The Effects Of Ice And Compression Wraps On Intramuscular Temperatures At Various Depths

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Abstract: *While ice and compression wraps are commonly used to treat musculoskeletal injuries, the literature describing intramuscular temperatures has not addressed the combination of ice and compression wraps. The purpose of this study was to evaluate intramuscular temperatures at three sites on the anterior thigh (skin surface, 1 cm below the fat layer, and 2 cm below the fat layer) using both ice and compression wraps. Temperatures were recorded in 11 subjects with an isothermex, using implantable and surface thermocouples. Each subject was tested under four conditions: control, compression only, ice only, and ice + compression according to a balanced Latin square. Surface and intramuscular temperatures were recorded at 30 second intervals during 5 minutes of preapplication, 30 minutes application, and 20 minutes postapplication. A repeated measures ANOVA and Duncan post hoc tests were used to evaluate peak temperature differences between the treatment conditions and the depths of measurement. Both ice alone and ice + compression produced significant cooling at all three depths ($F(6,60) = 168.5$, $p<.0005$). Likewise, during the 20-minute postapplication period, these temperatures did not return to their preapplication levels. The compression-only condition produced significant warming at the skin surface, but did not have any effect on intramuscular temperature. At all depths, the ice + compression condition produced significantly cooler temperatures than ice alone. We suggest that compression increases the effectiveness of ice in reducing tissue temperatures. Therefore, ice combined with compression should be more effective than ice alone in reducing the metabolism of injured tissue. This provides an additional rationale for combining ice with compression in treating acute musculoskeletal injuries.*

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Cryotherapy, the use of ice or cold in a therapeutic setting, has become one of the most common treatments in sports medicine. The mechanisms responsible for the physiological response and factors which influence treatment responses, however, are poorly understood or not understood at all.[21] Understanding cold physiology is vital for proper use of this modality.

The primary reason for using cryotherapy in acute injury management is to lower the temperature of the injured tissue which reduces the tissue's metabolic rate[12,19,21,27] and helps the tissue to survive the period of hypoxia following the injury.[14,21] It is well documented that metabolic rate decreases as tissue becomes hypothermic.[5,12,21,27] Most studies on metabolic reduction through cold application have been performed on amputated, stored limbs[19,27,35] or organs.[5,9,12] In these studies, tissue temperatures for the stored limbs and organs were in the range of 1°C to 15°C, with 5°C to 10°C being optimal.[9,12,21,27] In typical clinical cryotherapy, however, the tissues have not been removed from the body, and tissue temperatures range from 15°C to 35°C, depending upon the measurement site and depth and the duration and type of cold used.[10,11,16,26,31,32] These tissue temperatures are greater than those normally measured in tissue preservation protocols.[2,3,10,16,20,31]

Compression is often used in conjunction with cryotherapy for the care of acute injuries.[13,14,17,23] To date, the primary reason for using compression is to increase external pressure on the tissue to prevent edema formation.[13-15,23,34] This occurs by hindering fluid loss from the vessels in the injured area, making it more difficult for fluids to accumulate.[7,15,34]

Little is known about the effects of compression on intramuscular temperature or metabolic suppression. There is some evidence that elastic wraps provide an insulating effect when applied between the skin and a cold application.[29,34] This insulating effect results in a lesser degree of cooling at the skin surface than does ice alone. However, there are no data describing the effects of compression in conjunction with cryotherapy on intratissue temperatures. Therefore, we do not know whether compression affects tissue cooling. This study examined tissue cooling at several depths with both cryotherapy and compression.

Methodology

The effects of four treatment conditions were examined: ice alone, compression alone, ice + compression, and control (no treatment). Subjects underwent all four of the conditions with a minimum of 1 day between treatments. The specific order of treatments for each subject was determined using a 4 X 4 Latin square.

The subjects for this study were 11 volunteers from the student body at Indiana State University (age = 23.5±2.1 yr, ht = 175.3±10.3 cm, wt= 40.4±14.0 kg, anterior thigh skinfold = 15.8±3.7 mm). Prior to participating, subjects completed health status questionnaires and informed consent statements. Approval for this study was obtained from the University Institutional Review Board.

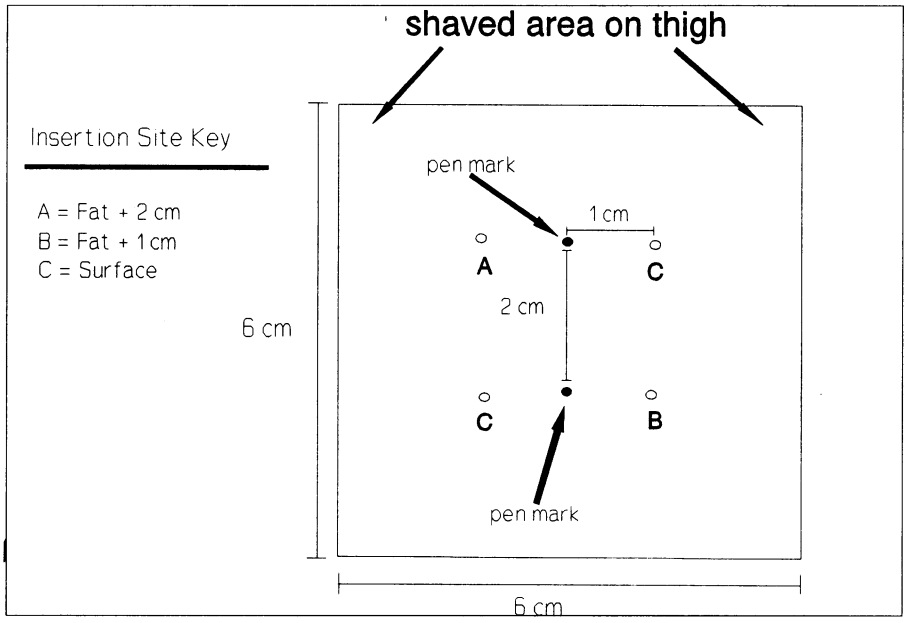

Fig 1.—Thermocouple placement.

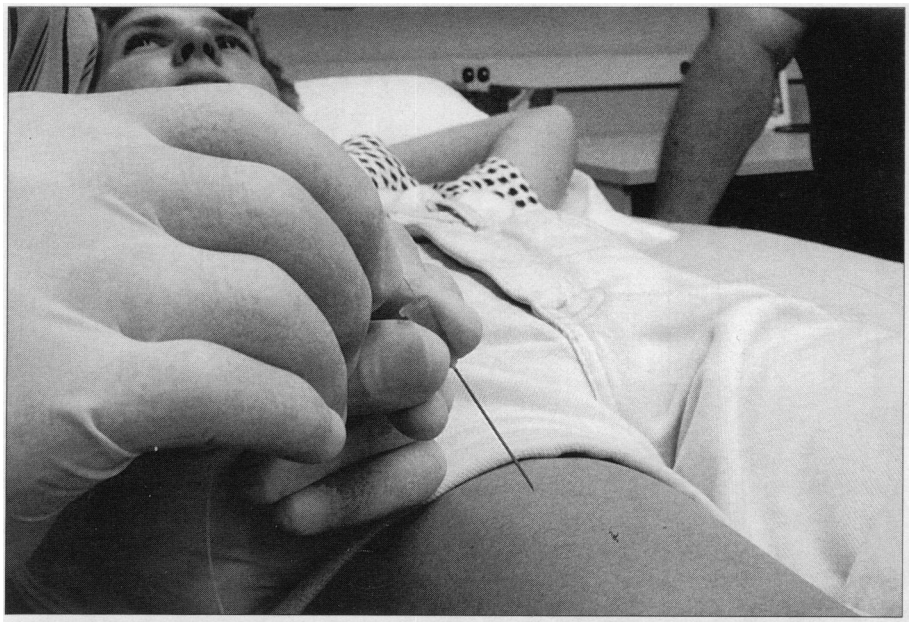

Fig 2.—Inserting needle electrode into thigh of a subject.

Skin, tissue, and air temperature measurements were made, using thermocouples interfaced with an electronic thermometer (Columbus Instruments, Iso-Thermex 16-channel). Two models of type T thermocouples were used, one for skin and air temperature measurement (Model TX-31, Columbus Instruments, Columbus, Ohio) and one for intratissue temperature measurement (diameter = 0.41 mm) (Columbus Instruments, Model TX-23-21).

Subjects assumed a supine position on a standard treatment table. The hair was clipped from a 6-cm X 6-cm area located on the anterior thigh halfway between the patella and the anterior superior iliac spine. This area was cleaned with a povidone-iodine surgical scrub solution for 30 seconds and was marked at 2-cm intervals with a felt-tip pen.(Fig. 1) Thermocouples were placed 1 cm medial and lateral to the pen marks, with an implantable or a surface thermocouple at each site (Fig 2).

Two tissue implantable thermocouples and two surface thermocouples were used. The implantable thermocouples were inserted perpendicular to the skin using sterile 21-gauge hypodermic needles. The needles were then removed. Because the subjects had differing amounts of subcutaneous fat, insertion depth was based upon skinfold measurements for each subject. This allowed the thermocouples to be placed at uniform depths into the muscle tissue. Skinfold measurements were made using skinfold calipers (Lafayette Instruments Co, Lafayette, Ind) as described by Michael and Katch.[22] The two depths of measurement (one implanted thermocouple each) were calculated as follows:

$$\text{shallow} = \frac{\text{skinfold}}{2} + 1\text{cm}$$

$$\text{deep} = \frac{\text{skinfold}}{2} + 2\text{cm}$$

Insertion depths were controlled by means of marks made 6 cm from the tips on the leads of the implantable thermocouples. By measuring the distance from the skin surface to these marks, probe depths could be accurately controlled. Dermiclear tape (2.54 cm X 3.75 cm) was placed over the ball tips of the surface electrodes to secure them to

the subjects' legs. Dermiclear tape was also used over the thermocouple insertion sites to secure them.

Once the thermocouples were in place, temperature was measured every 30 seconds. Testing sessions were divided into three subsections: a 5-minute preapplication, a 30-minute application, and a 20-minute post- application. In order to allow their temperatures to stabilize, subjects rested supine on the table for 15 minutes prior to the preapplication period. They received no treatment at this time. No treatments were applied during the 5-minute preapplication period. During the application period, subjects received one of four treatments for 30 minutes. During the 20-minute postapplication period, subjects received no treatments. The total time for each session was 55 minutes.

The four treatment conditions were: control, ice only, compression only, and ice + compression. No treatments were applied during control. The ice treatment consisted of a crushed ice pack (1 kg of ice in a 10 L plastic bag with the air evacuated) placed directly on the treatment area for 30 minutes. The compression treatment consisted of a 1.34-m X 15-cm elastic wrap (Depuy, Warsaw, Ind) placed around the treated limb for 30 minutes. The ice + compression treatment consisted of wrapping a 1 kg ice pack to the treatment area with a 15-cm-wide elastic wrap.

To ensure consistency between the two treatment conditions involving compression, a manometer (AirCast Inc, Summit, NJ) was used to quantify the compression. The bladder of the manometer was placed at the center of the distal margin of the clipped area. The compression wraps were adjusted until typical compression, established at a pressure between 42 and 48 mm Hg,[31] was applied.

At the conclusion of the postapplication period, the thermocouples were removed, and the insertion wounds were cleaned with a povidone-iodine solution and bandaged with adhesive bandage spots. After removal, the thermocouples were disinfected using Cidex (Surgikos Inc, Arlington, Tex) 2% glutaraldehyde solution.[8] The hypodermic needles were disposed of in a sharps biomedical waste container.

Treatment effect was defined as the greatest difference between mean treatment temperature and mean preapplication temperature for each measurement depth and condition. Then, the greatest treatment effects were used for analysis. A 3 X 4 X 4 repeated measures ANOVA was performed to determine differences between measurement depths, treatments, and ordinal position. Duncan post-hoc analyses were used to identify the sources of the differences observed in the ANOVA.

Results

Greatest treatment effect temperatures and times are found in Tables 1 and 2. There was no significant treatment effect for the control condition. For the compression-only condition, the only significant treatment effect was an increase in skin temperature of 1.88°C ($F(6,60)=168.5$, $p<.0005$; Duncan post-hoc analysis $p<.05$). For both the ice alone and the ice with compression conditions, significant treatment effects were decreases in temperature at all measurement depths. The ordinal position of treatment condition did not have a significant effect ($F(9,7)=0.59$, $p=.78$) on temperature.

At the skin surface, temperature decreased immediately and rapidly with the application of either ice or ice with compression (Fig 3). Skin temperature increased quickly and immediately when the source of cold was removed.

Both ice and ice + compression were significantly colder than control or compression alone ($F(6,60)=168.5$, $p<.0005$; Duncan post-hoc analysis $p<.05$). Likewise, ice with compression was significantly colder than ice alone. The compression-only treatment led to a significant increase in skin temperature which returned to normal roughly 10 minutes after the compression was removed. No change in skin temperature occurred with the control treatment.

At 1 cm into the muscle, temperature changes were less pronounced than at the skin surface (Fig 4). Both ice alone and ice with compression resulted in significant temperature decreases ($F(6,60)=168.5$, $p=.0005$; Duncan post-hoc analysis $p<.05$). Temperatures at this depth continued to decrease for approximately 5 minutes after the ice was removed (Table 2). As was true for the

Table 1.— Average Temperatures at the Time of the Greatest Treatment Effect (°C±SD)

	Depth of Measurement		
Treatment	**Skin Surface**	**Fat + 1 cm**	**Fat + 2 cm**
Preapplication	32.50±1.15	36.28±0.74	36.59±0.71
Control	32.79±0.87	36.13±0.62	36.38±0.52
Compression Only	34.38±0.66	36.25±0.51	36.47±0.47
Ice Only	7.24±1.19	26.58±3.66	28.21±2.34
Ice + Compression	4.94±0.68	23.54±3.33	26.46±3.04

Table 2.— Time at Which Greatest Treatment Effect Occurred (min from the beginning of application phase ±SD)

	Depth of Measurement		
Treatment	**Surface**	**Fat + 1 cm**	**Fat + 2 cm**
Control	30.41±2.2	30.32±1.95	30.32±1.95
Compression Only	29.32±1.49	30.73±6.40	31.41±6.38
Ice only	29.73±1.34	35.95±3.75	39.23±5.09
Ice + Compression	30.82±1.25	32.86±1.93	35.32±4.72

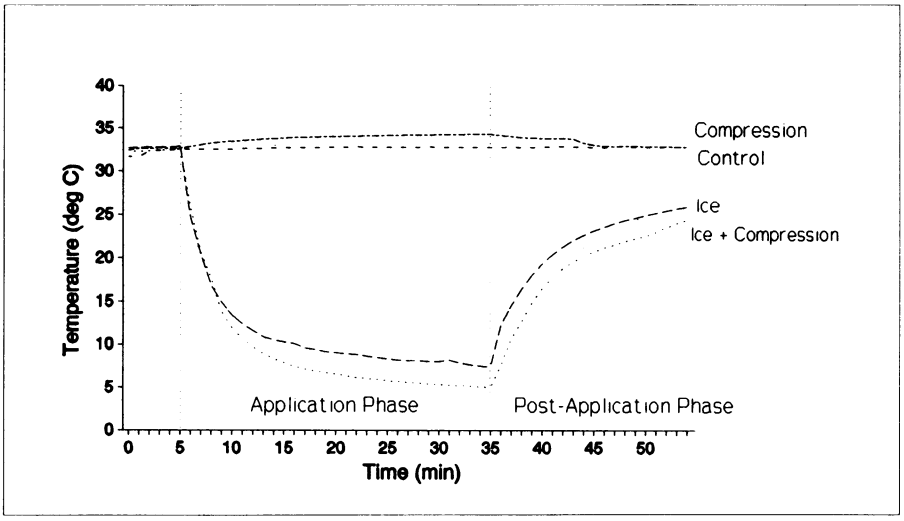

Fig 3.—Skin surface temperatures vs time.

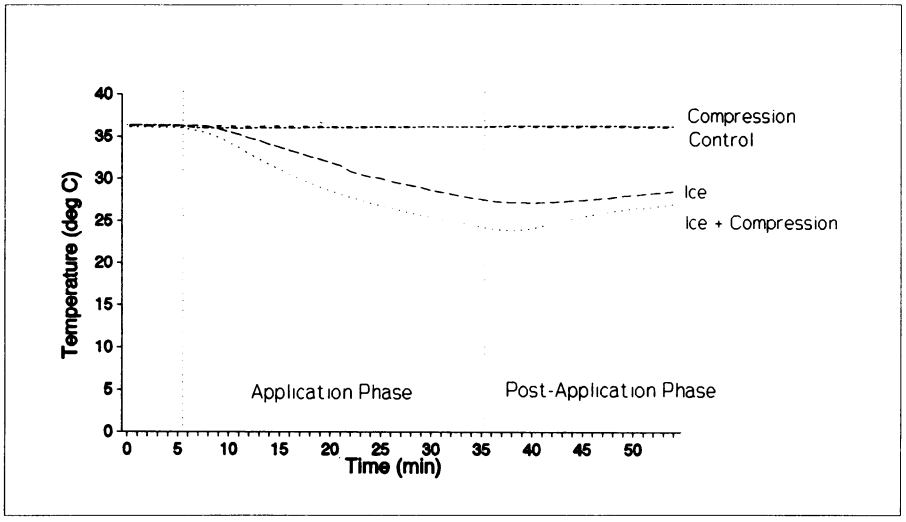

Fig 4.—Intramuscular temperatures (fat + 1 cm) vs time.

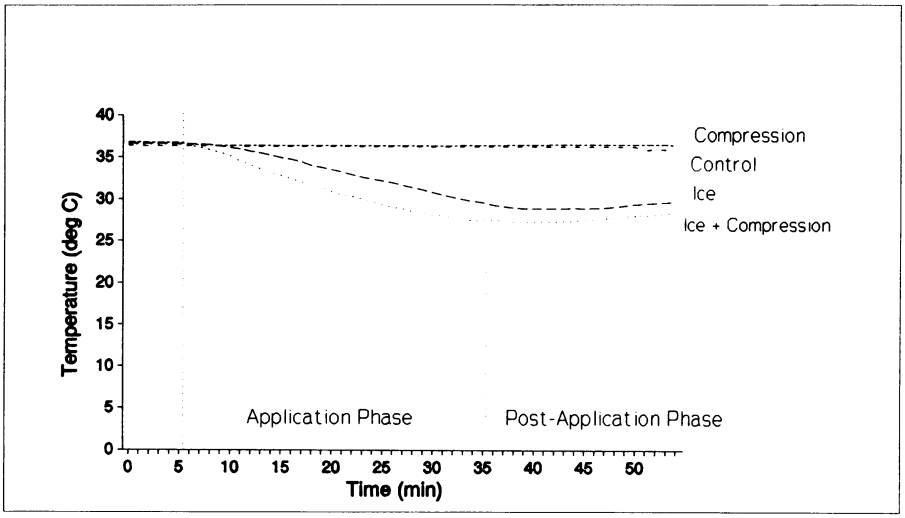

Fig 5.—Intramuscular temperatures (fat + 2 cm) vs time.

skin surface, ice with compression was significantly colder than ice alone. No changes occurred at the 1-cm depth during either the compression only or the control treatments(Table1).

At 2 cm into the muscle, temperature changes were even less pronounced than at 1 cm (Fig 5). Again, both ice and ice with compression resulted in significantly decreased temperatures ($F(6,60)=168.5$, $p=.0005$; Duncan post-hoc analysis $p<.05$). Temperatures continued to fall for roughly 7 minutes after the cold was removed, slightly longer than at 1 cm (Table 2). Ice with compression was again colder than ice alone. Neither compression nor control resulted in any temperature changes at 2 cm into the muscle.

During all of the treatment conditions, skin temperature was significantly cooler than either of the deep temperatures ($F(6,60)=168.5$, $p=.0005$; Duncan post-hoc analysis $p<.05$). During both the ice and the ice with compression treatments, the temperature at 1 cm into the muscle was significantly colder than the temperature at 2 cm into the muscle. These two depths were not different during control or compression alone.

Discussion

One of the primary purposes of this study was to examine the differences between ice alone and ice with compression. Ice with compression was significantly colder than ice alone at all three measurement depths. This can likely be explained by examining the effects that compression has upon the tissue.

First, compression may cause an improved contact between the skin and the ice bag. Normally, when an ice bag is placed on the skin, the interface temperature can be varied, depending on whether the temperature sensor is against an ice cube or against an air pocket in the bag.[14,18,24] Compression may cause more of the ice to be in closer contact with the skin, resulting in improved cooling.

Second, compression greater than 30- to 40-mm Hg reduces blood flow.[1,28] By reducing blood flow, the inflow of heat from other parts of the body is also

reduced. Although blood flow is decreased, no deep temperature changes occurred with compression alone. Therefore, reduced blood flow alone does not cool tissue significantly. However, combining reduced blood flow with an external source of cold reduces the body's ability to warm the area being cooled. This would produce significantly colder tissue temperatures than ice alone.

Third, elastic wraps used for compression have been shown to provide an insulating effect.[30] Placing wraps around the ice pack reduces heat gain from the environment, leading to colder tissue temperatures.

Fourth, by compressing tissue, we may decrease the area occupied by that tissue. We are not, however, changing the tissue's mass. Therefore, we may actually increase the density of the compressed tissue. This increased tissue density may lead to greater conductive cooling. Further study is required to substantiate this.

Not only was the ice + compression treatment colder than the ice-only treatment, it also reached its lowest temperature faster (Table 2). This suggests that compression wraps also increase the rate of cooling. Such an increase would be valuable in the treatment of acute injuries where immediate cooling is desired. The temperature decreases recorded with both ice alone and ice + compression treatments are in agreement with others.[4,18,24,26,30] At the skin surface, both ice alone and ice + compression produced a rapid immediate temperature decline followed by a more gradual decline, as others have reported.[4,18,24,26,30]

Skin temperatures for the human thigh during cold applications have not been reported adequately in the literature. The data from this study indicate that lowest skin temperatures for human thighs and for sheep thighs are very similar during ice treatments (5°C).[33] The skin temperature data we recorded suggest that cold applications produce thigh skin temperatures similar to those reported at the ankle during ice treatments.[18,24,30] The skin temperature decreases following 30 minutes of ice application to the thigh (decrease of 25.3°C, ice only; 27.6°C, ice + compression) are greater than those reported at the ankle by Mancuso[18] (20.4°C) or Post[26] (23.1°C and 23.7°C), but are less than those reported by Mylnarczyk[24] (28.0°C) or Urban[30] (28.7°C).

With compression alone, skin temperature increased slightly (increase of 1.9°C), then returned to normal roughly 10 minutes after the compression was removed. It is likely that this temperature increase is related to the insulating

effect of the elastic wrap. Urban[30] reported that elastic compression wraps provide an insulating effect between the skin and cold packs, even when the wraps are wet or frozen. Apparently the wraps are capable of preventing some degree of heat loss by the skin.

There is a variety of literature reporting deep temperature changes. Lowden and Moore[16] suggested that intramuscular temperature change is dependent upon depth of measurement, duration of treatment, mode of cryotherapy, and thickness of adipose tissue. In the studies reporting intramuscular temperature change, many do not report measurement depth.[6,17,20,32] In the majority of studies reporting measurement depth, it is measured from the skin surface.[2,3,11,16,33,35] Because adipose thickness varies from subject to subject, measuring from the skin surface does not ensure that the probes are located at similar depths into muscle tissue. Therefore, a temperature reported at 3 cm, may actually represent a temperature at 1.5 cm into the muscle in one subject and at 2 cm into the muscle in another. In order to avoid this inconsistency, we used temperature measurements at uniform depths beyond the adipose layer as determined by a skinfold. This makes direct comparisons with other authors difficult.

At 1 cm into the muscle tissue, temperature decline with both ice and ice + compression was delayed by several minutes, as has been reported by most authors.[10,11,25,32,35] There have also been a few reports of initial temperature increases with cold application.[3,6]

The gradual nature and delayed onset of cooling is most likely explained by conductive cooling. The rate of thermal conduction is dependent upon several factors, including the temperature difference between the two surfaces, the surface area of the contact region, and the temperature of the material being cooled. The rate of thermal conduction in living tissue is such that it takes a few minutes for conductive cooling to reach muscle tissue. Likewise, the temperature difference between muscle tissue and adipose tissue is significantly less than the difference between the skin and an ice pack. This leads to a smaller decline in temperature within the muscle.

Temperature decreases at 1 cm into the muscle tissue (decrease of 9.7°C, ice; 12.7°C, ice + compression) were less than those reported by Lowden and Moore[16] (decrease of 17.9°C). These comparisons are somewhat crude because Lowden and Moore reported measurements 2 cm from the skin surface in the biceps. In studies using the thigh, McGowen[17] reported temperature decreases of 7°C at an unknown depth, and Hobbs[11] reported decreases of 2.3°C at 4 cm and 6 cm, and 2.8°C at 7 cm. The greater depth of Hobbs' measurement does not allow direct comparison.

At 2 cm, compression alone did not affect deep tissue temperature. The temperature decreases with cold applications (decrease of 8.4°C, ice; 10.1°C, ice + compression) are significantly less than the temperature decreases at 1 cm (decrease of 9.7°C, ice; 12.7°C, ice + compression). They are also less than that reported by Bing et al[3] (decrease of 12°C) at 3 cm from the skin surface. The decreases are greater than reported by Hartviksen[10] (decrease of 7°C), whose measurements (2.5 to 3.5 cm into the gastrocnemius) are slightly deeper. Again, no real comparison can be made to Hobbs,[11] who measured at greater depths than we did. In addition, Hobbs' protocol was different. Rather than using small thermocouples, "... a thermometer was inserted into the thigh of a living person at depths of 4 cm, 6 cm, and 7 cm from the skin surface." This would be likely to cause localized inflammation, skewing his results.

When the ice pack was removed, deep temperature continued to fall for 5 minutes at 1 cm and 7 minutes at 2 cm. Such decreases have been reported by others.[10,32,33] It is likely that these can be attributed to conductive cooling. As was the case when applying the ice, the rate of thermal conduction of the tissue is such that it takes several minutes for deep tissue to be significantly rewarmed. Neither deep temperature nor skin temperature returned to normal for either the ice alone or the ice + compression condition at the end of the 20-minute postapplication period. This agrees with the findings of others.[10,25,32,33] In fact, there is literature to suggest that, at rest, deep temperature will not return to normal for at least 6 hours.[25]

The thickness of the adipose tissue is a major point in determining the rate of temperature decrease, as well as the absolute temperature decrease.[16] The subjects in this study were not athletes. An athletic population would very likely have less adipose tissue, and therefore would experience greater cooling with either of the ice treatments.

Skin surface temperatures cooled and rewarmed at a much greater rate than intramuscular temperatures did. These differences bring into question the validity of using skin temperature as a dependent measure for evaluating the effectiveness of cryotherapy. This is an area requiring further study.

During the postapplication phase, no compression was applied. Based upon compression's effect when combined with ice, postapplication compression may result in slowed rewarming. This too is an area deserving further study.

We commonly combine ice and compression when treating acute injuries because it lowers the tissue temperature, reducing local metabolism, which in turn reduces the amount of secondary hypoxic injury in the area. We use compression to reduce the accumulation of fluids in the injured tissue, thereby reducing the length of time needed for reabsorption of that fluid. Previously, ice was combined with compression in order to get the combination of these effects. We now know that combining ice with compression not only provides the combination of these effects, but also increases the effectiveness of the ice in reducing tissue temperatures. We are then providing a greater reduction in local metabolism and therefore a potentially greater reduction in secondary hypoxic injury, possibly allowing the athlete to recover sooner.

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