Cryotherapy is used in the treatment of various musculoskeletal and neurological disorders. Both physiological and clinical evidence suggest that cold application in various forms can be valuable in reducing musculoskeletal pain, muscle spasm, connective tissue distensibility, nerve conduction velocity, hemorrhage, edema, inflammation, and intramuscular temperature. Evidence also exists that cold can be used as an aid to neuromuscular facilitation. Despite the widespread use of cryotherapy, a lack of quantitative data exists for determining the exact specificity for its use. For example, the most effective mode of a cold application, the length of time needed to cool an area, the amount of time that an area remains cool after the removal of the cold application, and the amount of cooling that occurs beyond the area in contact with the cooling agent have not been addressed fully.

Several studies have been conducted relating cold applications to the skin to decreased subcutaneous and intramuscular temperatures. Investigators have demonstrated that the temperature of the skin is related to the temperature of the tissue underlying it; that is, the more the skin is cooled in absolute degrees, the greater the cooling of the underlying tissues.

A few individuals have evaluated the effectiveness of different cooling agents on deep and superficial tissues. McMaster et al evaluated four different modes of cooling: ice chips in a plastic bag, chemical ice envelopes, refrigerant-inflated bladders, and prefrozen gel packs. In their study, two dogs were anesthetized, their thighs were shaved, and their temperatures were recorded using a hypodermic thermistor probe inserted beneath the skin into the deep quadriceps muscle mass immediately adjacent to the femoral shaft. Readings were taken at 15-minute intervals for one hour. They found that chipped ice was the most efficient mode of cooling, followed by a slightly less efficient gel pack. The other two cooling mediums were the least efficient in cooling the deep tissues.

McKeeken et al compared the efficiency of two cold modalities—ice and cryogen packs—by measuring their respective effects on skin temperature directly beneath the cooling agent and on nerve conduction velocity of the underlying motor nerve fibers. After 20 minutes of cooling the upper arm, they found that ice was more effective than cold packs in cooling superficial and possibly deep tissues beneath the cooling agent. LaVelle and Snyder evaluated the cooling of the skin using chipped ice in a plastic bag applied directly to the skin and through various barriers, including padded and unpadded elastic bandages and dry and damp washcloths. They found that skin temperature was reduced significantly when ice was applied over a dry washcloth, a damp washcloth, and an unpadded elastic bandage and when applied directly to the skin; however, cold was not conducted through a padded elastic bandage. No significant differences in cooling, however, were found between the use of a damp washcloth and direct application to the skin. Although these articles provide the cli-
For musculoskeletal disorders, three cold modalities commonly used interchangeably in clinical practice are wet ice (WI), dry ice (DI), and cryogen packs (CGPs). Clinical application time generally is between 10 and 45 minutes, although the average application time is 15 minutes. No studies have used this clinical time frame to assess the effectiveness of these three modalities for reducing skin temperature in contact with the cooling agent, maintaining the temperature reduction, or cooling the skin surface beyond contact with the cooling agent. These factors are important for determining the effectiveness of the treatments and will provide a basis for determining more precise specifications for using the three methods.

The purposes of this study were to quantify and compare the ability of WI, DI, and CGPs to reduce skin temperature and to determine the magnitude of the warming that occurred after removal of the cooling agent. We also wanted to determine the effectiveness of each agent in cooling the skin surface area beyond contact with the cooling agent. We anticipated that skin temperatures would decrease directly beneath the cooling agent and that cooling would occur beyond the area of skin surface in contact with the agent. We also expected that rapid warming of the skin would not occur after removal of the cooling agent because therapeutic techniques such as joint mobilization and muscle stretching often are tolerated subsequent to cryotherapy. Because clinicians use ice and CGPs interchangeably, we have attempted to determine their comparability.

METHOD

Subjects

Ten healthy female volunteers participated in the study. Their mean age, body mass, and height were 23.3 ± 2.2 years, 58.6 ± 4.6 kg, and 165.9 ± 4.1 cm. Subjects were screened and excluded from the study if they had open leg sores, cardiovascular or peripheral vascular disease, known muscular or neurological pathological conditions, or a history of smoking. Each volunteer was informed of the procedure of the study and the risks involved, and informed consent was obtained before participation in the study.

Various precautions were taken to prevent hypothermia, frostbite, or ice burn. These precautions were excluding fair-skinned subjects from the study; covering the subject’s body, except for the lower limb being tested, with a blanket; monitoring the subject’s skin temperature at 5-minute intervals proximal and distal to the site of cold application; asking the subject to report any discomfort; and limiting the length of application to 15 minutes.

Fifteen minutes was chosen for this study because this time period commonly is used clinically and because observations have shown that minimal patient discomfort within this time frame has resulted in high patient compliance.

Equipment and Materials

Skin and air temperature were recorded to the nearest 0.1°C using a Yellow Springs Model 44TD telethermometer similar to that reported in the literature. A Yellow Springs Model T2630 proximal skin temperature probe was held in place by a 0.3-kg waterproof sandbag. The distal and central measurements were taken with a Yellow Springs Model T2625 “banjo” probe that also was held in place with a 0.3-kg sandbag. The probes used were calibrated in a water bath over the range of evaluation and checked against a laboratory mercury thermometer. The WI consisted of ice flakes, and the DI consisted of ice flakes enclosed in a plastic bag. We used a commercially available CGP. Each modality was wrapped in a wet, uniformly sized terry-cloth towel that had been dampened with cool water. Excess water was wrung out of the towels before wrapping. The surface area of each pack was 10 × 24 cm, total weight was 0.5 kg, and the starting temperature on the surface of the cold medium was between 0° and 2°C. The flaked ice was produced by a Scotsman ice machine, and the CGP was frozen for two hours before use, as recommended by the manufacturers.

Procedure

Each subject participated in three, 45-minute sessions that were conducted at least 6 hours apart. The three treatments were assigned randomly at each of these sessions. Each session consisted of 15 minutes rest, 15 minutes of cold application, and 15 minutes without treatment (corresponding to times 0, 15, and 30, respectively).

The subjects were instructed to refrain from heavy exercise and ingesting caffeine for two hours before each session. They were requested to wear shorts and long-sleeved shirts and to remove their shoes and socks during the testing session. Testing was conducted in a thermostatically controlled room in which the temperature ranged from 22° to 24°C. The subjects lay in the prone position on a plinth with one pillow under their tested lower leg, one under their stomach, and one under their head throughout the experiment. Subjects were requested to relax and limit the movement of their legs to prevent unnecessary muscle activity that could cause temperature changes.

Rest period. During the rest period, we tested the subjects for hot and cold sensation by touching the leg to be tested with one test tube filled with hot tap water and with another filled with cold tap water. Sensation was considered intact if the subject could discriminate between the hot and cold tubes. A point on the belly of the gastrocnemius muscle one quarter of the distance between the popliteal crease and the medial malleolus was marked with an indelible ink marker. Two other points were marked 8 cm proximal and distal to this point. A resting skin temperature was recorded at each of the three points. Air temperature also was recorded.

Cold application. One of the three modalities described above was selected randomly and applied over the central point on the gastrocnemius muscle with its length perpendicular to the axis of the three points. Proximal- and distal-point skin temperatures were recorded at 5-minute intervals during the 15 minutes of cold application. The cooling agent then was removed, and the central skin and air temperatures were recorded.

Recovery. Fifteen minutes after removal of the cooling agent, central, proximal, and distal skin temperatures and air temperatures were recorded.

Data Analysis

A 3 × 3 analysis of variance (ANOVA) for repeated measures was used...
to statistically analyze the data, using a level of significance of .05. The Bonferroni post hoc test was used to determine the differences between all possible pairs of means with significant probability values.16

RESULTS

Central Skin Temperature Measurement

Before the application of the cooling agent, the mean central starting temperatures on the skin were between 29.5° and 30.0°C. After 15 minutes of cold application, the skin temperatures decreased to 17.9°, 20.1°, and 22.1°C for WI, DI, and CGP, respectively. Fifteen minutes after removal of the cold modality, mean skin temperatures were between 27.0° and 28.2°C for all conditions (Fig. 1).

The ANOVA results shown in Table 1 illustrate significant differences (p < .05) for time, treatment, and time-treatment interaction. The post hoc analysis showed no significant differences between WI, DI, and CGP at time 0. After 15 minutes of cold application, the post hoc analysis revealed significant differences between the means of WI and DI and those of WI and CGP, with WI demonstrating the greatest mean decrease in skin temperature. The difference between DI and CGP, however, was not significant.

Fifteen minutes after the removal of the cold modality, we found no significant differences between the three treatments. All pair-wise means over time were significantly different for the WI treatment. For DI and CGP, the mean skin temperatures at time 15 differed significantly from those at time 0 and time 30, but no significant differences were found between them at time 0 and time 30.

Proximal and Distal Skin Temperature Measurements

No significant differences were found between distal mean skin temperatures, before, during, and after cold application for the three treatments (Fig. 2, Tab. 2). For the proximal mean skin temperature, we found no significant differences between treatments at different time intervals or for time-treatment interactions, although the ANOVA did reveal a significant time effect (p < .05) (Fig. 3, Tab. 3). The post hoc analysis revealed a significant pair-wise difference for WI between time 0 and time 15 that was the result of warming.

DISCUSSION

Results of this study provide support for previous related work and information that should prove valuable for therapists using cold therapy in the clinical setting. The data revealed that WI was significantly more efficient in reducing skin temperature than DI and CGP. These results are consistent with those of McKeeken et al,13 who measured superficial cooling in the upper arm in humans, and with those of McMaster et al,10 who measured cooling deep in the quadriceps femoris muscles of dogs.

The skin temperature decreases recorded in this study warrant further elaboration with respect to some basic research and clinical practicalities. Some studies have shown that skin temperatures less than 16°C are necessary for anesthesia,2,6 analgesia,7 and relaxation sufficient to permit active and passive exercising of painful areas immediately after treatment.6 None of the three cold modalities used in our experiment produced skin temperature cooling below 17°C. Further studies should investigate whether cooling times longer than 15 minutes, using the cold modalities in this study, could produce temperature decreases required for anesthesia or analgesia.

In clinical practice, CGPs are reusable and can be applied quickly and easily, DI is the most time-consuming to prepare, and WI is the least desirable modality because of melting and dripping. After 15 minutes of cold application, WI yielded the skin temperature decreases closest to those necessary for anesthesia and analgesia. Unfortunately, although CGPs are the most convenient medium to use, they are the least efficient in skin cooling and in our
Table 2

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The lack of spread of skin surface cooling may be due to the excellent insulating property of the skin and subcutaneous tissue and the body's homeostatic mechanism. The application of cold to the skin initiates complex physiological reactions aimed at conserving heat in the body's core. These reactions are brought about by peripheral venous constriction, decreased peripheral blood flow, and increased venous pressure. To investigate the proximal and distal spread of cold temperatures in deeper tissues, further investigations using invasive techniques are necessary.

Fifteen minutes after the removal of the cold modality, rewarming occurred. Waylonis, Lewis and Clayfield, and McKeeken et al demonstrated similar trends in rewarming of the skin. In our study, only WI demonstrated a significant temperature difference between time 0 and time 30. These findings are consistent with those of McKeeken et al., who demonstrated that posttreatment skin temperatures remained the coldest when ice was used. They also showed that greater changes in conduction velocity of nerve fibers were produced by ice packs, as compared with commercially produced CGPs.

These results suggest that therapeutic exercises and mobilization techniques should be started during or as soon as possible after cryotherapy because of the rapid rewarming demonstrated in this study. Because WI provides the greatest amount of cooling immediately after treatment and because the treated tissues remain slightly cooler after cold removal, we considered WI to be the best modality of those tested to use for therapeutic cooling.

**CONCLUSION**

Although not as convenient as DI and CGPs, WI resulted in skin temperature decreases closest to those necessary for anesthesia, analgesia, and relaxation sufficient to permit active and passive exercising of painful areas. Cooling did not extend beyond the surface area in contact with the cold modality. Two important considerations regarding the use of cryotherapy, therefore, are the placement and the size of the cold modality. Because of the rapid rewarming that occurred after removal of the cold modality, therapeutic exercise and mobilization techniques should be implemented during or as soon as possible after the removal of the cold modality. Although WI provided the only significant difference between time 0 and time 30, skin temperatures for all three cooling agents at time 30 were higher than those required for an anesthetic or analgesic effect.

This study provides valuable information for the use of cold modalities. It is evident from this work that research should be directed toward developing more precise specifications for the use of cold therapy to ensure optimal therapeutic results.

**Acknowledgment.** We thank the School of Physiotherapy, Dalhousie University, for the use of its facilities.

**REFERENCES**


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**Fig. 3.** Means and standard deviations of proximal skin temperatures at 0, 15, and 30 minutes for wet ice (WI), dry ice (DI), and cryogen pack (CGP).

**TABLE 3**

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