Motor and Sensory Nerve Conduction Are Affected Differently by Ice Pack, Ice Massage, and Cold Water Immersion

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Background. It is well known that reducing tissue temperature changes sensory and motor nerve conduction. However, few studies have compared the effect of different cold modalities on nerve conduction parameters.

Objective. The purpose of this study was to compare the effects of ice pack, ice massage, and cold water immersion on the conduction parameters of the sural (sensorial) and tibial motor nerves.

Design. An experimental study was conducted in which the participants were randomly assigned to 1 of 3 intervention groups (n=12 per group). Independent variables were cold modality and pre- and post-cooling measurement time. Dependent variables were skin temperature and nerve conduction parameters.

Methods. Thirty-six people who were healthy, with a mean (SD) age of 20.5 (1.9) years, participated in the study. Each group received 1 of the 3 cold modalities, applied to the right calf region for 15 minutes. Skin temperature and nerve conduction parameters were measured before and immediately after cooling.

Results. All 3 modalities reduced skin temperature (mean=18.2°C). There also was a reduction in amplitude and an increase in latency and duration of the compound action potential. Ice massage, ice pack, and cold water immersion reduced sensory nerve conduction velocity (NCV) by 20.4, 16.7, and 22.6 m/s and motor NCV by 2.5, 2.1, and 8.3 m/s, respectively. Cold water immersion was the most effective modality in changing nerve conduction parameters.

Limitations. The cooling area of the ice massage and ice pack was smaller than that of the cold water immersion. The examiner was not blinded to the treatment group. The population included only participants who were healthy and young.

Conclusions. All 3 modalities were effective in reducing skin temperature and changing sensory conduction at a physiological level that is sufficient to induce a hypoalgesic effect. The results suggest that cold water immersion, as applied in this study, is the most indicated modality for inducing therapeutic effects associated with the reduction of motor nerve conduction.

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Cryotherapy is the therapeutic application of a substance to remove body heat, resulting in diminished tissue temperature.[1,2] It often is used in sports and rehabilitation settings during the immediate and rehabilitative phases of injury management.[3] Reduced tissue temperature, blood flow, and cellular metabolism are some of the physiological effects of cryotherapy.[2-8] Cryotherapy also reduces nerve conduction velocity (NCV) in the sensory and motor nerves[9,10] and has a controversial effect on muscle strength (force-generating capacity).[11-13] These physiological changes lead to some therapeutic effects such as a reduction in pain and muscle spasm and the prevention of posttraumatic edema.[1-13]

Various modalities are frequently used to deliver cryotherapy treatment. The efficacy of cooling depends on the method, application time, and treatment area and the individual's physical activity level immediately before or after the intervention.[14] Overall, crushed ice pack, ice massage, and cold water immersion are considered the most effective clinical modalities for reducing tissue temperature.[14-17] The efficacy of the cryotherapy modalities has been assessed by comparing their capacity to decrease intramuscular,[18] intra-articular,[19] and skin temperature[10,14-17,20,21] and to maintain the temperature changes. Skin temperature measurement has been widely used because it is a simple and noninvasive procedure. Some authors, based on skin temperature measurements, have hypothesized that skin temperature changes are closely related to changes in subcutaneous and intramuscular temperature.[10,15-17] However, the study by Jutte et al,[22] which used a multiple regression model, showed that skin temperature was a weak predictor of intramuscular temperature because it explained only 21% of temperature variance within the muscle. The influence of subcutaneous and muscular tissue thickness on the cooling of deeper tissues also has been debated.[23,24]

A more precise way of analyzing the efficacy of cryotherapy modalities would be to compare their effects on deep tissues directly associated with clinical intervention using quantitative, direct, and reliable measurement. For example, nerve fibers are targeted for cryotherapy intervention to reduce muscle pain and spasm,[3] and the changes attributed to cooling can be identified through nerve conduction studies (NCS) in which reliability has been established previously.[25]

Prior electrophysiological studies have determined a direct linear relationship between skin temperature and NCV and an inverse relationship with latency, amplitude, and duration of compound action potential.[26-30] Nevertheless, this relationship varies according to the type of nerve fiber. Sensory nerves can show a reduction of 1.4 to 2.6 m/s for every degree of skin temperature reduction, whereas motor NCV can decrease by 1.1 to 1.5 m/s/°C.[1] There are other factors that affect the relationship between skin temperature and NCV, such as the depth of the nerve, the amount of surrounding subcutaneous tissue, age, range of temperature variation,[27-30] and possibly the type of modality used to alter skin temperature.

In the literature, there is a lack of studies comparing the effects of the different cold modalities on motor and sensory nerve conduction parameters. We found only one study[31] that established a greater effect of cold packs compared with gel packs on reducing ulnar motor NCV. However, this study did not analyze the effect of these modalities on sensory nerve conduction. Therefore, it is important to compare the effectiveness of the different cryotherapy modalities on motor and sensory nerve conduction to provide physiological parameters that contribute to the indication of the most adequate modality according to the desired therapeutic effect.

Considering that each cold modality has a different capacity to cool the skin and subcutaneous tissues and that nerve fiber conduction is affected by skin temperature changes, the hypothesis of this study was that cryotherapy protocols with different characteristics should have different effects on sensory and motor nerve conduction. The purpose of this study was to compare the effects of 3 commonly used therapeutic cold modalities (ice pack, ice massage, and cold water immersion) on the conduction parameters of the sural nerve and tibial motor nerve in participants who were healthy.

Method
Research Design
An experimental study was conducted with 3 randomly assigned intervention groups. The independent variables were cold modality type (ice pack, ice massage, and water immersion) and measurement time (pre- and post-cooling). The dependent variables were skin temperature (degrees Celsius) and nerve conduction parameters: NCV (meters per second), latency and duration (milliseconds), amplitude of compound muscle (millivolts), and sensory action potentials (microvolts).

Participants

The participants were informed of the experimental procedures and the risks involved with the study and signed a consent form. Thirty-six participants who were healthy (18 women and 18 men) were enrolled in this study. The participants' mean (SD) age, mass, height, and body mass index were 20.5 (1.9) years, 60.2 (8.4) kg, 1.63 (0.1) m, and 22.4 (1.6) kg/m^2, respectively.

The sample size for each cold modality group was determined through the application of the *sampsi* command of Stata 9.0 software.* The following design specifications were taken into account: $\alpha=.05$; $(1-\beta)=0.9$; ratio=1:1; and method of calculation=analysis of covariance (ANCOVA) for repeated measurements, with a baseline measurement and a final measurement. The correlation between the initial and final measurements was $r=.2$. This method defined a sample of 10 to 12 participants for each cold modality group.

All participants filled out a health questionnaire that indicated the presence of any of the following exclusion criteria: history of alcoholism or smoking, peripheral vascular or cardiovascular disease, diabetes, neurological or skeletal muscle disorders, recent trauma or injury to the right leg, local hot or cold insensitivity, cold adverse reactions, Raynaud phenomenon, and pregnancy. Additionally, the participants were asked to avoid eating and drinking any stimulants (eg, alcohol, caffeine, chocolate) 2 hours before the intervention and to not exercise for at least 4 hours before intervention. These exclusion criteria and recommendations were considered according to previous studies.[10,31]

Instruments

Skin temperature was measured using an infrared thermometer (Raytek ST PRO[†]) that displays a precision of 1°C, high reliability (intraclass correlation coefficient=.97), validity ($r=.92$), and responsiveness (change index=4.2). Nerve conduction measurements were acquired using a Nicolet Compass Meridian System[‡] and standard surface electrodes from the same manufacturer. The selection of cold modalities was based on their high effectiveness in reducing skin temperature and their frequent application in the clinical setting.[14–17] The ice pack consisted of 279 g of crushed ice in a plastic bag of 18 × 8 cm without air. Ice massage was applied by using an ice block of 279 g with dimensions of 8 × 10 × 5 cm. Water immersion was conducted in an acrylic container of 20 × 35 × 30 cm, filled with water and crushed ice until the water temperature reached approximately 10°C, as reported previously.[17,20] The temperature of this modality was measured throughout the intervention, showing an initial mean of 8.9 (1.0)°C and a final mean of 7.8 (1.2)°C.

Procedure

The participants were randomly assigned to 1 of 3 cold modality groups by using a computer-generated random number sequence.[32] Furthermore, to minimize the influence of the circadian cycle on body temperature regulation, all participants received the cold modality at the same time (eg, 2–6 PM). The intervention and measurement procedures were performed on the right calf of each participant. Given that the post-cooling measurement had to be taken immediately after the cold modality application, the same room was used for the application of inter-

vention and for the measurement procedures. Room temperature was maintained at 24 (0.08)°C, and there were no significant variations during the tests ($P=.29$).

Before the experimental protocol, the participants were asked whether they had followed the recommendations regarding stimulant intake and exercise. Their height and weight were recorded to calculate the body mass index. The participants wore T-shirts and shorts and, for acclimatization, assumed the prone position on the standard examining table for 15 minutes. During the acclimatization time, the treatment area to be cooled was determined and the electrodes for NCS were placed.

Cold modalities. The cold modalities were applied for 15 consecutive minutes by the same trained physical therapist (M.C.S.). This duration is frequently used for treatments because it is sufficient to achieve therapeutic effects and it avoids complications from cold modalities.[21,33] The ice massage and the ice pack were applied to a previously determined rectangular area (18 × 8 cm) on the calf (Fig. 1). The ice pack was applied directly to the skin and without compression. The ice massage was applied by continuous longitudinal displacements. For the cold water immersion, the participants remained seated while immersing the right leg as far as the top border of the rectangle determined for the previous modalities (Fig. 1). At the end of intervention, the leg was quickly dried without friction, and the participant returned to the prone position for the post-cooling measurement. All participants completed the experimental protocols without adverse reactions to the cold.

Skin temperature measurement. Skin temperature was measured immediately before (pre-cooling) and after (post-cooling) the cold modal-
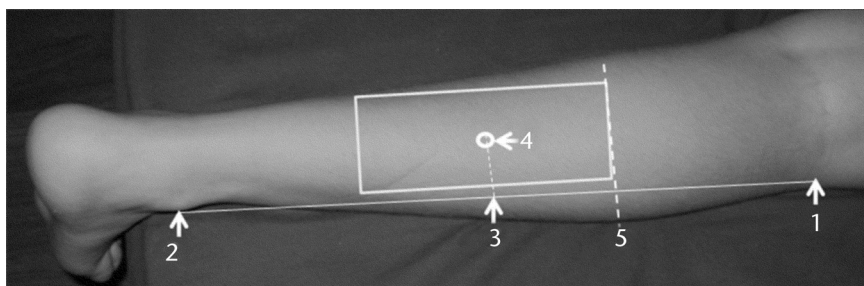
Figure 1.
Cooling area. Ice pack and ice massage were applied to the same rectangular area defined according to the following procedure: (a) measurement of the length of the leg between the head of the fibula (1) and the lateral malleolus (2); (b) definition of the midpoint between the head of the fibula and the lateral malleolus (3); (c) projection of a perpendicular line to the posterior part of the leg, marking the midpoint of the calf (4); and (d) placement of the center of an acetate mold in the midpoint of the calf to mark a rectangle (18 × 8 cm) where the ice pack and ice massage would be applied. For the cold water immersion, the participants immersed their right leg in a cold water tank as far as the top border of the rectangle (5).
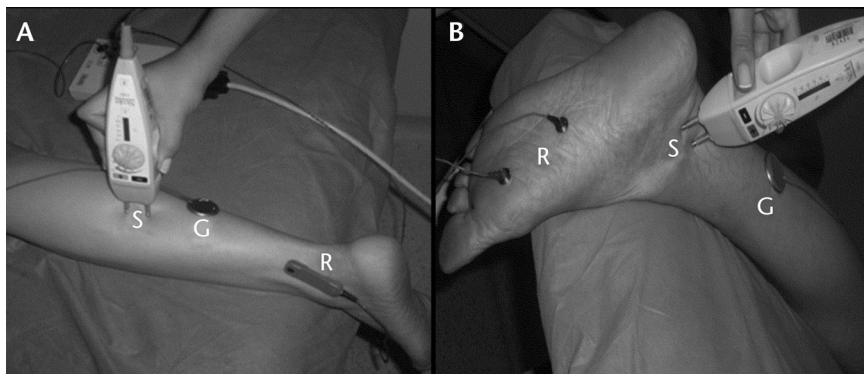

Figure 2.
Stimulation and recording electrode sites for the sural nerve and tibial motor nerve conduction studies. (A) Sural nerve: antidromic technique was performed. (B) Tibial motor nerve: distal stimulation on the medial malleolus and proximal stimulation on the medial aspect of the knee crease (not shown). S=stimulation site, R=recording site, and G=ground electrode.

ity application. The temperature was measured at the center of the previously defined rectangle (Fig. 1) with an infrared thermometer placed in a perpendicular position and kept as close as possible to the skin without touching.

Nerve conduction measurement.
Compound action potentials resulting from stimulation of the posterior tibial motor and sural nerves were recorded twice, before and after cooling, according to standardized techniques described by Oh.[34] These nerves were selected because they are located within the treatment area. Furthermore, the posterior tibial nerve has a high quantity of motor fibers, and the sural nerve is a pure sensory nerve,[26,34] allowing the assessment of the cooling effects in both motor and sensory fibers.

Nerve conduction studies were obtained by the same examiner (E.H.). In order to reduce technical variations, the stimulation and recording sites were delimited with a permanent ink marker during the pre-cooling measurement, and the recording electrodes were not removed during the intervention, except in the participants who received cold water immersion. In this case, the recording electrodes were removed after the pre-cooling measurement and replaced at the sites previously marked for the post-cooling measurement.

Before the NCS measurement, the participants were instructed to avoid leg movements. The sural nerve recordings were obtained with a bandwidth of 20 Hz to 3 kHz, a gain of 20 μV per division, and a sweep speed of 1 millisecond per division. The surface bar recording electrode was placed immediately behind the lateral malleolus and the stimulating electrode, was placed about 14 cm proximal to the active recording electrode, just lateral to the midline of the width of the calf muscle[34] (Fig. 2A). Stimuli were 100-microsecond rectangular pulses, with amplitude adjusted slightly higher than needed to ensure a maximum response. The nerve signals were obtained by averaging 20 responses. The following sensory nerve parameters were measured: NCV, peak latency, peak-to-peak amplitude, and duration (onset to end of negative wave) of the compound sensory action potential.

The tibial motor nerve recordings were obtained with a bandwidth of 2 Hz to 10 kHz, a gain of 2 mV per division, and a sweep speed of 2 milliseconds per division. The active disc recording electrode was placed over the abductor hallucis muscle, and the reference disc recording electrode was placed at the base of the big toe. The ground electrode was positioned on the calf muscle. The distal stimulation site was on the ankle immediately behind the medial malleolus, and the proximal stimulation site was on the knee on the medial aspect of the knee crease[34]

(Fig. 2B). The following motor nerve parameters were measured: NCV for the nerve segment between ankle and knee, distal latency, amplitude, and duration of the negative wave of the compound muscle action potential.

Intrarater reliability of sural and tibial motor NCS. Before data collection, we assessed intrarater reliability of the tibial motor and sural nerve recordings in 20 participants following the same recording techniques described above. The same examiner who performed the assessments of the current study tested each participant twice on 2 separate days with a minimum 8-day lapse between the measurements.[25]

Statistical Procedures

Intrarater reliability of nerve conduction parameters was evaluated using the Bland-Altman method.[35] Data were reported as mean difference (95% limits of agreement). For the present study, descriptive statistics were used to summarize the characteristics of the population, the skin temperature, and nerve conduction data, which are presented as mean (SD). The baseline characteristics of the cold modality group participants were compared using analysis of variance (ANOVA) and a chi-square test, depending on the scale of measurement of each variable.[32] The measurements obtained before and after cooling were compared using a paired t test because the normal distribution of all variables was proven by the Shapiro-Wilk test.[32,36] In addition, an ANCOVA[37] compared the effects of the 3 modalities of skin temperature and the nerve conduction parameters using the ice massage group as reference. For the statistical analysis, the Stata 9.0 software was used, with a significance level of $\alpha=.05$.

Results

Intrarater Reliability of NCS

The intrarater analysis showed mean differences close to zero, and there was no evidence of systematic error. The mean differences (95% limits of agreement) for the sural nerve parameters were: latency=0.17 millisecond (−0.73, 1.07), NCV=−0.07 m/s (−4.48, 4.33), amplitude=−2.9 μV (−20.73, 14.95), and duration=0.04 millisecond (−0.3, 0.37).[25] Respective data for the tibial motor nerve parameters were: latency=0.23 millisecond (−1.10, 1.56), NCV=−0.32 m/s (−6.20, 5.53), amplitude=−0.1 mV (−4.30, 4.10), and duration=0.36 millisecond (−0.91, 1.63) (unpublished data).

Effects of Cold Modalities on Skin Temperature and Nerve Conduction Parameters

A total of 39 potential participants were assessed for eligibility; 2 did not meet inclusion criteria, and 1 was not assisted to the experimental session. Twelve participants were randomly allocated to each experimental group (Fig. 3). There were no significant differences in baseline characteristics among the cold modality group participants (P>.05) (Tab. 1). There was a decrease in skin temperature after the application of the 3 modalities (P<.0001) (Tab. 2). The ice massage caused a greater decrease in skin temperature compared with the ice pack (β=3.03, P=.001) and the cold water immersion (β=9.36, P<.0001). All 3 modalities induced an increase in latency and duration of the compound action potential of the sural and tibial motor nerves (P<.05). There also was a reduction in the amplitude of the potentials and the NCV (P<.05) (Tabs. 3 and 4). The effect of the cold water immersion on all motor nerve parameters, as well as on amplitude and duration of sural nerve potential, was different and greater compared with the effect of ice massage (Tab. 5). There

were no differences between the effects of the ice pack and ice massage on the motor and sensory conduction parameters (P>.05) (Tab. 5).

Discussion

The 3 cold modalities resulted in significant changes in every sural nerve parameter, except cold water immersion in amplitude (Tab. 4). Mean differences among parameters determined before and after cooling were greater than those determined in the intrarater reliability analysis. The effects of ice massage and ice pack on the tibial motor nerve parameters were more subtle (Tab. 3). Although latency and duration differences were statistically significant for the effect of ice pack intervention on the tibial motor nerve, mean differences were lower or similar to those determined in the intrarater reliability analysis for this nerve. However, it is important to note that assessments after ice pack and ice massage protocols did not require the removal of electrodes, which usually is the main source of error in NCS. Mean differences in tibial motor nerve parameters from cold water immersion were greater than those determined in the intrarater reliability analysis. Therefore, we believe that the motor and sensory nerve conduction changes determined for each modality were a real consequence of cooling rather than error in measurement methods.

The results of this study support the proposed hypothesis because the cold modalities applied have different effects on motor and sensory nerve conduction. The modality of cold water immersion, as applied in this study, had the greatest effect on the conduction parameters, especially of the tibial motor nerve (Tab. 5). The modalities of ice pack and ice massage, as applied in this study, differed substantially from the cold water immersion. First, the ice massage and ice pack were applied
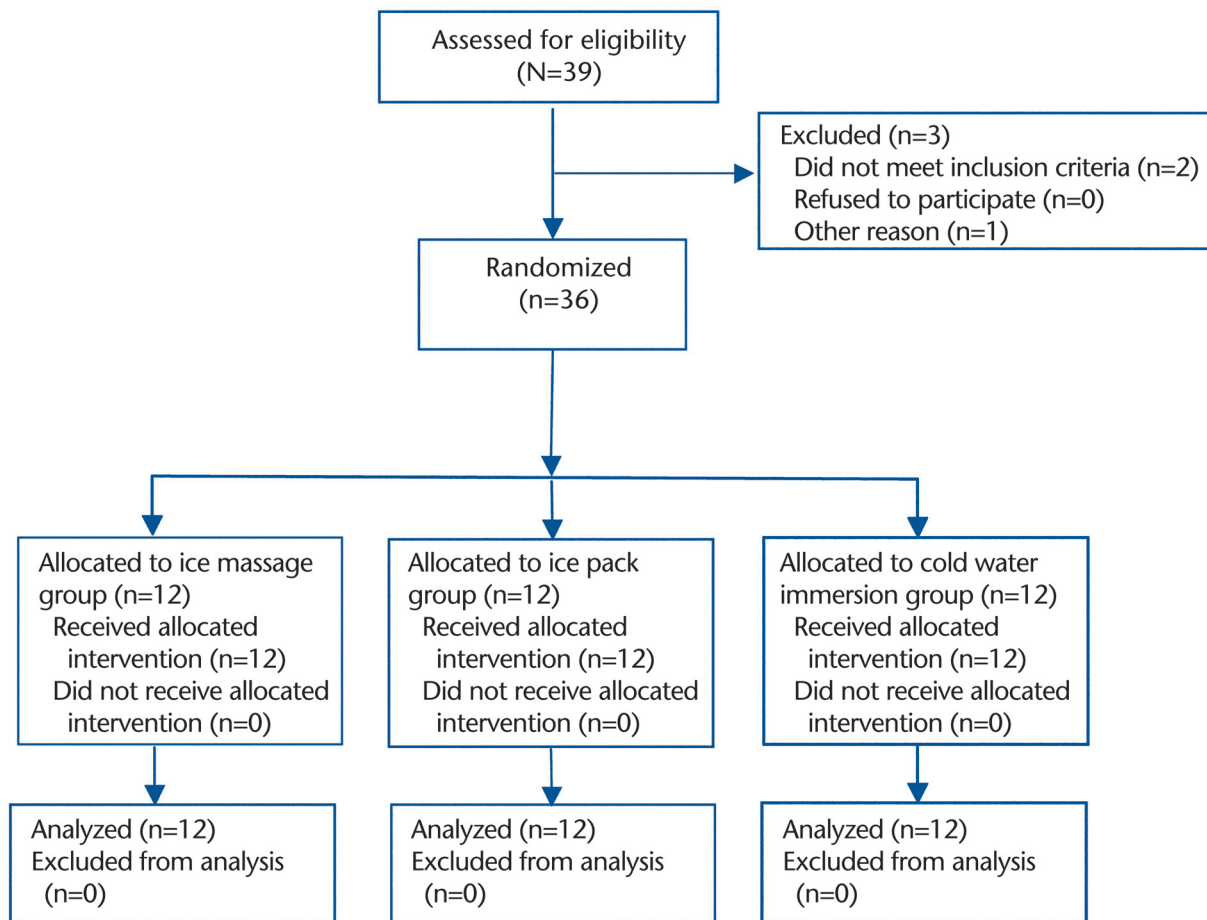
Figure 3.
Flow of participants through the study.

to the same calf area (44 cm²), whereas the area/volume covered by cold water immersion was much greater, including the calf, ankle, and foot regions where the nerve becomes more superficial and thus more susceptible to cooling. Second, these modalities also have thermodynamic differences: in the ice massage and ice pack modalities, heat exchange occurs by conduction, whereas cold water immersion involves conduction and convection processes.[1] Our results can be explained mainly by the differences in the area/volume, and this parameter of the cold modalities may contribute to a greater cooling effect on the

Table 1.
Demographic Characteristics of the Participants[a]

	Intervention Group			
Variable	**Ice Massage (n=12)**	**Ice Pack (n=12)**	**Cold Water Immersion (n=12)**	**P**
Age (y)	19.7 (1.3)	20.7 (1.3)	20.9 (2.6)	.26
Female participants, n (%)	5 (41.7)	6 (50)	7 (58.3)	.72
Height (m)	1.61 (0.1)	1.64 (0.1)	1.65 (0.1)	.54
Mass (kg)	58 (7.1)	60.4 (8.6)	62.1 (9.7)	.51
Body mass index (kg/m²)	22.2 (1.6)	22.3 (1.4)	22.6 (1.7)	.81

[a] Data are presented as mean (SD), except for the number and percentage of female participants.

Table 2.
Skin Temperature in Participants Submitted to Different Cold Modalities[a]

Intervention Group	Skin Temperature (°C)		
	Pre-Cooling	Post-Cooling	Difference[b]
Ice massage	31.58 (1.07)	3.98 (1.15)	−27.6 (1.32)[c]
Ice pack	31.12 (2.13)	6.68 (3.4)	−24.43 (2.87)[c]
Cold water immersion	31.55 (0.89)	13.32 (1.33)	−18.23 (1.46)[c]

[a] Data are presented as mean (SD).
[b] Difference=post-cooling − pre-cooling.
[c] P<.0001.

subcutaneous tissues, including the peripheral nerve. Future studies are needed to compare the effects of the cold modalities on nerve conduction with different thermodynamic properties applied to an area of similar magnitude.

Paradoxically, cold water immersion was the modality that caused the least skin temperature reduction (Tab. 2), possibly due to the fact that a greater area received the treatment, leading to a faster activation of the thermoregulatory responses that protect the body from abrupt temperature changes.[38] Consequently, skin temperature was quickly stabilized and did not adequately reflect the effects of cooling on subcutaneous tissues.[22]

The cooling induced by the 3 modalities was effective in reducing the NCV and prolonging the latency and duration of the compound muscle and sensory action potentials (Tabs. 3 and 4). The effects of temperature reduction on nerve conduction parameters are well described in the literature[27-30] and may result from the changes in the structure of the axonal membrane[39] and from the conductance of the voltage-sensitive sodium and potassium channels.[27] Therefore, the cold reduces the nerve membrane current, which lengthens the refractory periods following a stimulus; as a result, the duration of the nerve action potential increases and the rate of impulse transmission decreases.

In the scientific literature, the relationship between the amplitude of compound action potential and temperature remains a controversial issue. Some studies that analyzed the effect of temperature changes on conduction parameters showed a negative relationship,[40,41] whereas other authors did not identify this relationship.[27] In the present study, cold water immersion significantly reduced the amplitude of compound muscle action potential (Tab. 3). Similarly, the ice massage and the ice pack reduced the amplitude of sensory compound action potential (Tab. 4). Perhaps the differences between the results of the present study and those of previous studies[27,40,41] are due to the differences in the skin temperature changes. In previous studies,[27,40,41] skin temperature decreased only from 33.6°C to 22.5°C, whereas in the present study, the cooling induced by all modalities was greater (from 31.6°C to 4°C).

The amplitude of the compound action potential represents the number of nerve fibers that responds to an appropriate electrical stimulus.[34] Therefore, the reduction of this parameter after the cold modality application could suggest an increase in the activation threshold of some nerve fibers, as well as a block of the fibers that are more sensitive to cooling. Additionally, the increase in the duration of the compound action potential is an indicator of alteration in the discharge synchronization of nerve fibers.[34]

The physiological mechanisms of the hypoalgesic effect of cryotherapy have not yet been completely elucidated. Different hypotheses have been proposed: (1) closing of the pain gate, (2) counter-irritant effect that activates inhibitory control mechanisms, (3) increase in the activation threshold of nociceptors, and (4) participation of descending pathways of the central nervous system that modulate pain by releasing endogenous opiates. It also has been suggested that the hypoalgesic effect of cryotherapy could be related to an increase in pain threshold and pain tolerance associated with a decrease in NCV.[9] We suggest that the inactivation of some nerve fibers, which is evident in the decrease in compound action potential amplitude, as well as the change in the synchronization response of these fibers could be other important physiological mechanisms for the hypoalgesic effect of cryotherapy. Studies are needed to investigate this hypothesis.

Although the present study did not include specific pain measurements, the results for the 3 modalities suggest that the hypoalgesic effect of cryotherapy may be produced mainly by the reduction in sensory fiber conduction because the cooling effect on the conduction parameters was usually greater in the sensory nerve than in the motor nerve (Tabs. 3 and 4). Ice massage, ice pack, and cold water immersion reduced sural NCV by 37.9%, 31.9%,

Table 3.
Parameters of Tibial Motor Nerve Conduction Before and After Cold Modality Application[a]

Nerve Conduction Parameter	Ice Massage			Ice Pack			Cold Water Immersion		
	Pre-cooling	Post-cooling	Difference[b]	Pre-cooling	Post-cooling	Difference	Pre-cooling	Post-cooling	Difference
Latency (ms)	3.47 (0.43) [3.19, 3.74]	3.62 (0.46) [3.32, 3.91]	0.15 (0.17)[c] [0.04, 0.26]	3.82 (0.60) [3.44, 4.21]	4.02 (0.63) [3.61, 4.42]	0.19 (0.14)[c] [0.10, 0.28]	3.61 (0.55) [3.26, 3.96]	6.99 (0.93) [6.40, 7.58]	3.38 (0.73)[d] [2.92, 3.85]
Motor nerve conduction velocity (m/s)	49.67 (3.31) [47.56, 51.77]	47.17 (3.11) [45.20, 49.14]	-2.50 (1.31)[c] [-3.34, -1.67]	49.58 (3.73) [47.21, 51.95]	47.50 (2.81) [45.71, 49.29]	-2.08 (1.56)[d] [-3.08, -1.09]	49.00 (3.59) [46.72, 51.28]	40.67 (2.84) [38.86, 42.47]	-8.33 (2.19)[c] [-9.72, -6.94]
Amplitude (mV)	14.9 (4.00) [12.36, 17.44]	14.04 (3.98) [11.51, 16.57]	-0.86 (1.77) [-1.99, 0.27]	16.72 (2.70) [15.00, 18.43]	16.12 (2.80) [16.12, 14.34]	-0.60 (1.04) [-1.26, 0.06]	15.63 (3.04) [13.69, 17.56]	12.53 (3.06) [10.58, 14.47]	-3.09 (3.20)[c] [-5.13, -1.06]
Duration (ms)	5.39 (0.50) [5.07, 5.70]	5.74 (0.58) [5.37, 6.11]	0.35 (0.26)[c] [0.18, 0.52]	5.63 (1.04) [4.96, 6.29]	6.00 (1.01) [5.36, 6.64]	0.38 (0.16)[d] [0.27, 0.48]	5.46 (0.67) [5.03, 5.88]	8.64 (1.49) [7.70, 9.59]	3.18 (1.37)[c] [2.31, 4.05]

[a] Data are presented as mean (SD) [95% confidence interval].
[b] Difference=post-cooling − pre-cooling.
[c] $P < .05$.
[d] $P < .0001$.

Table 4.
Parameters of Sural Nerve Conduction Before and After Cold Modality Application[a]

Nerve Conduction Parameter	Ice Massage			Ice Pack			Cold Water Immersion		
	Pre-cooling	Post-cooling	Difference[b]	Pre-cooling	Post-cooling	Difference	Pre-cooling	Post-cooling	Difference
Latency (ms)	2.93 (0.27) [2.76, 3.11]	4.62 (1.21) [3.85, 5.39]	1.68 (1.04)[c] [1.02, 2.35]	3.17 (0.33) [2.96, 3.38]	4.50 (0.71) [4.05, 4.95]	1.33 (0.60)[d] [0.95, 1.71]	3.08 (0.38) [2.84, 3.32]	5.39 (0.70) [4.95, 5.83]	2.31 (0.38)[d] [2.07, 2.55]
Sensory nerve conduction velocity (m/s)	53.92 (2.84) [52.11, 55.72]	33.50 (5.76) [29.84, 37.16]	-20.42 (5.96)[c] [-24.20, -16.63]	52.42 (4.27) [49.70, 55.13]	35.67 (6.91) [31.28, 40.05]	-16.75 (5.53)[c] [-20.26, -13.24]	54.08 (4.56) [51.18, 56.98]	31.50 (2.71) [29.78, 33.22]	-22.58 (2.35)[c] [-24.08, -21.09]
Amplitude (µV)	39.29 (12.18) [31.55, 47.03]	18.95 (11.30) [11.77, 26.13]	-20.34 (9.54)[d] [-26.40, -14.28]	39.97 (11.31) [32.78, 47.15]	24.86 (12.32) [17.03, 32.69]	-15.11 (11.10)[c] [-22.16, -8.05]	40.79 (14.85) [31.36, 50.22]	44.18 (14.49) [34.97, 53.39]	3.39 (7.99) [-1.69, 8.47]
Duration (ms)	1.26 (0.10) [1.20, 1.32]	1.40 (0.17) [1.30, 1.50]	0.14 (0.14)[c] [0.05, 0.23]	1.38 (0.15) [1.28, 1.47]	1.53 (0.19) [1.40, 1.64]	0.15 (0.11)[c] [0.08, 0.22]	1.33 (0.14) [1.23, 1.42]	2.68 (0.20) [2.55, 2.80]	1.35 (0.17)[d] [1.24, 1.46]

[a] Data are presented as mean (SD) [95% confidence interval].
[b] Difference=post-cooling − pre-cooling.
[c] $P < .05$.
[d] $P < .0001$.

Table 5.
Effects of Cold Modalities on Nerve Conduction Parameters (Analysis of Covariance, Using the Ice Massage Group as Reference)

Parameter	Tibial Motor Nerve				Sural Nerve			
	Ice Pack		Cold Water Immersion		Ice Pack		Cold Water Immersion	
	Coefficient (β)	Probability (P)	Coefficient (β)	Probability (P)	Coefficient (β)	Probability (P)	Coefficient (β)	Probability (P)
Latency	0.03	.87	3.23	<.0001	−0.54	.08	0.50	.09
Nerve conduction velocity	0.39	.51	−6.02	<.0001	3.18	.12	−2.11	.29
Amplitude	0.65	.47	−2.08	.022	5.43	.15	24.16	<.0001
Duration	0.04	.92	2.84	<.0001	0.02	.73	1.22	<.0001

and 41.8%, respectively. In contrast, these modalities reduced tibial motor NCV by only 5.0%, 4.2%, and 17.0%, respectively. It is difficult to compare these results with those of previous studies[9,31] because of the different intervention protocols and analyzed nerves. Algafly and George[9] applied an ice pack for a mean time of 26 minutes and obtained a skin temperature of 10°C and a 33% reduction in sensory plantar NCV. McMeeken et al[31] used an ice pack for 15 minutes and obtained a skin temperature of 5.6°C and an approximate reduction of 13% in ulnar motor NCV. Even though these studies measured different nerves, in a broad sense they corroborate the results of the present study, which demonstrated a greater cooling effect on the sensory fibers than on the motor fibers. The greater sensibility of the sensory fibers to cooling may be due to their more superficial location compared with the motor fibers, which would explain why the functional effects of cryotherapy on sensibility[42] are more pronounced than the effects on muscle function.[12]

The depression of sensory and motor NCV derived from cooling modalities also may indicate the risks of deleterious effects associated with prolonged icing, such as skin burn and superficial nerve damage. Previous studies[33,43] have shown cases of nerve palsy resulting from ice application near the subcutaneous course of nerves. The consequent disability was transient (1–4 days) or prolonged (4–6 months), with all patients eventually reaching full recovery. The application of cryotherapy is typically safe and beneficial if the protocol is appropriate and sufficiently monitored. However, clinicians must be aware of the location of major peripheral nerves, the thickness of the overlying subcutaneous fat, the method of application, the duration of tissue cooling, and the surface area covered.[33,43]

The results of the comparison of the effects of the 3 cold modalities on conduction parameters show that the cold water immersion protocol used in this study, although neither the most comfortable modality for the participant nor the easiest to apply, may be the most indicated for greater therapeutic effect mediated by the change in motor conduction (eg, in muscle spasm and spasticity [hypertonicity]). In contrast, the hypoalgesic effect could be induced by any of the 3 assessed modalities. Cold water immersion was more efficient in changing some parameters of sensory conduction, but the application of the 3 modalities lowered skin temperature to less than 13.6°C and reduced NCV by more than 10%. As suggested in previous studies,[10,17] these changes could be associated with the hypoalgesic effect of cryotherapy.

The present study had some methodological limitations that restrict the generalization of the results. The cooling area of the ice massage and ice pack was small compared with that of the cold water immersion and possibly smaller than those used in the clinical setting. The study sample comprised only young participants who were healthy, and the responses might have been different in older adults and individuals with clinical disorders. The time used for each modality (15 minutes) also may have been insufficient to induce greater effects on the motor nerve, especially in the case of the ice pack and the ice massage, which were applied to restricted areas. Considering that the nerve conduction evaluations were taken immediately before and after the cold modality application, the examiner was not blinded to the treatment group. This fact may limit the internal validity of the study. Subsequent studies are needed to determine the functional relevance of changes in nerve conduction induced by the cold modalities on sensibility and muscle strength, as well as the clinical importance of these changes. The present study contributes to the literature because, to our knowledge, it is the first study comparing the effect of 3 modalities frequently used in clinical practice on the parameters of motor and sensory nerve conduction.

Conclusions

Ice massage, ice pack, and cold water immersion were effective in reducing skin temperature and changing most of the motor and sensory conduction parameters, with greater effects on the sensory nerve. Cold water immersion, as applied in this study, was the most effective modality in changing nerve conduction, especially in the tibial motor nerve. Our results can be considered clinically relevant and contribute to the informed choice of a cryotherapy modality based on the desired physiological and therapeutic effects.

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