

Changes in Forearm Blood Flow During Single and Intermittent Cold Application

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Study Design: Two-factor repeated measures design.

Objectives: To compare the effects of a 20-minute cold application to the effects of a 20-minute cold application followed by 20 additional minutes of intermittent cold on forearm blood flow over a 60-minute period.

Background: The appropriate duration of cold application as a therapeutic modality following soft tissue trauma is an important clinical question because the goal of using this modality is to limit edema, decrease pain, and produce effective muscle relaxation without causing cold-induced reactive vasodilatation or nerve damage.

Methods and Measures: Thirteen subjects (mean age, 21.46 ± 4.01 years) volunteered to participate in this study. A bilateral tetrapolar impedance plethysmograph was used with venous occlusion to measure changes in local limb blood volume at the forearm for a period of 60 minutes under 2 conditions: Condition 1: Prolonged intermittent cold application (20 minutes ice application; 10 minutes off; 10 minutes ice on; 10 minutes off; 10 minutes ice on); Condition 2: Cold followed by application of a room-temperature pack of equal weight to the ice bag (20-minute ice application; 10 minutes off; 10 minute room-temperature pack on; 10 minutes off; 10-minute room-temperature pack on).

Results: A significantly lower blood flow was noted during the last 10 minutes of Condition 1 compared with Condition 2.

Conclusions: The findings of this study indicate that blood flow is reduced when a prolonged intermittent cold application (Condition 1) is used compared to a single cold application (Condition 2). *J Orthop Sports Phys Ther* 1999;29:177-180.

Key Words: cryotherapy, plethysmography, rehabilitation

The use of cold as a therapeutic modality to decrease the local inflammatory reaction following a soft tissue injury has been widely accepted. Cold causes vasoconstriction and decreases the permeability of local blood vessels, reducing swelling and raising the pain threshold.

Although this modality appears to be effective, confusion exists with regard to the pathophysiologic response and specific protocol for the duration of cold therapy application. Studies^{2,5,6,10,13} have shown that local vasodilatation may follow initial vasoconstriction as a result of prolonged cold application. It was subsequently recommended that ice application should be restricted to 20 minutes to avoid the risk of cold-induced vasodilatation.^{2,5,13} Recent evidence,²⁹ however, does not support the occurrence of cold-induced vasodilatation.

Lehman and Delateur¹⁸ have shown that prolonged cold application is necessary to bring about effective muscle relaxation that is essential in the subacute phase of injury rehabilitation. However, Drez et al¹⁸ reported cases in which prolonged continuous ice application resulted in nerve damage. These findings suggested that this complication can be avoided

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by not using ice for more than 30 minutes and by guarding superficial nerves in the area. McMaster^{20,21} suggested that cold should be applied for at least 20 minutes with a preferred duration of 30 minutes, but warned that too long an application may be deleterious. This evidence raises the question of whether or not a protocol of prolonged cold application is beneficial in the treatment of soft tissue injuries without predisposing the tissue to cold-induced vasodilatation. Although several different cryotherapy application protocols are currently used in the clinical setting, the protocol developed for the present study was designed to examine the vasodilation response, based on anecdotal observations of common cryotherapy treatments.

The purpose of this study was to compare the effects of a 20-minute cold application to the effects of a 20-minute cold application followed by 20 additional minutes of intermittent cold on local blood flow over a 60-minute period.

METHODS

Subjects

Thirteen college students (9 men, 4 women, mean age = 21.46 ± 4.01 years) volunteered to participate in this study. Subjects were excluded from the study if they showed hypersensitivity to cold or had cardiac or pulmonary problems, Raynaud's phenomenon, anesthetic skin, or uncovered open wounds. Before participation in the study, the procedure was explained verbally to each subject. All subjects signed informed consent approved by the Biomedical Institution Review Board at the University of Pittsburgh.

Instrumentation and Blood Flow Measures

We collected data using a bilateral impedance plethysmograph (BIP-750, Electrodiagnostic Instruments, Burbank, Calif), which is a safe and noninvasive method of detecting changes in blood flow. Plethysmography uses 1-mA sinusoidal current at a frequency of 100 kHz that is not perceived by the subject. The bilateral impedance plethysmograph, which measures impedance to current, detects decreases in blood flow as measured by an increase in impedance. A direct linear relationship between the percent change in impedance and percent change in blood volume with an impedance plethysmograph using a 100-kHz current frequency has been previously demonstrated.¹

Procedure

Subjects reported for testing on Day 1 and 24 hours later on Day 2. The order of the treatment procedure was randomized, and the left arm of each

subject was tested. The cold modality used in this study was a 450-g ice bag measured to the nearest gram (Fisher Scientific, Inc., Model 711). The first procedure consisted of prolonged intermittent cold application with the following schedule: 20 minutes of continuous ice application; 10 minutes ice off; 10 minutes ice on; 10 minutes ice off; and 10 minutes ice on. The second procedure involved cold application followed by application of a 450-g room-temperature pack with the following schedule: 20 minutes of continuous ice application; 10 minutes off; 10 minutes room-temperature pack on; 10 minutes off; and 10 minutes room-temperature pack on. The first procedure was selected on the basis of anecdotal observations of cryotherapy treatments used in the clinical settings. Each treatment procedure lasted 60 minutes. Subjects were asked to lie in a supine position with their forearm extended and fully supinated. The arm of each subject was cleaned with isopropyl alcohol prior to electrode placement. Circumferential Mylar electrodes were placed 1 cm and 10 cm proximal to the radial styloid process of the wrist. Skinfold thickness was measured at a point midway between the 2 electrodes, and a pneumatic cuff was secured on the left upper arm. Subjects were asked to rest quietly for a period of 20 minutes, during which a baseline blood flow was established followed immediately by either of the 2 treatment procedures. A decrease in the volume of blood flow was determined by an increase in impedance. The percent change in impedance has a direct linear relationship with percent change in blood volume when measured with a bilateral impedance plethysmograph using a 100-kHz current frequency. Impedance was recorded every 5 minutes during the 60-minute duration of treatments 1 and 2.

Statistical Design and Analysis

A 2-factor analysis of variance (ANOVA) with repeated measures (treatment by time) was used to detect significant main and interaction effects. An alpha level of .05 was used for all tests for statistical significance. We performed a test of parallelism to identify how blood flow changed across any 2 successive times between the 2 conditions (Treatment 1 and Treatment 2).²⁶

RESULTS

The percent blood volume at the end of each 5-minute interval for each treatment procedure is displayed in Figure 1. The value at time 0 represents the first measured value 5 minutes into the cryotherapy procedure. The results from this study demonstrated a significant time main effect ($F_{12,144} = 18.46$, $P < .05$) as blood flow decreased during both conditions (Table 1). A significant treatment by time inter-

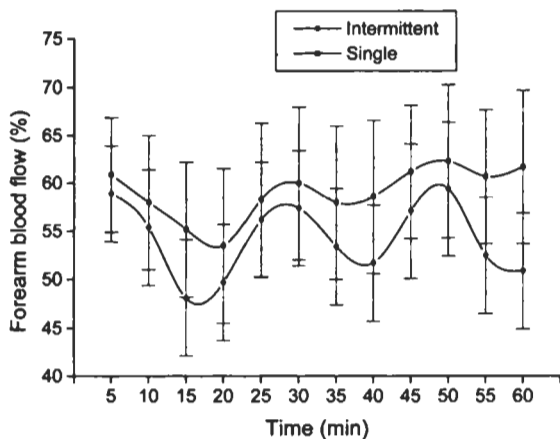


FIGURE. Intermittent ice application compared to single ice application on forearm blood flow over 60 minutes (mean \pm SE).

action was also detected ($F_{12,144} = 3.44, P < .05$). Specifically, significant group by time interactions were detected at 35 vs. 40 minutes, 50 vs. 55 minutes, and 55 vs. 60 minutes, as the intermittent cold condition produced a greater reduction in blood flow than the control condition (Table 2).

DISCUSSION

The results of the present study show that blood flow decreases significantly following 20 minutes of cold application and that intermittent ice application every 10 minutes maintains this decrease for as long as 35 additional minutes. The apparently greater reduction in blood flow during the initial 20-minute cryotherapy treatment of the intermittent condition was an unexpected finding in this study (Figure). As described previously, this particular protocol was performed 24 hours before administration of the second protocol (control). Although the notion of a reflex compensatory mechanism following an initial cryotherapy exposure may seem argumentative at best, a possible explanation of such a finding may lie in this premise. Cryotherapy produces its effects by causing vasoconstriction and a decrease in cell permeability.^{14,21} These immediate effects help to limit the primary edema caused by the initial injury. By limiting the primary edema and by decreasing the metabolic requirement of the injured site as well as that of surrounding tissue, secondary hypoxic injury is prevented.^{14,15} Cold also decreases the rate of impulse transmission along motor and sensory peripheral nerve fibers, thereby raising the threshold for pain¹¹⁻¹³ and decreasing muscle spasm.²⁶ Cold may also act directly on the muscle spindles, lowering spasticity.^{9,19,22,23}

Research has suggested that the duration of ice application in the treatment of injuries be limited to 20 minutes to avoid cold-induced vasodilatation and nerve injuries.^{2,5-8,10,13} Weston et al²⁹ demonstrated a decrease in blood flow below baseline measures dur-

TABLE 1. Two-factor ANOVA summary table (treatment by time).

Source	df	MS	F Value	P Value
Treatment	1	0.169	1.401	.259
Error	12	0.121		
Time	12	0.049	18.46	.001
Error	144	0.026		
Treatment \times Time	12	0.057	3.44	.001
Error	144	0.0166		

ing the entire 20 minutes of ice application. During this time, no significant vasodilatation was observed. The results from our study showed that cold application for 10 minutes following the initial 20-minute procedure significantly reduced blood flow when compared to the control condition. Further, the reduction in blood flow was shown to be greater than 35 minutes following the initial ice period when compared to the control treatment. As such, the prevention of reactive vasodilatation was achieved with the intermittent ice protocol.

Deep tissue cooling is another cryotherapy issue that has generated investigation. Lehman and Delateur¹⁸ have shown that at least 10 minutes is required to cool the muscle of a thin person, whereas 30 minutes may be necessary to derive the same effect in a more obese person. They therefore suggested¹⁸ that the longer duration of cooling should be used to produce effective muscle relaxation. This premise is based on the fact that once the muscle is cooled to a desired level, the effects usually last long enough to be of therapeutic value. Following local cooling, the temperature of the skin and subcutaneous tissue decreases sharply, then more gradually, and finally plateaus.^{4,17,18,24,25} Following removal of the source of cold, tissue temperature increases sharply, similar to the initial decrease but to a lesser degree. Deep tissue temperatures, however, do not begin decreasing until minutes after cold application^{3,28,30}; they occur much more gradually and to a lesser magnitude than the subcutaneous temperature.³⁰ Tissue depth also determines the duration to which this temperature decrease is sustained. The return of tissue temperature to initial baseline levels is related to 2 factors: the amount of heat removed from the body and the amount of heat available to rewarm to area. Rewarming of the fingers occurs more quickly than the ankle or forearm. Studies have shown that more than 2 hours is required to rewarm the forearm and ankle.¹⁶ Delayed rewarming following cooling may be due to the diminished blood flow that accompanies the tis-

TABLE 2. Significant treatment by time interactions.

Variables	F Value	P Value
Time 35 vs. 40	14.49	.002
Time 50 vs. 55	10.60	.007
Time 55 vs. 60	30.25	.001

sue cooling.¹⁸ Our results suggest that blood flow increases 35 minutes following a 20-minute application to the forearm (blood flow approaches baseline values) and that intermittent ice application retards the rebound or increase in blood flow.

CONCLUSION

Our findings suggest that the intermittent cold application procedure can be used to sustain a reduction in blood flow for up to 1 hour. McMaster^{20,21} suggested that cold should be applied for at least 20 minutes, with an optimal duration of 30 minutes. Although this premise has been accepted in many therapeutic settings, the claim is not supported by documented evidence. Our results support the use of an intermittent cryotherapy procedure up to 1 hour if the desired effect is to sustain a reduction in blood flow without inducing reactive vasodilation.

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