperature decrease of 2.63°C (7.47%) and 2.88°C (8.21%)

respectfully during the first 10 minutes of ice bag application. These significant differences remained throughout the remainder of the experiment (80 minutes). After 20 minutes of ice bag application, there was a significant main effect between compression types, with elastic wrap significantly colder than Flex-i-Wrap™, ( $F(2,26) = 21.468$ ,  $p = 0.035$ ). At this time, Flex-i-Wrap™ decreased intramuscular temperature by 5.54°C (15.73%) compared to the 6.63°C (18.9%) intramuscular temperature decrease with elastic wrap (Table 2).



**Table 2. Intramuscular Temperature (°C, Mean ± St Dev) with Three Compression Types**

Time (Min)	Ice Application Technique					
	Ice Only		Elastic Wrap		Flex-I-Wrap™	
	Temp °C	% Decrease	Temp °C	% Decrease	Temp °C	% Decrease
Pre	35.30 ± 0.61	0%	35.08 ± 0.62	0%	35.21 ± 0.59	0%
0	35.12 ± 0.63	0.51%	34.93 ± 0.65	0.43%	35.04 ± 0.58	0.48%
5	34.72 ± 0.71	1.64%	33.99 ± 0.68	3.11%	34.05 ± 0.81	3.29%
10	33.78 ± 0.77	4.31%	32.20 ± 0.86	8.21%	32.58 ± 1.20	7.47%
15	32.61 ± 0.92	7.62%	30.28 ± 1.15	13.68%	31.07 ± 1.34	11.76%
20	31.52 ± 1.05	10.71%	28.45 ± 1.42	18.90%	29.67 ± 1.52	15.73%
25	30.49 ± 1.11	13.63%	26.90 ± 1.52	23.32%	28.39 ± 1.67	19.37%
30	29.52 ± 1.18	16.37%	25.53 ± 1.56	27.22%	27.17 ± 1.77	22.83%
40	28.48 ± 1.28	19.32%	24.87 ± 1.47	29.10%	26.26 ± 1.61	25.42%
50	28.55 ± 1.33	19.12%	25.46 ± 1.26	27.42%	26.39 ± 1.34	25.05%
60	28.80 ± 1.33	18.41%	26.00 ± 1.23	25.88%	26.77 ± 1.13	23.97%
70	29.04 ± 1.31	17.73%	26.51 ± 1.31	24.43%	27.21 ± 1.16	22.72%
80	29.31 ± 1.31	16.97%	26.98 ± 1.36	23.10%	27.59 ± 1.24	21.64%
90	29.57 ± 1.32	16.23%	27.41 ± 1.37	21.86%	27.82 ± 1.50	20.99%

This significant difference was maintained throughout ice application and until 50 minutes of ice removal. Flex-i-Wrap™ produced an 8.04°C (22.83%) intramuscular temperature decrease after 30 minutes of ice bag application, while elastic wrap produced a 9.55°C (27.22%) decrease at the same time. No compression, Flex-i-Wrap™, and elastic wrap each generated their largest tissue temperature decrease, 6.82°C (19.32%), 8.95°C (25.42%), and 10.21°C (29.1%) respectively, 10 minutes after the ice bag was removed from the limb.

## CHAPTER 5

### DISCUSSION

Ice bags are the most common way to apply cryotherapy to the body<sup>1</sup> and externally compressing the bag will greatly enhance tissue temperature reduction by improving the contact between the ice bag and the body, further reducing local blood flow, changing the density of the area, and added insulation.<sup>17, 65</sup> However, there are two popular ways to apply external compress the ice to the body (Flex-i-Wrap™ and elastic wrap) and it remains unknown if different external compression forms generate different surface and intramuscular tissue temperatures. There is strong evidence that cryotherapy of any kind will reduce tissue temperature.<sup>8, 9, 16-18, 40-43, 50, 59, 60, 86</sup> It is believed that a greater decrease in tissue temperature will result in reduced edema formation,<sup>15</sup> local blood flow,<sup>10-14</sup> and secondary injury.<sup>1, 4, 7, 19</sup> Previously, it has been demonstrated that repeated intermittent ice pack applications assist in retaining a decreased tissue temperature.<sup>59, 87</sup> Conversely, it is believed that overlying adipose thickness affects the rate of temperature decrease during cryotherapy,<sup>8, 9, 42</sup> and surface temperature is a poor predictor of intramuscular temperature.<sup>9</sup> Our study is the first designed to examine cryotherapy with two different forms of external compression on tissue temperature cooling.

Surface temperature reduction under a variety of treatment conditions has been widely published (Table 3).<sup>2, 9, 16, 17, 39, 40, 59, 87</sup>

**Table 3. Comparison of the Research on Surface Temperature Changes in Human Tissue After Applications of Cryotherapy**

Author	Treatment	Area	Compression	Tx Time (min)	Lowest Tissue Temperature (°C)
Merrick <sup>17</sup>	Ice Bag	Thigh	Elastic Wrap	30	4.94
Merrick <sup>17</sup>	Ice Bag	Thigh	None	30	7.24
Jutte <sup>9</sup>	Ice Bag	Thigh	Elastic Wrap	30	7
Merrick <sup>31</sup>	Ice Bag	Thigh	Elastic Wrap	30	6.47
Merrick <sup>31</sup>	Wet-Ice	Thigh	Self	30	6.24
Merrick <sup>31</sup>	Flex-i-Cold	Thigh	Elastic Wrap	30	9.86
Palmer <sup>59</sup>	Ice Bag	Thigh	Elastic Wrap	30	4.2
Palmer <sup>59</sup>	Ice Bag	Ankle	Elastic Wrap	30	5.2
Mancuso <sup>30</sup>	Ice Bag	Ankle	Elastic Wrap	30	7.9
Holcomb <sup>16</sup>	Pro-Stim	Thigh	Self	30	14
Belitsky <sup>2</sup>	Ice Bag	Gastroc	None	15	17.9

Typically, surface temperature decreases between 20 to 25°C after 30 minutes of an ice bag application. Surface temperature decreased by 15.6°C, 18.63°C, and 21.89°C during no compression, compression with Flex-i-Wrap™, and compression with elastic wrap for final surface temperatures of 14.59°C, 11.55°C, and 9.49°C, respectfully (Table 1). These final surface temperatures were higher than almost all previous reported surface temperatures.<sup>2, 9, 17, 39, 40, 59, 88</sup> The only significant difference between groups with respect to treatment type was compression provided greater cooling than no compression. These significant differences remained for the duration of the experimental protocol. At no time during the experimental protocol was there a significant difference between the surface temperature decrease generated by Flex-i-Wrap™ and elastic wrap. The graph of surface temperature decrease and recovery (Figure 1) is similar in appearance to

previous publications.<sup>2, 9, 17, 39, 40, 59, 88</sup> Once cryotherapy is applied, a steep temperature decrease between 10°C and 15°C is typically observed after the initial 5 minutes. Surface temperature re-warms by about 10°C during the first 5 minutes of cryotherapy removal. The rapid temperature decrease and increase occurs within the first 5 minutes of cryotherapy application and removal. After 60 minutes of rewarming the surface temperature had warmed to within 5°C of its baseline temperature.

The measured intramuscular temperature at the specific depth of 2 cm on every subject was different than previous authors. Earlier authors have used the equation,  $(\text{skinfold}/2) + (\text{desired implantation depth})$ , to measure intramuscular temperature at a constant depth below adipose.<sup>8, 9, 17, 40-42, 50, 60</sup> We chose to control adipose tissue depth by using individuals with a low area skinfold measurement, no greater than 15 mm. Using this procedure, the intramuscular thermocouple was no less than 12.5 mm into the muscular tissue with no greater than a 7.5 mm layer of adipose between the ice bag and muscle tissue. The pre-determined depth of 2 cm is similar to, but slightly deeper than the 1 cm sub-adipose depth used by others (Table 4).<sup>17, 40, 41, 50, 60</sup>

Table 4. Comparison of the Research on Intramuscular Temperature Changes in Human Tissue After Applications of Cryotherapy

Author	Treatment	Body Area	Depth	Compression	Tx Time (min)	Lowest Tissue Temp (°C)
Merrick <sup>17</sup>	Ice Bag	Gastroc	Fat + 1 cm	Elastic Wrap	30	23.54
Merrick <sup>17</sup>	Ice Bag	Thigh	Fat + 1 cm	None	30	26.58
Merrick <sup>17</sup>	Ice Bag	Gastroc	Fat + 2 cm	Elastic Wrap	30	26.46
Merrick <sup>17</sup>	Ice Bag	Thigh	Fat + 2 cm	None	30	28.21
Jutte <sup>9</sup>	Ice Bag	Thigh	Fat + 2 cm	Elastic Wrap	30	27
Merrick <sup>31</sup>	Ice Bag	Thigh	Fat + 1 cm	Elastic Wrap	30	27.77
Merrick <sup>31</sup>	Ice Bag	Thigh	Fat + 2 cm	Elastic Wrap	30	31.82
Merrick <sup>31</sup>	Wet-Ice	Thigh	Fat + 1 cm	Self	30	27.21
Merrick <sup>31</sup>	Wet-Ice	Thigh	Fat + 2 cm	Self	30	30.59
Merrick <sup>31</sup>	Flex-i -Cold	Thigh	Fat + 1 cm	Elastic Wrap	30	29.46
Merrick <sup>31</sup>	Flex-i-Cold	Thigh	Fat + 2 cm	Elastic Wrap	30	32.07
Myrer <sup>41</sup>	Ice Bag	Gastroc	Fat + 1cm	None	20	29.67
Zemke <sup>32</sup>	Ice Bag	Gastroc	Fat + 1 cm	None	15	31.74
Myrer <sup>60</sup>	Ice Bag	Gastroc	Fat + 1 cm	None	20	27.8
Myrer <sup>42</sup>	Ice Bag	Gastroc	< 8 mm Fat + 1 cm	None	20	20.81
			10-18 mm Fat + 1 cm			
Myrer <sup>42</sup>	Ice Bag	Gastroc	cm	None	20	26.48
Myrer <sup>42</sup>	Ice Bag	Gastroc	> 20 mm Fat +1 cm	None	20	30.54

During this study the measured intramuscular tissue temperature decreased 5.78°C with no external compression, decreased 8.04°C with Flex-i-Wrap™, and decreased 9.55°C with an elastic wrap, with temperatures being 29.52°C, 27.17°C, and 25.53°C at the end of 30 minutes. However, the lowest temperatures were recorded 10 minutes post-treatment (40 minutes), they were 28.48°C, 26.26°C, and 24.87°C (Table 2). A significant difference between elastic wrap and Flex-i-Wrap™ was present, with elastic wrap being significantly colder than Flex-i-Wrap™ after 20 minutes of an ice bag

application. An additional 1.64°C intramuscular temperature decrease occurred when an elastic wrap was used instead of Flex-i-Wrap™ as external compression.

During the Flex-i-Wrap™ condition the temperature at the conclusion of the ice treatment was 27.17°C, while this is higher than most previous studies at the fat + 1 cm depth.<sup>9, 17, 40, 41, 50, 60</sup> The intramuscular temperature with an elastic wrap was 25.53°C after 30 minutes of ice bag application, however this is lower than all but Merrick et al.<sup>17</sup> at the fat + 1 cm depth.<sup>9, 17, 40, 41, 50, 60</sup> The graph of intramuscular temperature decrease is similar in appearance to others previously published (Figure 2).<sup>9, 17, 40, 41, 50, 60</sup> When cryotherapy is applied, intramuscular temperature decreases gradually by approximately 5°C to 8°C after 30 minutes. When cryotherapy is removed, the temperature continues to decrease by approximately another 2°C to 3°C during the next 10 minutes, before it gradually increases towards baseline. After 60 minutes of rewarming, the intramuscular temperature was still depressed between 5°C and 8°C when compared to baseline temperatures across all conditions.

Merrick et al.<sup>17</sup> was the first to examine the effect of external compression during cryotherapy on surface and intramuscular temperatures. Merrick et al.<sup>17</sup> standardized the amount of external compression force between 42 and 48 mm Hg when the authors applied an ice bag to the anterior thigh for 30 minutes measuring; surface, fat + 1 cm, and fat + 2 cm temperatures. Surface temperature decreased from 25.26°C to 7.24°C with no compression and from 27.56°C to 4.94°C with compression. Intramuscular temperature 1 cm sub-adipose decreased by 9.7°C to 26.58°C when no external compression was applied and by 12.74°C to 23.54°C when an elastic wrap externally compressed the ice bag. Intramuscular temperatures at the fat + 2 cm depth were

measured at 28.21°C and 26.46°C, a decrease of 8.38°C and 10.13°C, when no compression and compression were applied.

Barlas et al.<sup>65</sup> examined how externally compressing chemical instant cold packs affect intramuscular temperature in canine thighs. The pack was either compressed with a tubular elastic wrap or no compression during a 60-minute treatment. Externally compressing the instant cold packs resulted in an additional 2.5°C tissue temperature decrease when compared to no external compression applied.

Both Merrick et al.<sup>17</sup> and Barlas et al.<sup>65</sup> determined that externally compressing cryotherapy to the limb will produce a greater rate and magnitude of tissue cooling. The results of Merrick et al.<sup>17</sup> are more applicable to athletic training since Barlas et al.<sup>65</sup> utilized canine thighs, chemical instant cold packs, and a tubular elastic wrap.

Chemical instant ice packs are poor sources of cryotherapy and a tubular elastic wrap is not commonly utilized by ATCs.<sup>1</sup> However, these cryotherapy application techniques are common in emergency departments. Merrick et al.<sup>17</sup> applied a common cryotherapy source in a manner that is typical of athletic training settings,<sup>1</sup> determined that a 25.26°C and 27.56°C surface temperature decrease occurred after a 30-minute treatment with no external compression and with an elastic wrap. Additionally, they found a 9.7°C and 12.74°C temperature decrease without and with external compression at the fat + 1 cm depth after 30 minutes of ice bag application. Tissue temperature decreased by 15.6°C, 18.63°C, and 21.89°C at the surface and 5.7°C, 8.04°C, and 9.55°C at the 2 cm depth with no compression, Flex-i-Wrap™, and elastic wrap at the conclusion of a 30-minute cryotherapy application in this study. Both surface and intramuscular temperatures were higher than those reported by Merrick et al.<sup>17</sup> The area of the body used was different;

this study measured temperature in the posterior gastrocnemius muscle while Merrick et al.<sup>17</sup> utilized the anterior thigh. Both studies applied a crushed ice bag for 30 minutes.

The different methods of determining a measurement depth may contribute to the difference in temperature measured between studies. Merrick et al.<sup>17</sup> used the formula  $(\text{site skinfold} / 2) + 1 \text{ cm}$  to determine a constant depth 1 cm under the adipose tissue, while a constant pre-determined depth of 2 cm was used in this study. No subject in this study had a site skinfold greater than 15 mm with a mean skinfold of  $13.14 \pm 1.61$  mm. Merrick et al.<sup>17</sup> reported the mean anterior skinfold as  $15.8 \pm 3.7$  mm. The area measured by Merrick et al.<sup>17</sup> was greater in site skinfold than this study then Merrick et al.<sup>17</sup> went an additional 1 cm into the tissue. This procedure would put the intramuscular thermocouple of Merrick et al.<sup>17</sup> at an average depth of 17.9 mm with an average of 7.9 mm of adipose overlying the thermocouple. If the same formula as Merrick et al.<sup>17</sup> was used in this study, the measuring tip of the intramuscular thermocouple under a maximum of 7.5 mm of adipose tissue and a minimum of 12.5 mm below adipose. The average implantation depths are similar however, the standard deviation reported by Merrick et al.<sup>17</sup> (3.7 mm) is greater than this study (1.61 mm). The higher site skinfold mean and standard deviation reported by Merrick et al.<sup>17</sup> would result in a greater amount of adipose tissue between the surface and the intramuscular thermocouple tip than the present protocol. This may result in different rates and magnitudes of intramuscular tissue cooling.

It has been demonstrated that a greater adipose tissue thickness results in a prolonged ice application time to produce the same temperature decrease as a lower site skinfold<sup>8</sup> and greater overlying adipose tissue depth results in different intramuscular



temperatures during a predetermined period of ice application.<sup>42</sup> After 20 minutes of ice application, Myrer et al.<sup>42</sup> found a 14.43°C temperature decrease in individuals with less than 8 mm of adipose tissue, 9.06°C temperature decrease in individuals with 10 to 18 mm of adipose overlying the treatment site, and a 5°C decrease when the skinfold is 20 mm or greater. The authors did not state whether their ice bag was compressed. Our elastic wrap compression intramuscular temperature decreased 6.63°C after 20 minutes. Myrer et al.<sup>42</sup> reported a 14.43°C decrease when 8 mm or less of adipose overlies the treatment site after 20 minutes of ice application. If the present study had an implantation depth underlying a lower amount of adipose, one would expect the resultant temperatures of our study to be less than those reported by others.<sup>8, 17, 42, 50</sup> However, this was not observed.

With Merrick et al.<sup>17</sup> reporting lower average temperatures than this study, other explanations for the difference need to be considered besides location and adipose thickness. Instrumentation differences may result in variations in tissue temperatures. Merrick et al.<sup>17</sup> used the same electrothermometer, surface thermocouple, and intramuscular thermocouple as us. During this study, the same thermocouples were used for each trial in an attempt to prevent errors occurring between trials. Merrick et al.<sup>17</sup> did not state whether the same thermocouples were used throughout the entire experimental. The variance between surface and intramuscular thermocouples in our laboratory was calculated to be  $0.26^{\circ}\text{C} \pm 0.042^{\circ}\text{C}$  and  $0.49^{\circ}\text{C} \pm 0.05^{\circ}\text{C}$  respectfully (unpublished laboratory data). This standard deviation is not large enough to account for the extra intramuscular temperature decreases of 2.94°C and 1.99°C with and without compression observed by Merrick et al.<sup>17</sup>

Another explanation for the difference between the temperatures reported by Merrick et al.<sup>17</sup> and this study is the amount of compression applied. Merrick et al.<sup>17</sup> used a compressive force between 42 and 48 mm Hg. This external compression force used by Merrick et al.<sup>17</sup> was relatively high.<sup>18</sup> It was shown that an extremely tight application of external compression (50 to 60 mm Hg) did not produce a significant intramuscular temperature decrease when compared to an average compression force (30 to 40 mm Hg).<sup>18</sup> Some authors<sup>17, 18, 39, 70</sup> used a manometer to measure the amount of external compression applied. This study was unable to quantify the amount of external compression applied during the experimental conditions. To control for the amount of external compression applied, the same individual applied all wraps in this study, this individual has been an ATC for several years and has applied numerous ice bags with both Flex-i-Wrap™ and elastic wraps. Although no significant temperature differences were observed between different compression forces,<sup>18</sup> actual differences exist and may contribute to the difference in intramuscular temperatures seen between our studies.

Differing amounts of external pressure affect blood flow;<sup>63</sup> which may lead to differing cooling rates.<sup>18</sup> Sabri et al.<sup>63</sup> examined how external pressure affects hemodynamics of the lower limb. Nine patients undergoing varicose vein surgery had external pressures applied to one limb during surgery with either a below-knee splint or a full-length leg and thigh splint. Inflatable splint pressures between 5 and 40 mm Hg were utilized. Although no formal statistical analysis was performed, the authors stated that it was quite clear that the full-length splint inflated to 5 mm Hg produced an increase in femoral venous blood flow by 15%. Examining the graphs provided by the authors, it appears that, as pressure increased there was a gradual decrease in the

femoral vein blood flow with the below-knee splint. Contrastingly, femoral vein blood flow percentage increased initially, then gradually decreased afterwards. The results of Sabri et al.<sup>63</sup> were based on patients who were under general anesthesia, thus completely at rest with no muscular contractions. A trend was evident that as more external pressure was applied, blood flow gradually decreased. If blood flow is restricted with external compression, intramuscular tissue temperature may be further reduced when less blood flows through the area. However, in the study, pressures were only applied for 3-minute intervals. When ATCs apply an ice bag with external compression the time is commonly 20 to 45 minutes. Providing an elastic wrap would allow the athlete to apply external compression during the periods when cryotherapy is not applied. When Flex-i-Wrap™ is used as compression; the individual should be given an additional form of external compression to prevent the accumulation of edema subsequently to an acute injury.

Starling's hypothesis,  $CFP = (CHP + TOP) - (COP + THP + EFP)$  is the formula used to describe the interaction between blood flow entering and leaving tissue.<sup>1, 26</sup> Applying external compression increases external force pressures (EFP). EFP is typically zero in normal circumstances and increases as a result of external force pressures resulting from tissue elasticity and bandages.<sup>1, 26</sup> When an acute injury is sustained, applying external compression will increase EFP; allowing Starling's hypothesis to become more balanced.<sup>1, 26</sup> Subsequently assisting in reduced edema formation, by not allowing tissue oncotic pressure (TOP) to increase free protein migration to the area.<sup>1, 26</sup>

Merrick et al.<sup>17</sup> explained several modes by which externally compressing an ice bag to the body would result in a significant decrease in intramuscular temperature when

compared to ice alone: 1) compression improves the contact between the skin and the ice bag, 2) compression greater than 30 to 40 mm Hg reduces blood flow, and 3) compression may change the density of the tissue, and 4) insulation effects of the compressive wrap. Merrick et al.<sup>17</sup> first discussed that compression allows for improved contact between the skin and the ice bag, describing that merely placing an ice bag on a body part may result in pockets of air between the ice and the body part resulting in improved cooling.<sup>17</sup> This may not occur with Flex-i-Wrap™

As described by Ashton,<sup>68</sup> when external compression is greater than 30 to 40 mm Hg blood flow will be reduced. When blood flow is reduced, the inflow of heat from other body parts is restricted. Merrick et al.<sup>17</sup> determined that although blood flow may be obstructed, compression alone (with elastic wraps) significantly increased tissue temperature. Combining a reduction in blood flow (compression) with an external source of cold (ice) restricts the body's ability to re-warm the area being cooled; resulting in a significant decrease in tissue temperature when compared to an identical treatment with no compression. By compressing the tissue, the area occupied by the tissue may be decreased. However, the tissue's mass remains unchanged. If this belief holds true, then the density of the area will be increased resulting in greater conductive cooling.<sup>17</sup>

Lastly, Urban<sup>46</sup> determined that skin temperature was significantly colder when the ice bag was applied directly to the skin as compared to applying the ice bag with a dry, wet, or frozen elastic wraps between the ice bag and the skin. He concluded that this is evident of an insulation effect provided from elastic wraps. Merrick et al.<sup>17</sup> used this as their fourth point; stating that placing elastic warps around the pack reduces heat gain

from the environment, leading to colder tissue temperatures. Compressive wraps allow the ice bag to interact more with the tissue and less with the atmosphere.

This study determined that compression of any kind will result in a greater rate and magnitude of tissue cooling compared to no compression applied during cryotherapy. Compressing an ice bag to the body will reduce the amount of space between the ice bag and the tissue, and this act allows more ice to be in contact with the tissue. This study did not apply a compression only trial or measure blood flow so it cannot determine if an elastic wrap or Flex-i-Wrap™ will alter surface or intramuscular temperature more than the other when no cryotherapy is placed under the compressive wrap or if blood flow is decreased more with one type of compression than the other. This study also did not examine the density of the gastrocnemius muscle before or during the cryotherapy treatment and are unable to comment whether a density change of the area was a causative factor in decreased tissue cooling.

Elastic wraps provide more insulation than Flex-i-Wrap™. By placing two additional PT-6 surface probes on the outside of the wraps on 4 of the 14 subjects during all three cryotherapy treatments then analyzing the interface temperature between the top of the wrap and the atmosphere during 25 minutes of ice bag application one could determine how the ice bag interacts with the body (Table 5).

Table 5. Interface Temperature Between the Wrap and the Atmosphere with Three Compression Types

Time (Minutes)	Ice Application Technique		
	Ice Only	Elastic Wrap	Flex-i-Wrap™
	Temp °C	Temp °C	Temp °C
4	9	11.82	8.17
9	8.96	11.54	8.8
14	9.13	11.92	9.36
19	9.31	12.06	10.09
24	9.62	12.21	10.55
29	9.9	12.39	10.97
25 Minute Average	9.32	11.99	9.66

The average interface temperature between the atmosphere and the surface of the elastic wrap was 11.99°C, while the same measurement with Flex-i-Wrap™ and no compression were 9.66°C and 9.32°C respectfully (Figure 3).

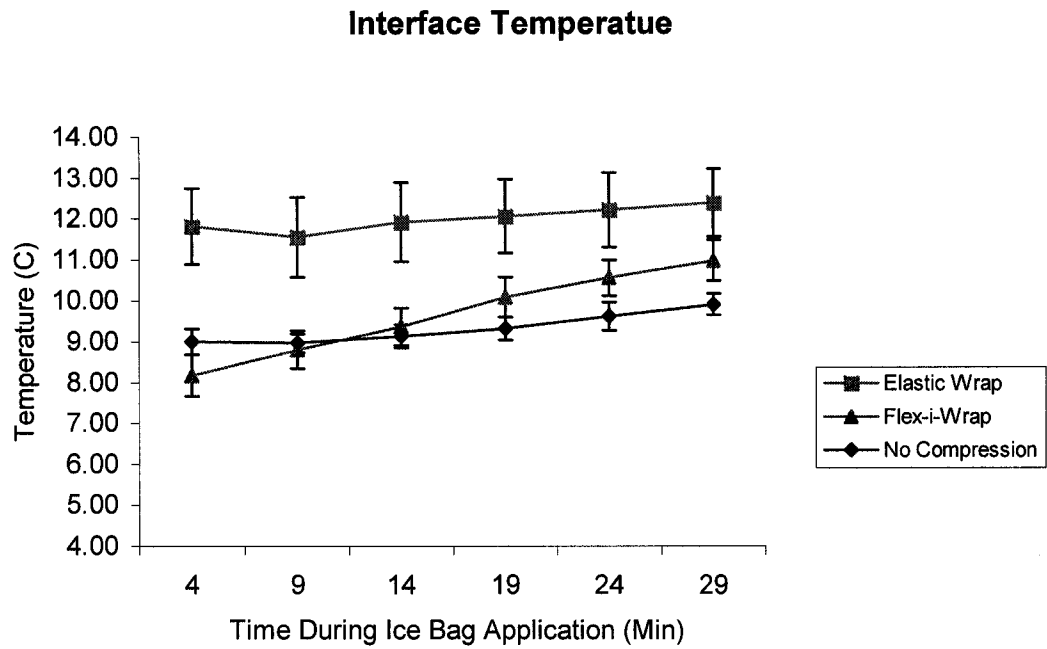


Figure 3. Interface Temperature Between Compression Types Over Time (Temp°C Mean  $\pm$  St. Error)

The higher interface temperatures generated by elastic wrap demonstrate that the ice bag was absorbing more heat from the body and less heat from the atmosphere. Flex-i-Wrap™ and no compression had similar interface temperatures, resulting in the ice bag absorbing more heat from the atmosphere and less from the treatment area compared to an elastic wrap. It is possible that the primary factor in reduced tissue temperature between elastic wrap and Flex-i-Wrap™ is an increased insulation effect present in elastic wraps and not in Flex-i-Wrap™. This is substantiated by the average Flex-i-Wrap™ interface temperature (9.66°C) being 2.33°C lower than the elastic wrap interface temperature (11.99°C). A higher interface temperature assists in generating the additional 2.06°C surface and 1.64°C intramuscular temperature decrease after a 30-

minute ice bag application with an elastic wrap. Since Flex-i-Wrap™ and no compression had similar interface temperatures; it is proposed that the primary factor in reduced tissue temperature between compression and no compression may be improved contact between the tissue and the ice bag during a compression application.

Previously, it has been stated that in order to prevent secondary injury, the tissue temperature needs to be cooled approximately 5°C below baseline at a depth of 2 to 3 cm below adipose.<sup>1, 5, 6, 19</sup> We created an intramuscular temperature decrease of 5.78°C, 8.04°C, and 9.55°C when an ice bag is applied with no compression, Flex-i-Wrap™, and elastic wrap. Each of our intramuscular temperatures were measured at the constant depth of 2 cm; but as previously stated, we controlled adipose tissue by not allowing individuals to participate in this study who had more than 15 mm of skinfold over the posterior gastrocnemius. Our intramuscular thermocouple tip was under a maximum of 7.5 mm of adipose tissue, making our intramuscular thermocouple at least 12.5 mm under the adipose tissue. We feel that our cryotherapy treatments with either form of compression would achieve the goal of a 5°C tissue temperature decrease 2 cm sub-adipose, while an ice bag with no compression may not achieve this goal.

The results of this study further demonstrate that intramuscular temperature values cannot be accurately predicted from surface temperature as presented by Jutte et al.<sup>9</sup> This study is the first to describe a significant intramuscular temperature decreases between compression types, elastic wrap and Flex-i-Wrap™, without observing a significant decrease in surface temperature between the same two treatment types. This observation was unexpected, but it is interesting that there was no significant difference



between surface temperatures, but there was a significant difference in intramuscular temperature between the two different types of external compression.

There is a temperature difference between forms of external compression when intramuscular temperature was examined. When cryotherapy is used in conjunction with an elastic wrap the intramuscular temperature will be significantly cooler than when an ice bag is compressed with Flex-i-Wrap™ after only 20 minutes of ice bag application. This difference in intramuscular cooling will continue to be significant for at least another 10 minutes. After an acute injury, the protocol RICES should be used to treat the area, and an elastic wrap used as external compression instead of Flex-i-Wrap™. If a cooler intramuscular temperature is created and the rate of that temperature decrease is faster, the cryotherapy treatment will reduce secondary injury, edema formation, and blood flow. This may allow the athlete to return to participation sooner.

### Conclusions

A greater rate and magnitude of tissue cooling is proposed to reduce secondary injury, edema formation, and blood flow. External compression with elastic wraps will provide a greater rate and magnitude of tissue temperature cooling after a 30-minute ice bag treatment than when Flex-i-Wrap™ is used as external compression. This can be explained by the greater insulation provided by the elastic wrap. ATC's should utilize elastic wraps on athletes to create a greater rate and magnitude of tissue cooling.

### Practical Recommendations

Some athletes, who have chronic injuries, may need to leave the treatment facility because of a class or team meeting and applying external compression with Flex-i-Wrap™ is more convenient and cost effective on athletes who will subsequently leave with the ice bag compressed to the injured area. When athletes remain in the training room for the entire treatment protocol an elastic wrap should be applied as external compression instead of Flex-i-Wrap™. Elastic wraps should be used under all acute care circumstances.

### Recommendations for Future Research

Additional cryotherapy research should be conducted to assist in determining the ideal rate and magnitude of tissue cooling to prevent secondary injury, reduce edema formation, and reduce blood flow. Research examining the rate and magnitude of temperature decrease during activity should be conducted. When new cryotherapy products are on the market they should be examined to determine if an adequate rate and magnitude of tissue cooling is generated.

## APPENDIX I

### PICTURES OF THERMOCOUPLE AND ICE APPLICATION TECHNIQUES

## LIST OF FIGURES

Figure 1. Posterior Gastrocnemius Before Thermocouple Application.....	83
Figure 2. Posterior Gastrocnemius Cleaned with Betadine® .....	83
Figure 3. Preparation of the Intramuscular Thermocouple Before Implantation.....	84
Figure 4. Implantation of the Intramuscular Thermocouple.....	84
Figure 5. Intramuscular Thermocouple After Implantation.....	85
Figure 6. Posterior Gastrocnemius After Thermocouples Applied.....	85
Figure 7. Posterior Gastrocnemius During an Elastic Wrap Treatment.....	86
Figure 8. Posterior Gastrocnemius During a Flex-i-Wrap™ Treatment.....	86
Figure 9. Posterior Gastrocnemius During an Ice Only Treatment.....	87

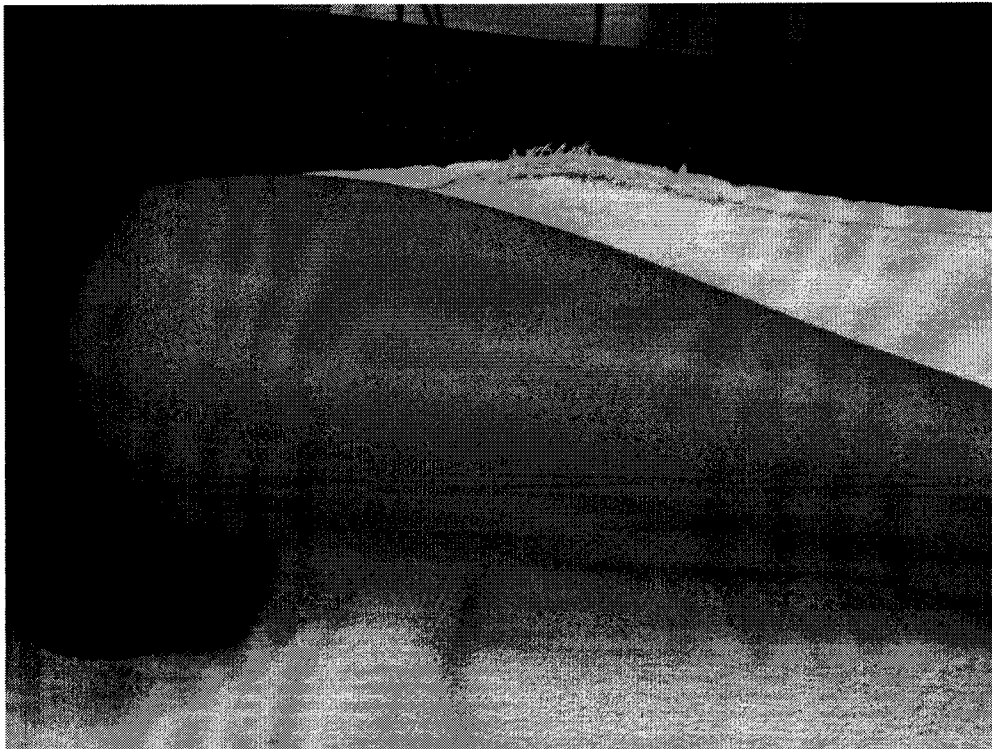


Figure 1. Posterior Gastrocnemius Before Thermocouple Application

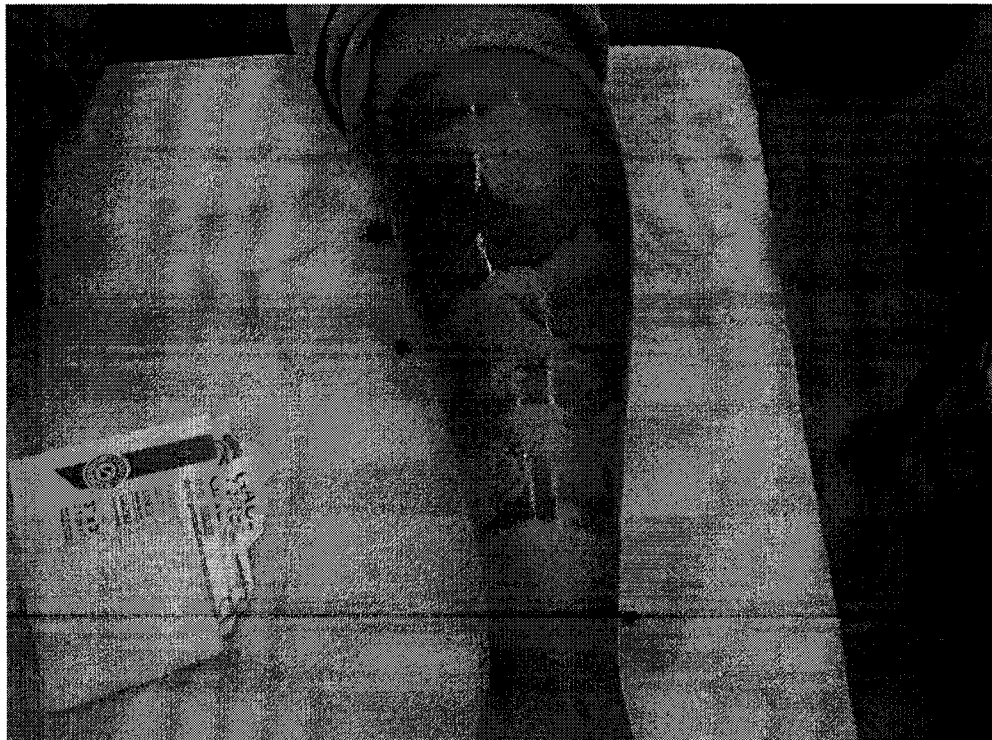


Figure 2. Posterior Gastrocnemius Cleaned with Betadine®

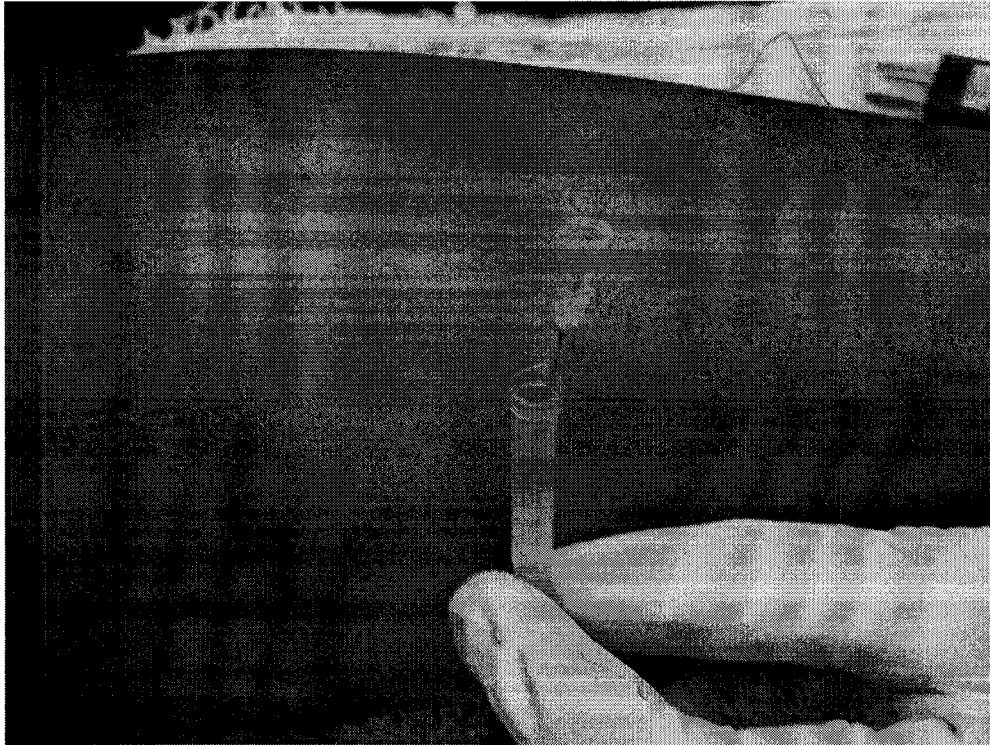


Figure 3. Preparation of the Intramuscular Thermocouple Before Implantation



Figure 4. Implantation of the Intramuscular Thermocouple

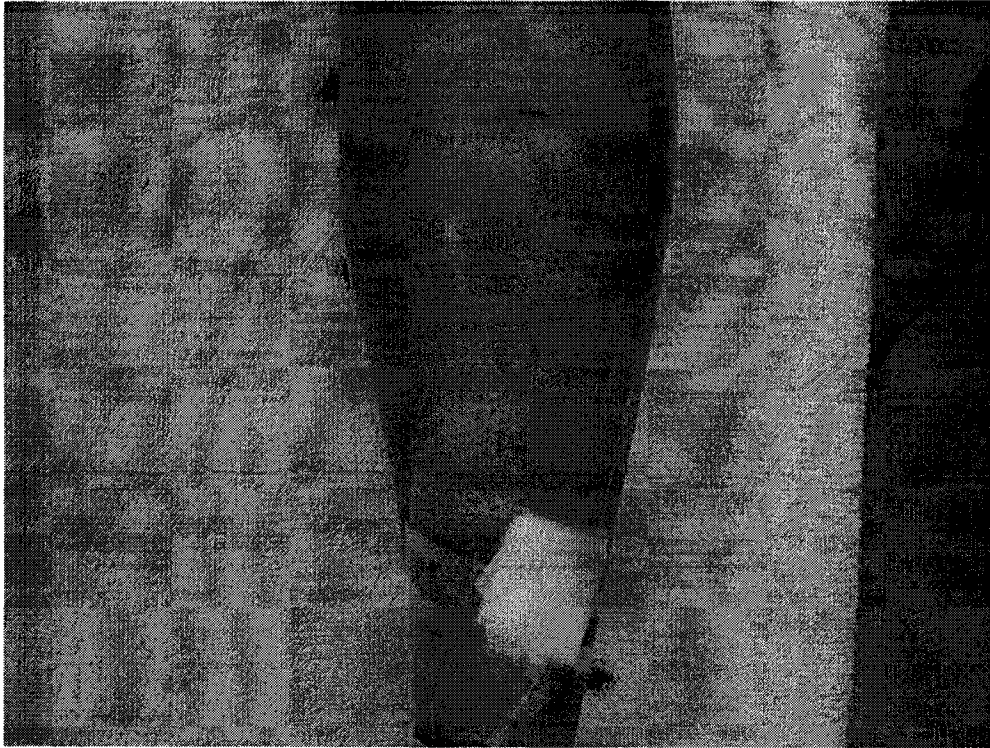


Figure 5. Intramuscular Thermocouple After Implantation



Figure 6. Posterior Gastrocnemius After Thermocouples Applied





Figure 7. Posterior Gastrocnemius During an Elastic Wrap Treatment



Figure 8. Posterior Gastrocnemius During a Flex-i-Wrap™ Treatment



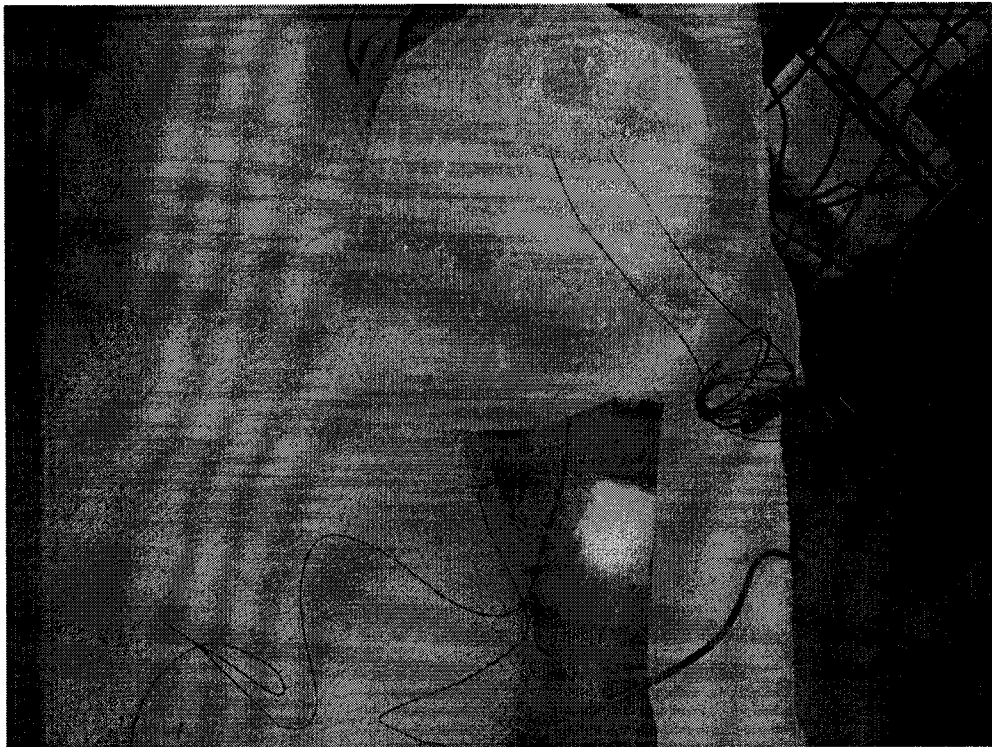


Figure 9. Posterior Gastrocnemius During an Ice Only Treatment

## APPENDIX II

### BIOMEDICAL SCIENCES INSTITUTIONAL REVIEW BOARD APPROVAL AND SUBJECT FORMS

**Department of Kinesiology and the Athletic Training Research Laboratory**  
**INFORMED CONSENT TO BE A RESEARCH SUBJECT**

**Investigator:** Mack D. Rubley, PH. D., ATC, CSCS

**Co-Investigators:** William R. Holcomb, Ph. D., ATC, CSCS, and David Tomchuk, ATC, CSCS

**Department:** Kinesiology

**Title of Study:** The Rate of Tissue Cooling During Cryotherapy

**Protocol Number:** 0402-1091

---

This investigation is intended to examine skin and muscular temperature during a 30-min application of ice to your calf and for 60-min after the ice is removed (total time 90 to 110 min).

**Procedures:**

Prior to the first treatment session the skinfold thickness on your calf will be measured. Then the hair on a small area on your right calf (about the size of a playing card) will be shaved and then cleaned with betadine to reduce the chances of an infection. Then a sterilized temperature sensor (a flexible wire about the diameter of fishing line) will be inserted into this area using a sterile needle. The temperature sensor contains **no** Mercury. You will feel a small "needle prick" when the needle, with the temperature sensor, is inserted but then the needle will be removed almost immediately leaving just the flexible wire temperature sensor in place. Once the needle is removed, most people report that they can't tell the temperature sensor is in place and that they have little or no discomfort. Additional temperature sensors (no more than 2) will be taped to the skin surface within the shaved area very near to where the needle was placed. With the temperature sensors in place, your calf temperature will be measured before, during, and after an ice bag (4 pound bag of crushed ice) is applied to your leg for 30 minutes. After 30 minutes, the ice bag and wrap, if used, will be removed. You will remain lying on the examination table for another 60 minutes while temperature is measured as your calf re-warms. Afterwards, the temperature sensors will be removed (gently pulled out - most people can not feel the sensors being removed) and the small wound will be cleaned and covered with a band-aid. You will return 24 to 48 hours later for additional treatment with a different method of ice bag compression.

Dr. Rubley, Dr. Holcomb and Mr. Tomchuk are the researchers who may be placing the needle and temperature sensor. Each of these persons has been trained to perform this procedure by Dr. Tarno and have previously performed this procedure on other subjects. Dr. Tarno is a team physician for UNLV Athletics and he will be on-call should medical services be needed.

**Common Risks and Discomforts:**

- You should expect minor discomfort with the **"needle prick"**.
- Aside from the needle prick, the most common discomforts and risks are that you may have some **minor bleeding and/or bruising** where the needle is inserted.
- There is a risk of developing an **infection** at the needle insertion site.

**Uncommon Risks and Discomforts:**

- There is a small chance that the needle may accidentally cause **nerve damage**.
- There is a risk of **transmitting bloodborne diseases**. Only sterile needles and temperature probes are used, so your risk is minimal. If you have a bloodborne disease like hepatitis or HIV you should not participate in this study in order to reduce this risk to others and yourself.
- Because the ice is being compressed there is a minimal chance of **frostbite**.
- There is a very small risk of skin irritation if you are **allergic to latex or iodine**.

**Possible benefits for subjects:**

You will not benefit by participating in the study. Your participation may help improve the understanding and use of common cold and compression treatments. You will not receive payment, course credit, or extra-credit for participating in this study.

**Anticipated duration of subject's participation (including number of visits):**

You will commit to 4 appointments including this orientation session, and three experimental sessions (approximately 2 hours each and 24-48 hours apart), for a total of approximately 7 hours. You may also choose to attend an optional session where the findings of the study are summarized.

It is our intention to report and publish the results of this study. Only group data will be reported, all personal data will be kept confidential, in a locked file cabinet at UNLV. This information is intended to give you some impression of the procedure and the risks associated with this study. If you have any questions, comments, or concerns please voice them to the primary examiner at any time during the study. Participation in this study is voluntary. You are free to withdraw your consent and to discontinue participation in this study or refuse to undergo any particular test at any time without prejudice. For specific questions regarding this study, contact Dr. Mack Rubley (702) 895-2457. For general information regarding the rights of research subject, contact: Brenda Durosini Human Protections Administrator, Office for the Protection of Research Subjects, University of Nevada Las Vegas, Las Vegas, NV, 89154: phone: (702) 895-2794.

- I agree to have my calf skinfold thickness obtained for the purposes of this study.
- I agree that I will not hold the University of Nevada, Las Vegas, or the individual examiners financially responsible for any medical exams or medication in the event of adverse side effects by my voluntary participation in this research study.
- I understand that the University of Nevada, Las Vegas will not provide medical care for any injury I might sustain by participating in this study.
- I understand that the temperature probe will be implanted in my calf for 90 minutes.
- I understand that ice will be applied to my calf for 30 minutes.
- I understand I will lie down for approximately 2 hours.
- I understand that I may withdraw from the study at any time.
- I have read the description of the study and give my consent to participate.
- I will receive a copy of this form to keep for future reference.

**Department of Kinesiology and the Athletic Training Research Laboratory**  
**INFORMED CONSENT TO BE A RESEARCH SUBJECT**

**Investigator:** Mack D. Rubley, PhD, ATC, CSCS

**Co-Investigators:** William R. Holcomb, PhD, ATC, CSCS, and David Tomchuk, ATC, CSCS

**Department:** Kinesiology

**Title of Study:** The Rate of Tissue Cooling During Cryotherapy

**Protocol Number:** 0402-1091

---

I agree to participate in this research project entitled *The Rate of Tissue Cooling During Cryotherapy*.

\_\_\_\_\_  
Participant Signature / Printed Name

\_\_\_\_\_  
Date

I hereby certify that I have explained the proposed study and its risks and potential complications.

\_\_\_\_\_  
Witness

\_\_\_\_\_  
Date

**Department of Kinesiology and the Athletic Training Research Laboratory**  
**SUBJECT INFORMATION AND INJURY HISTORY QUESTIONNAIRE**

Subject #: \_\_\_\_\_  
 Gender: \_\_\_\_\_

Height: \_\_\_\_\_ cm      Weight: \_\_\_\_\_ kg      Age: \_\_\_\_\_ yrs  
 Calf Skinfold Thickness: \_\_\_\_\_ mm

TO THE BEST OF YOUR KNOWLEDGE, HAVE YOU HAD ANY OF THE FOLLOWING? CIRCLE ALL THAT APPLY. PLEASE INCLUDE ANY OTHER MEDICAL CONDITIONS NOT LISTED.

QUESTIONS	YES	NO	EXPLANATIONS
CURRENT INJURY TO THE LOWER EXTREMITY? _____			

**SPECIFIC TO CRYOTHERAPY**

HAVE YOU USED CRYOTHERAPY PREVIOUSLY?	YES	NO	_____
WERE THERE ANY ADVERSE SIDE EFFECTS?	YES	NO	_____
HISTORY OF HEART DISEASE?	YES	NO	_____
ANY CARDIOVASCULAR DISORDER?	YES	NO	_____
ANY NEUROLOGICAL DISEASE OR INJURY?	YES	NO	_____

**SPECIFIC TO NEEDLE INSERTION**

DO YOU HAVE A FEAR OF NEEDLES?	YES	NO	_____
DO YOU HAVE A LATEX ALLERGY?	YES	NO	_____
DO YOU HAVE AN IODINE ALLERGY?	YES	NO	_____

Are you currently seeing a physician or taking medication for any medical problems?  
 Yes \_\_\_\_\_ No \_\_\_\_\_

Examiner \_\_\_\_\_

Notes: \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_  
 \_\_\_\_\_

**Department of Kinesiology and the Athletic Training Research Laboratory**  
**SUBJECT INFORMATION TAKE-HOME SHEET ON INFECTION**

This is an informative take-home sheet about infection. The following list contains some signs and symptoms of infection. If you experience any of the following, or have any concerns about a possible infection to your calf, please contact the examiner listed on the bottom of this sheet **immediately, by phone**. This investigator will evaluate the area to determine the extent of the damage and recommend to you if further medical attention is required. This sheet is not intended as a substitute for proper and timely medical attention by a board certified physician.

**CONTACT THIS EXAMINER IF ANY OF THE FOLLOWING  
OCCUR AND/OR APPEAR:**

REDNESS

LOCALIZED SWELLING

PUS

RED STREAKS

LOCAL TEMPERATURE INCREASE

David Tomchuk, ATC, CSCS  
Graduate Assistant  
Department of Kinesiology  
702-895-3419 (office)

### APPENDIX III

#### PROCEDURE FOR IMPLANTING INTRAMUSCULAR THERMOCOUPLE



1. 1 hour before subject, measure and place a mark on the intramuscular thermocouple (with a permanent marker) just above the depth you wish to place the thermocouple into the muscle.
2. 50 minutes before subject, place intramuscular thermocouple into a 10% povidone-iodine solution for at least 10 minutes making sure the length of the thermocouple wire is bathed in the solution.
3. 40 minutes before subject, remove the intramuscular thermocouple from the 10% povidone-iodine solution and place in a solution of Cidex® or Cidexplus® for a minimum of 40 minutes to perform high-level disinfection.
4. When subject arrives, have them change into appropriate clothing and become comfortable on the table.
5. If the first day of the experiment, measure area adipose.
6. Examine the area to determine if any skin abnormalities exists, if there are any signs of infections, or reports of pain/discomfort. Make sure the area is free of body hair.
7. Put on latex gloves.
8. Cleanse the area with 10% povidone-iodine and sterile gauze pads in a circular motion moving from the desired implantation area towards the periphery.
9. Take another piece of sterile gauze and “blot” the area of implantation to remove some excess povidone-iodine.
10. Take an alcohol prep-pad and swab the area of implantation.
11. Remove the intramuscular thermocouple from the Cidex® or Cidexplus® and place it in a container of sterile water to rinse the Cidex® or Cidexplus® from the wire that will be implanted.
12. Remove a sterilized needle from the packing.
13. Place a strip of surgical tape around the outside of the needle at the predetermined depth of the implantation. This mark should be slightly deeper than the desired intramuscular thermocouple implantation depth.
14. Feed the rinsed intramuscular thermocouple through the sterile needle before you place the needle into the body area to be tested.

15. Once the intramuscular thermocouple is fed through the sterile needle retract the intramuscular thermocouple so that it remains in the needle; but the needle can enter the area without excess pressure.
16. Place the needle into the area to the desired (taped) depth.
17. Stabilize the intramuscular thermocouple wire with 1 hand and place the other around the needle.
18. Slowly remove the needle from the tissue while pushing down on the intramuscular thermocouple wire. You should feel resistance to the wire moving deeper.
19. When the needle is slightly removed from the tissue, place the needle against the skin, place 1 finger over the intramuscular thermocouple wire where it was just implanted and slide the needle down the body area.
20. Look to determine the proper depth of the intramuscular thermocouple. The mark you made (step #1) should be at approximately skin level.
21. Tape the intramuscular thermocouple into place with a small piece of surgical tape.
22. Wrap a sterile gauze pad around the needle and secure the needle to the body away from the implantation site so it does not interfere with the rest of the protocol, nor injury the subject.
23. Watch the temperatures on the subject. It should take approximately 20 minutes for the subject's temperature to return to baseline after they stop locomotion. If the temperature seems high have the subject continue to rest before the experiment is begun.
24. Begin experimental protocol.
25. When your experimental protocol is complete, put on another pair of latex gloves. Remove the tape securing the intramuscular thermocouple wire from to the skin.
26. Remove the intramuscular thermocouple from the tissue.
27. Place the needle in a sharps container.
28. Dispose of the tape & gauze in appropriate containers.
29. Cleanse the area of excess povidone-iodine by washing it off with a towel.

30. Cleanse the insertion site with an alcohol prep-pad and apply a Band-Aid® type bandage.
31. Remind subject of care and how to inspect the area for signs of infection.
32. Provide them with care sheet and contact information in case of infection. Remind them when in doubt to consult a physician and to call the investigator.

APPENDIX IV

RAW TEMPERATURE DATA

## LIST OF TABLES

Table 6-1. Surface Temperature Raw Data—No Compression (°C).....	100
Table 6-2. Surface Temperature Raw Data— Flex-i-Wrap™ (°C).....	101
Table 6-3. Surface Temperature Raw Data— Elastic Wrap (°C).....	102
Table 6-4. Intramuscular Temperature Raw Data— No Compression (°C).....	103
Table 6-5. Intramuscular Temperature Raw Data— Flex-i-Wrap™ (°C).....	104
Table 6-6. Intramuscular Temperature Raw Data— Elastic Wrap (°C).....	105

Table 6-1. Surface Temperature Raw Data—No Compression (°C)

	Subject Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pre 5	31.59	30.77	29.03	31.07	29.71	30.01	29.08	29.24	31.69	28.3	29.34	30.82	31.04	31.7
0	31.58	30.59	29	31.15	29.49	30.28	27.86	29.28	31.52	28.62	29.23	31.17	31.38	31.23
5	21.36	22.44	15.92	21.69	13.02	19.06	19.42	15.58	20.77	17.92	23.32	25.82	26.35	19.66
10	18.79	20.38	13.56	18.89	10.84	17.27	16.47	12.8	17.67	14.89	20.87	24.25	24.23	17.37
15	17.37	19.19	12.08	17.49	9.78	16.23	14.71	11.84	16.23	13.16	19.52	23.12	23.08	16.06
20	15.68	18.52	11.4	16.59	9.19	15.66	13.67	11.59	15.16	11.86	18.5	22.22	21.86	15.28
25	16.95	18.16	10.77	15.99	8.81	15.13	13.28	11.47	14.39	10.69	17.72	21.29	20.94	14.85
30	17.25	17.83	10.65	15.47	8.33	14.87	12.97	11.31	13.66	9.82	17.2	20.33	20.12	14.53
40	25.58	24.71	20.42	23.93	21.14	23.94	21.72	21.05	22.42	18.98	22.75	24.93	24.62	23.81
50	27.26	25.96	22.66	25.9	23.35	25.76	23.44	23.44	24.64	21.2	24.22	25.64	25.41	25.26
60	28.09	26.5	23.88	26.97	24.36	26.42	24.65	24.47	25.87	22.67	24.85	25.92	25.91	25.82
70	28.45	26.8	24.38	27.62	24.78	26.91	25.1	25.06	26.56	23.64	25.34	26.22	26.23	26.33
80	28.72	26.97	24.77	27.95	25	27.14	25.44	25.38	27.01	24.36	25.71	26.48	26.51	26.48
90	29.08	27.15	24.96	28.25	25.21	27.32	25.65	25.64	27.28	24.89	25.99	26.57	26.72	26.31

Table 6-2. Surface Temperature Raw Data— Flex-i-Wrap™ (°C)

		Subject Number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pre	5	32.03	30.6	29.86	29.46	28.57	29.9	29.41	29.43	30.59	29.13	30.19	33.19	30.17	29.52
0		32.11	30.67	29.89	29.2	28.69	29.82	28.83	29.94	30.18	28.8	29.88	32.84	29.79	29.72
5		14.76	23.61	15.43	13.42	16.93	11.79	21.08	9.67	7.82	14.24	17.18	23.75	18.1	17.96
10		12.93	21.47	13.73	11.11	13.89	10.89	17.57	7.63	5.85	12.52	14.29	21.41	16.88	16.3
15		11.99	20.32	12.84	10.61	12.41	11.63	15.18	7.14	5.23	11.44	13.07	19.94	16.31	15.41
20		11.37	19.29	12.01	10.2	11.62	11.74	13.81	7.1	4.97	10.46	12.67	18.83	15.98	14.8
25		10.78	18.77	11.38	9.66	10.6	11.6	12.71	7.09	4.93	10.08	12.07	17.94	15.54	14.3
30		10.47	18.23	10.8	9.28	9.86	11.55	11.96	7.06	4.61	9.62	11.47	16.98	15.19	13.76
40		22.95	24.25	19.94	20.15	19.55	22.14	19.54	20.14	17.21	18.15	20.91	23.65	23.8	22.08
50		24.96	25.37	22.37	23.36	21.26	23.63	21.62	23.36	20.82	20.61	22.87	24.65	25.18	23.54
60		26.39	25.8	23.73	25.03	22.06	24.52	22.71	24.84	22.7	21.86	23.77	25.12	25.76	24.13
70		27.62	25.92	24.48	26.21	22.25	25.13	23.49	25.61	23.95	22.83	24.32	25.49	26.12	24.54
80		28.55	25.85	24.96	26.68	22.46	25.65	24.09	25.94	24.9	23.4	24.69	25.86	26.38	24.72
90		29.04	26.01	25.24	27.75	22.49	25.93	24.73	26.47	25.34	23.94	25.03	25.91	26.72	25.11

Table 6-3. Surface Temperature Raw Data— Elastic Wrap (°C)

		Subject Number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pre 5		31.57	30.96	29.18	29.39	29.52	30.03	28.98	32.27	30.55	28.08	30.44	32.28	29.56	32.55
0		31.67	30.8	29.25	29.5	29.48	29.96	28.8	31.97	30.26	28.2	30.21	32.01	29.54	32.25
5		15.52	15.54	22.14	9.07	8.87	13.93	20.9	20.76	12.89	20	11.22	17.59	20.47	22.53
10		11.01	13.24	18.39	6.48	6.58	12.93	16.26	18.21	9.37	16.54	7.87	15.71	18.77	20.02
15		9.42	11.87	15.69	5.79	5.73	12.19	13.61	16.53	7.75	13.95	6.75	14.77	17.81	17.92
20		8.52	10.63	13.72	5.43	5.04	11.82	11.87	15.32	6.91	12.35	6.38	14.14	15.91	16.26
25		7.65	9.75	12.18	4.98	4.57	11.6	10.34	14.45	6.22	10.98	6.18	13.34	15.15	14.9
30		6.99	9.14	11.11	4.48	4.35	11.25	9.05	13.95	5.72	9.93	5.96	12.44	14.69	13.83
40		21.85	20.92	18.94	19.09	17.09	21.88	18.88	21.59	17.31	18.22	20.85	21.86	23.12	22.17
50		25.01	22.63	21.42	22.02	20.17	23.53	21.04	23.5	20.51	20.8	22.39	23.5	24.41	23.47
60		27.3	23.52	22.64	23.75	21.64	24.35	22.16	24.58	22.03	22.41	23.5	24.28	25.43	24.14
70		28.37	24.23	23.41	24.45	22.56	24.93	22.87	25.1	23.1	23.48	23.92	24.72	25.89	24.72
80		29.14	24.77	23.65	25.01	23.15	25.43	23.53	25.34	23.88	24.16	24.55	25.02	26.29	24.97
90		29.21	25.02	24.23	25.4	23.66	25.56	23.82	26.09	24.48	24.66	25.03	25.23	26.39	25.4



Table 6-4. Intramuscular Temperature Raw Data— No Compression (°C)

		Subject Number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pre	5	35.67	35.85	35.16	36.02	35.25	35.65	34.22	35.26	35.64	34.85	34.08	35.82	34.88	35.86
0		35.39	35.69	34.96	36.03	35.13	35.42	34.04	34.96	35.52	34.63	33.89	35.64	34.71	35.67
5		34.95	35.5	34.34	35.94	34.8	35.09	33.5	34.29	35.22	34.28	33.54	34.97	34.36	35.35
10		33.77	34.7	33.16	35.38	33.89	34.25	32.54	32.74	34.28	33.54	33.04	34	33.47	34.13
15		32.44	33.81	31.93	34.62	32.8	33.3	31.3	31.16	33.01	32.24	32.21	32.74	32.28	32.76
20		31.28	32.88	30.8	33.85	31.65	32.45	30.16	29.8	31.89	30.91	31.33	31.56	31.14	31.52
25		30.38	31.96	29.66	32.96	30.58	31.66	29.12	28.85	30.85	29.69	30.43	30.49	29.97	30.32
30		29.45	31.12	28.68	32.11	29.5	30.87	28.26	27.89	29.91	28.31	29.54	29.44	28.94	29.24
40		29.24	29.96	27.88	31.15	28.24	29.8	27.5	27.18	28.64	26.15	28.37	28.89	27.56	28.19
50		30.35	29.78	28.05	31.16	28.36	29.9	27.31	27.39	28.65	26.41	27.89	28.69	27.31	28.4
60		30.76	29.74	28.26	31.46	28.51	30.24	27.99	27.68	29.1	26.89	27.81	28.68	27.36	28.7
70		31.12	29.75	28.48	31.63	28.74	30.52	28.24	27.98	29.42	27.4	27.94	28.78	27.55	29
80		31.51	29.83	28.61	31.9	29.03	30.8	28.57	28.3	29.78	27.8	28.18	28.9	27.8	29.31
90		31.98	29.91	28.75	32.13	29.15	31.06	29.03	28.56	30.12	28.22	28.45	29.03	28.09	29.54

**Table 6-5. Intramuscular Temperature Raw Data— Flex-i-Wrap™ (°C)**

		Subject Number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pre	5	35.97	35.76	35.86	35.31	35.04	34.96	34.36	34.53	35.56	34.89	34.29	36.14	35.14	35.12
0		35.86	35.65	35.65	35.1	34.84	34.75	34.46	34.63	35.47	34.7	34.16	36.01	34.47	34.8
5		35.25	35.09	35.06	34.58	34.09	34.17	33.94	32.41	34.08	34	33.29	33.1	33.33	34.25
10		33.9	34.49	33.86	33.21	33.3	32.59	32.47	30.05	31.44	32.38	32.07	31.2	31.89	33.22
15		31.81	33.51	32.4	31.72	32.21	31.06	31.01	28.72	29.07	30.64	30.62	29.49	30.77	31.94
20		30.03	32.61	31.04	30.38	31.06	29.79	29.78	27.44	26.98	28.99	29.06	27.93	29.61	30.66
25		28.37	31.81	29.67	29.29	29.76	28.64	28.41	26.39	25.06	27.69	27.92	26.55	28.53	29.41
30		26.71	30.68	28.48	28.34	28.6	27.56	27.06	25.48	23.38	26.42	26.67	25.26	27.65	28.15
40		25.77	29.62	26.95	27.54	27.67	26.46	25.81	25.83	22.31	25.14	25.77	25.84	26.75	26.17
50		26.64	29.15	26.89	27.82	27	26.55	25.13	26.77	23.4	25.36	25.68	26.3	26.95	25.87
60		27.69	28.86	27.05	28.4	26.6	26.87	25.8	27.6	24.65	25.83	25.88	26.51	27.14	25.96
70		28.78	29.17	27.34	29.02	26.66	27.31	26.24	28.11	25.69	26.25	26.12	26.7	27.36	26.2
80		29.74	29.13	27.6	29.7	26.72	27.74	26.25	28.6	26.53	26.74	26.39	26.95	27.59	26.51
90		30.54	29.23	27.9	30.34	26.84	28.18	25.26	29.08	27.35	27.15	26.7	27.18	26.84	26.83

Table 6-6. Intramuscular Temperature Raw Data— Elastic Wrap (°C)

		Subject Number													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pre	5	35.33	35.77	34.15	35.21	34.91	35.12	34.33	36.15	34.96	34.43	34.28	35.77	35.01	35.65
0		35.35	35.56	34.05	34.99	34.74	34.91	34.15	36.08	34.91	34.22	34.15	35.67	34.66	35.63
5		34.72	34.83	33.17	34.09	33.77	33.59	33.38	34.97	33.86	33.71	32.8	34.45	33.67	34.83
10		32.67	33.52	31.8	31.63	31.25	31.84	32.28	33	31.51	32.49	30.37	32.57	32.55	33.34
15		30.05	31.8	29.82	29.4	28.99	30.25	30.59	31.01	29.11	30.83	27.89	30.94	31.47	31.79
20		27.71	30.13	27.9	27.65	26.71	28.85	28.74	29.45	27.11	29.03	25.44	29.29	30.14	30.17
25		25.83	28.65	26.28	26.29	25.12	27.72	26.96	28.06	25.4	27.48	23.7	27.81	28.78	28.52
30		24.48	27.13	24.78	25.12	23.79	26.72	25.37	26.79	23.86	25.89	22.3	26.45	27.72	27
40		24.06	26.17	25.05	25.48	23	25.69	24.53	26.59	22.23	24.46	22.46	26.12	26.58	25.72
50		26.56	26.11	25.63	26.58	23.54	26.18	24.65	26.91	23.06	25.22	23.71	26.2	26.6	25.49
60		28.24	26.29	26.26	27.05	24.22	26.6	25.02	27.26	23.87	25.83	24.58	26.37	26.71	25.67
70		29.72	26.62	26.56	27.54	24.92	27	25.48	27.68	24.58	26.33	25.26	26.5	26.88	26.04
80		30.73	26.92	26.81	27.99	25.55	27.39	25.99	28.06	25.35	26.85	25.81	26.68	27.13	26.47
90		31.38	27.26	27.1	28.45	26.16	27.74	26.46	28.43	25.99	27.29	26.34	26.92	27.35	26.91

## REFERENCES

1. Knight KL, *Cryotherapy in Sport Injury Management*. 1995, Champaign, IL: Human Kinetics.
2. Belitsky R, Odam S, Hubley-Kozey C. Evaluation of the effectiveness of wet ice, dry ice, and cryogen packs in reducing skin temperature. *Phys Ther*. 1987;67:1080-1084.
3. Rubley M, Denegar C, Buckley W, Newell K. Cryotherapy, sensation, and isometric-force variability. *J Athl Train*. 2003;38:113-119.
4. Knight K. The effects of hypothermia on inflammation and swelling. *Athl Train*. 1976;11:7-10.
5. Knight K, Brucker J, Stoneman P, Rubley M. Muscle injury management with cryotherapy. *Athletic Therapy Today*. 2000;5:26-30.
6. Rubley M. Cold storage harnessing the healing power of cold. *Biomechanics*. 2002;28-35.
7. Merrick M, Rankin J, Andres F, Hinman C. A preliminary examination of cryotherapy and secondary injury in skeletal muscle. *Med Sci Sports Exerc*. 1999;1516-1521.
8. Otte J, Merrick M, Ingersoll C, Cordova M. Subcutaneous adipose tissue thickness alters cooling time during cryotherapy. *Arch Phys Med Rehabil*. 2002;83:1501-1505.
9. Jutte L, Merrick M, Ingersoll C, Edwards J. The relationship between intramuscular temperature, skin temperature, and adipose thickness during cryotherapy and rewarming. *Arch Phys Med Rehabil*. 2001;82:845-850.
10. Thorsson O, Lilja B, Ahlgren L, Hemdal B, Westlin N. The effect of local cold application on intramuscular blood flow at rest and after running. *Med Sci Sports Exerc*. 1985;17:710-713.
11. Knight K, Londeree B. Comparison of blood flow in the ankle of uninjured subjects during therapeutic applications of heat, cold, and exercise. *Med Sci Sports Exerc*. 1980;12:786-80.
12. Ho S, Coel M, Kagawa R, Richardson A. The effects of ice on blood flow and bone metabolism in knees. *Am J Sports Med*. 1994;22:537-540.
13. Ho S, Illgen R, Meyer R, Torok P, Cooper M, Reider B. Comparison of various icing times in decreasing bone metabolism and blood flow in the knee. *Am J Sports Med*. 1995;23:74-76.

14. Karunakara R, Lephart S, Pincivero D. Changes in forearm blood flow during single and intermittent cold application. *J Orthop Sports Phys Ther.* 1999;29:177-180.
15. Dolan M, Thornton R, Fish D, Mendel F. Effects of cold water immersion on edema formation after blunt injury to the hind limbs of rats. *J Athl Train.* 1997;32:233-237.
16. Holcomb W, Mangus B, Tandy R. The effect of icing with the pro-stim edema management system on cutaneous cooling. *J Athl Train.* 1996;31:126-129.
17. Merrick M, Knight K, Ingersoll C, Potteiger J. The effects of ice and compression wraps on intramuscular temperatures at various depths. *J Athl Train.* 1993;28:236-245.
18. Serwa J, Rancourt L, Merrick M, Cordova M, Ingersoll C. Effect of varying application pressures on skin surface and intramuscular temperatures during cryotherapy. *J Athl Train.* 2001;36:S-90.
19. Merrick M. Secondary injury after musculoskeletal trauma: A review and update. *J Athl Train.* 2002;37:209-217.
20. McMaster W. A literary review on ice therapy in injuries. *Am J Sports Med.* 1977;5:124-126.
21. McGriff-Lee N. Management of acute soft tissue injuries. *J Pharm Prac.* 2003;16:51-58.
22. Swenson C, Sward L, Karlsson J. Cryotherapy in sports medicine. *Scand J Med Sci Sports.* 1996;6:193-200.
23. Blalock A. A comparison of the effects of the local application of heat and of cold in the prevention and treatment of experimental traumatic shock. *Surgery.* 1942;11:356-359.
24. Mason A, Williams H, Woolhouse F. Correlation of edema formation, hemoconcentration, and mortality in experimental burns treated with hypothermia. *Surg Forum.* 1964;15:469-471.
25. Delorme E. Experimental cooling of the blood-stream. *Lancet.* 1952;914-915.
26. Michlovitz SL, *Thermal Agents in Rehabilitation.* 3 ed. 1996, Philadelphia: F.A. Davis Company.
27. Arnheim DD, Prentice WE, *Principles of Athletic Training.* 9 ed. 1997, St. Louis: WCB/McGraw-Hill.
28. Olson J, Stravino V. A review of cryotherapy. *Phys Ther.* 1972;52:840-853.
29. Abraham W. Heat vs. cold therapy for the treatment of muscle injuries. *Athl Train.* 1974;9:177.
30. Lewis T, Haynal I, Kerr W, Stern E, Landis E. Observations upon the reactions of the vessels of the human skin to cold. *Heart.* 1930:177-208.
31. Chu D, Lutt C. The rationale of ice therapy. *JNATA.* 1969;4:8-9.
32. Hocutt JJ. Cryotherapy. *Am Fam Physician.* 1981;23:141-144.
33. Behnke R. Cold therapy. *Athl Train.* 1974;9:178-179.
34. Behnke R. Cryotherapy and vasodilation. *Athl Train.* 1973;8:106, 133-137.
35. Edwards A. Increasing circulation with cold. *J Natl Athl Train.* 1971;6:15-16.
36. Knight K, Aquino J, Johannes S, Urban C. A reexamination of lewis' cold-induced vasodilatation - in the finger and ankle. *Athl Train.* 1980:248-250.

37. Weston M, Taber C, Casagrande L, Cornwall M. Changes in local blood volume during cold gel pack application to traumatized ankles. *J Orthop Sports Phys Ther.* 1994;19:197-199.
38. McMaster W, Liddle S, Waugh T. Laboratory evaluation of various cold therapy modalities. *Am J Sports Med.* 1978;6:291-294.
39. Mancuso D, Knight K. Effects of prior physical activity on skin surface temperature response of the ankle during and after a 30-minute ice pack application. *J Athl Train.* 1992;27:242-249.
40. Merrick M, Jutte L, Smith M. Cold modalities with different thermodynamic properties produce different surface and intramuscular temperatures. *J Athl Train.* 2003;38:28-33.
41. Zemke J, Andersen J, Guion W, Millan J, Joyner A. Intramuscular temperature responses in the human leg to two forms of cryotherapy: Ice massage and ice bag. *J Orthop Sports Phys Ther.* 1998;27:301-307.
42. Myrer J, Measom G, Fellingham G, Evers S. Muscle temperature is affected by overlying adipose when cryotherapy is administered. *J Athl Train.* 2001;36:32-36.
43. Enwemeka C, Allen C, Avila P, Bina J, Konrade J, Munn S. Soft tissue thermodynamics before, during, and after cold pack therapy. *Med Sci Sports Exerc.* 2001;34:45-50.
44. LaVelle B, Snyder M. Differential conduction of cold through barriers. *J Adv Nurs.* 1985;10:55-61.
45. Tsang K, Barton B, Guion W, Joyner A, Browder K. The effects of cryotherapy applied through various barriers. *J Sport Rehab.* 1997;6:343-354.
46. Urban C. *Insulating Effects of Elastic Wraps Used During the Application of Ice, Compression, and Elevation to the Lateral Aspect of the Ankle.* 1980, Indiana State University: Terre Haute, IN.
47. Metzman L, Gamble J, Rinsky L. Effectiveness of ice packs in reducing skin temperature under casts. *Clin Orthop.* 1996;330:217-221.
48. Martin S, Spindler K, Tarter J, Detwiler K, Petersen H. Cryotherapy: An effective modality for decreasing intraarticular temperature after knee arthroscopy. *Am J Sports Med.* 2001;29:288-291.
49. Sapega A, Sokolow D, Graham T. The bioenergetics of preservation of limbs before replantation: the rationale for immediate hypothermia. *J Bone Joint Surg.* 1988;70:1500-1513.
50. Myrer J, Measom G, Fellingham G. Exercise after cryotherapy greatly enhances intramuscular rewarming. *J Athl Train.* 2000;35:412-416.
51. Wirth V, VanLunen B, Mistry D, Saliba E, McCue F. Temperature changes in deep muscles of humans during upper and lower extremity exercise. *J Athl Train.* 1998;33:211-215.
52. MacAuley D. Do textbooks agree on their advice on ice? *Clin J Sport Med.* 2001;11:67-72.
53. Barcroft H, Edholm O. The effect of temperature on blood flow and deep temperature in the human forearm. *J Physiol.* 1943;102:5-20.
54. Meeusen R, Lievens P. The use of cryotherapy in sports injuries. *Sports Med.* 1986;3:398-414.

55. Sallis R, Chassay C. Recognizing and treating common cold-induced injury in outdoor sports. *Med Sci Sports Exerc.* 1999;31:1367-1373.
56. Snowise M, Dexter W. Cold, Wind, and Sun Exposure: Managing--and Preventing--Skin Damage. *Phys Sports Med.* 2004;32:26-32.
57. Day M. Hypersensitive response to ice massage: Report of a case. *Phys Ther.* 1974;592.
58. Horton B, Brown G, Roth G. Hypersensitiveness to cold with local and system manifestation of a histamine-like character: Its amenability to treatment. *JAMA.* 1936:1263.
59. Palmer J, Knight K. Ankle and thigh skin surface temperature changes with repeated ice pack application. *J Athl Train.* 1996;31:319-323.
60. Myrer J, Measom G, Fellingham G. Temperature changes in the human leg during and after two methods of cryotherapy. *J Athl Train.* 1998;33:25-29.
61. Martini FH, *Fundamentals of Anatomy & Physiology.* 4 ed. 1998, Upper Saddle River, NJ: Prentice Hall.
62. Drez Jr. D, Faust D, Evans J. Cryotherapy and nerve palsy. *Am J Sports Med.* 1981;9:256-257.
63. Sabri S, Roberts V, Cotton L. Effects of externally applied pressure on the haemodynamics of the lower limb. *Br Med J.* 1971;3:503-508.
64. Wilkerson G, Horn-Kingery H. Treatment of the inversion ankle sprain: comparison of different modes of compression and cryotherapy. *J Orthop Sports Phys Ther.* 1993:240-246.
65. Barlas D, Homan C, Thode H. In vivo tissue temperature comparison of cryotherapy with and without external compression. *Ann Emerg Med.* 1996;28:436-439.
66. Wilkerson G. Management of the acute inflammatory response following joint trauma. *Sports Med Update.* 1992;7:12-15,28.
67. Duffley H, Knight K. Ankle compression variability using the elastic wrap, elastic wrap with a horseshoe, edema II boot, and airstirrup brace. *Athl Train.* 1989;24:320-323.
68. Ashton H. The effect of increased tissue pressure on blood flow. *Clin Orthop Rel Resch.* 1975:15-26.
69. Sloan J, Giddings P, Hain R. Effects of cold and compression on edema. *Phys Sports Med.* 1988;8:116.
70. Varpalotai M, Knight K. Pressure exerted by elastic wraps applied by beginning and advanced student athletic trainers to the ankle and the thigh with and without an ice pack. *J Athl Train.* 1991;26:246-250.
71. Waylonis G. The Physiologic Effect of Ice Massage. *Arch Phys Med Rehabil.* 1967;48:37-42.
72. Moore R, Nicolette R, Behnke R. The therapeutic use of cold (cryotherapy) in the care of athletic injuries. *J Natl Athl Train.* 1967;2:6-13.
73. Johnson D, Moore S, Moore J, Oliver R. Effect of cold submersion on intramuscular temperature of the gastrocnemius muscle. *Phys Ther.* 1979;59:1238-1242.
74. Konrath G, Lock T, Goitz H, Scheidler J. The use of cold therapy after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1996;24:629-633.

75. Warren T, McCarty E, Richardson A, Michener T, Spindler K. Intra-articular knee temperature changes. *Am J Sports Med.* 2004;32:441-445.
76. Whitelaw G, DeMuth K, Demos H, Schepsis A, Jacques E. The use of the cryo/cuff versus ice and elastic wrap in the postoperative care of knee arthroscopy patients. *Am J Knee Surg.* 1995;8:28-31.
77. Ohkoshi Y, Ohkoshi M, Nagasaki S, Ono A, Hashimoto T, Yamane S. The effect of cryotherapy on intraarticular temperature and postoperative care after anterior cruciate ligament reconstruction. *Am J Sports Med.* 1999;27:357-362.
78. Fincher L, Woods G, O'Connor D. Intraoperative arthroscopic cold irrigation solution does not affect postoperative pain and swelling. *J Athl Train.* 2004;39:12-16.
79. Wakim K, Porter A, Krusen F. Influence of physical agents and of certain drugs on intra-articular temperature. *Arch Phys Med.* 1951:714-721.
80. Dahlstedt L. Cryotherapy after cruciate knee surgery: skin, subcutaneous and articular temperatures in 8 patients. *Acta Medica Scand.* 1996;67:255-257.
81. Holcomb W, Joyce C. A comparison of temperature increases produced by 2 commonly used ultrasound units. *J Athl Train.* 2003;38:24-27.
82. Draper D, Schulthies S, Sorvisto P, Hautala A. Temperature changes in deep muscles of humans during ice and ultrasound therapies: an in vivo study. *J Orthop Sports Phys Ther.* 1995;21:153-157.
83. Lowdon B, Moore R. Determinants and nature of intramuscular temperature changes during cold therapy. *Am J Phys Med.* 1975;54:223-233.
84. Clarke R, Hellon R, Lind A. Vascular reactions of the human forearm to cold. *Clin Sci.* 1958;17:165-179.
85. Heyward V, Stolarczyk L, *Applied body composition assessment.* 2nd ed. 1996, Champaign, IL: Human Kinetics.
86. Myrer J, Draper D, Durrant E. Contrast therapy and intramuscular temperature in the human leg. *J Athl Train.* 1994;29:318-322.
87. Post J, *Ankle skin temperature change with a repeated ice pack application.* 1990, Indiana State University: Terre Haute, IN.
88. Mylnarczk J, *Temperature Changes in the Ankle During and After Ice Pack Application of 10, 20, 30, 45, and 60 minutes.* 1985, Indiana State University: Terre Haute, IN.



## VITA

Graduate College  
University of Nevada, Las Vegas

David Tomchuk

### Local Address:

3225 South Pecos Road #408  
Las Vegas, NV 89121

### Home Address

12530 33<sup>rd</sup> Street SW  
Belfield, ND 58622-9721

### Degrees:

Bachelor of Science, Health/PE-Athletic Training, 2002  
Southern Oregon University

Bachelor of Science, Health/PE-Health Promotion and Fitness Management, 2002  
Southern Oregon University

Masters of Science, Kinesiology-Emphasis in Athletic Training, 2005  
University of Nevada, Las Vegas

Dissertation/Thesis Title: Tissue Cooling During Cryotherapy With Varied Types of  
Compression

### Dissertation/Thesis Examination Committee:

Chairperson, Dr. Mack D. Rubley, Ph. D., ATC, CSCS  
Committee Member, Dr. William R. Holcomb, Ph. D., ATC, CSCS\*D  
Committee Member, Dr. Mark Guadagnoli, Ph. D.  
Graduate Faculty Representative, Mr. Peter Altenburger, MSPT