Review of Physiological Effects of Cryotherapy

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The purpose of this work is to provide the physical therapist with the research-documented conclusions that he would find if he were to review the literature on the physiological effects of cold therapy. The conclusions are that the results of the studies reviewed were consistent in describing reductions in musculoskeletal pain, spasm, connective tissue distensibility, intramuscular temperature, nerve conduction velocity, and spasticity (except the initial seconds of application). Other conclusions are that the results of the studies reviewed were inconsistent in describing the changes in swelling, blood flow, heart rate, blood pressure, intraarticular temperature, rheumatoid arthritis, monosynaptic reflex, and the muscle spindle.

Cold is a fundamental modality of physical therapy. Those who strive to use it wisely are obliged to research it by reviewing the literature, experimenting with it clinically, and interacting with their peers. Here an attempt is made to present an unbiased presentation of the research that has been done on cryotherapy in this order: gross effects on swelling, blood flow, pain, spasm, motor performance, connective tissue, the heart, tissue temperature, visceral function, cancer, rheumatoid arthritis, and spasticity; and subtler effects on nerve conduction velocity, the monosynaptic reflex, and the muscle spindle.

Three objective and controlled studies dealing with the effect of cold therapy on acute traumatic edema were found. In the McMaster and Liddle study, the potential of local cooling to reduce posttraumatic swelling was investigated on rabbits. A standard forelimb crush injury was given to all rabbits in the experiment. Experimental group one was given forelimb immersion in 30°C water for the first hour following injury. Group two was given forelimb immersion in 20°C water for the first hour following injury. Groups three and four were given repeated forelimb immersion in three cycles consisting of 1 hour of immersion in 20°C and 30°C water, respectively, and 1 hour of exposure to room air. At 24 hours postinjury, all swelling was gone from the control group. Group one had less residual swelling after 24 hours than the control group. Groups two, three, and four demonstrated residual swelling at 24 hours postinjury.

In the Masten et al. study, seven groups of rabbits with bilateral laboratory-induced tibial fractures were studied. One randomly chosen limb of each rabbit served as a control limb and was enclosed in a water jacket of 32°C, the usual temperature of the hindlimb. Four groups of experimental limbs were enclosed in water jackets of 5 or 8, 10 or 15, 20 or 25, and 10°C, respectively. The treatment time for the first three groups was 24 hours, and for group four was 6 hours. The limbs cooled in 5 or 8, and 10 or 15°C jackets swelled significantly more than the controls. This did not become evident until 6 hours posttreatment. Those limbs cooled in 20 or 25°C jackets were not significantly different from the controls. Swelling observed 96 hours postfracture tended to increase as the temperature of the water jacket decreased. Cooling in the group of limbs treated for 6 hours in 10°C jackets was as effective in reducing edema as the control water jacket. In the control limbs, treated at 32°C, there was hemorrhage and swelling in the deep tissues surrounding the bone. In the limbs cooled to 15°C or lower, the deep structures were similar to those of the control limbs, but the subcutaneous tissue was also markedly swollen.

Farry and Prentice used the radiocarpal ligament of the live domestic pig as an experimental...
model to examine the effects on inflammation of a pack consisting of finely crushed ice in a plastic bag applied over the ligament, held in place by a sphygmomanometer cuff at 106 newtons per square meter. The cuffs and ice pack were removed after 20 minutes and were reapplied 1 hour later for a further 20 minutes. Forty-eight hours after injury, the ice- and compression-treated limbs were more edematous than those not treated with ice and compression, but the inflammatory reaction within the injured ligament itself, including microscopic evidence of edema in the injured ligament, was reduced.

Studies of the effect of local application of cold on blood flow varied considerably. Five studies dealt with venous occlusion plethysmography. Abramson et al. immersed both hands of his subjects into 11–14°C water baths. After 25 minutes of immersion, blood flow had decreased by 83%. The subjects’ entire bodies were then warmed, except the hands in the cold water bath, with hot packs for 33 minutes. Blood flow then became 91% of the pretreatment blood flow. Clarke and Hennon immersed the forearm for 30 minutes in water at 10, 18, 26, 34, and 42°C while either sustained or rhythmic exercise was done. The more the cooling, the more marked the reduction in postexercise hyperemia produced by sustained contractions. For the rhythmic exercise at 30 cycles per second, the hyperemic effect was unaltered by cooling, but at 60 cycles per second there was a marked increase in the amount of hyperemia at 18°C.

Knight and Londeree measured blood flow to the uninjured ankle with a repeated measures design of heat packs, cold packs, control, alternating heat and exercise, alternating cold and exercise, and alternating no treatment (control) and exercise, for 45 minutes. Blood flow was significantly greater during heat applications than for either cold or control. Blood flow decreased during cold applications. Exercise appeared to supersede the effects of cold on blood flow.

Clarke et al. measured blood flow to the forearm during 45 minutes of immersion in water at 1, 6, and 10°C. In forearms treated in both the 1 and 6°C baths, there was a gradual increase in blood flow throughout the 45-minute treatment time, more for the forearms treated in 1°C water than for those treated in the 6°C water. Those forearms that were treated in the 10°C water demonstrated inconsistent changes in blood flow. Keating reported two significant findings. First he reported that Greenfield and Shepherd wrote that venous occlusion plethysmography was not a valid method of measuring blood flow in cold extremities. Second, he reported that the magnitude and timing of vasodilation in one digit submerged in 0°C water depended upon the temperature of the rest of the body and the subject.

Other reports on blood flow did not involve plethysmography and included Virtue, who found that clotting time was increased by cold. Licht described a phenomenon whereby cold-induced vasoconstriction spread to adjacent body parts. Some authors described a hunting reaction in which cutaneous blood flow wavered between vasoconstriction and vasodilation. Knight et al. saw it occur in the distal two phalanges of the third digit of the hand when in 1.5°C water. Vasodilation occurred after approximately 25 minutes of cold application. He did not find the hunting reaction to occur in the ankle. The Abramson et al. study reported that a hunting reaction occurred in the hand also. Licht stated that in cold conditions in which the skin temperature dropped below 10°C for any length of time, the hunting reaction caused replacement of general skin vasoconstriction about every half hour by a distinct skin vasodilatation lasting 10–15 minutes. Guyton reported that as skin temperature approached 15°C, more vasoconstriction occurred in the cutaneous vessels. Vasodilatation occurred below 15°C, reaching maximum at 0°C.

Besides the plethysmography studies, few studies encountered measured cold’s effect on blood flow in joints or in tissues other than the skin. The Cobbold and Lewis study showed that cold applied to the knee joint of a dog caused vasoconstriction and decreased intraarticular temperature.

Clinically, cold has been demonstrated to be effective in relieving pain in certain situations. Grant reported treating 7000 outpatients with ice massage of sufficient duration to cause numbness (5–7 minutes), followed by range of motion and mobilization exercises. He reported that 80% achieved “a predictably rapid and satisfactory treatment” with regained function using only this treatment in less than three formal treatments.
Chambers treated 23 patients with a variety of musculoskeletal and neurological disorders
for 20 minutes with towels soaked in 35–40 °C ice water. After one to several treatments, pain was sufficiently decreased or eliminated in 74% of those patients with pain. Range of motion improved in 94% of the patients limited in range of motion, and spasticity was decreased in 67% of patients with spasticity. Numerous other reports confirmed the pain-relieving ability of a treatment involving cold application. Waylonis reported surface anesthesia after 4.5 minutes of ice massage over the calf. Skin temperature had decreased 18 °C after 5 minutes.

There were many testimonials to the effectiveness of local muscle cooling on painful spasms with one or a few treatments. Many of these involved the use of a vapo-coolant and a spray-and-stretch technique. Mennell emphasized that the effectiveness of cold treatment for spasm was that the cooling decreased sensation, allowing the recovery of range of motion and the stretching out of the spasm. Nielson gave this same rationale for myofascial pain.

The literature abounds with reports of the effects on motor performance of cold application. McGown compared the effects of a 28 °C ice massage for 5 minutes on the anterior thigh. Significantly higher (7%) maximum isometric quadriceps contractions were found following the ice massage than massage with a wooden block. Edwards et al. measured quadriceps strength 2 minutes after entire leg immersion in 12, 26, and 44 °C water for 45 minutes. For legs given baths in all three temperatures, endurance time for a single contraction was reduced. Endurance was significantly better in legs immersed in cold than warm baths.

Clarke and Stelmach immersed arms in 10 °C water for 10 minutes, then had the subjects perform a maximum 2-minute handgrip in the water, then monitored recovery while immersed for another 10 minutes. Cold caused a significant reduction in initial strength of 11% measured after 10 minutes of immersion, and an increase in final strength of 13% measured after 20 minutes of immersion.

Grosse immersed the forearm in 10 °C water for 8 minutes and found that posttreatment strength was 11% less than the pretreatment strength. Oliver et al. put the leg in 10 °C water for 30 minutes. A definite relationship was found between intramuscular temperature and plantar flexion strength. Strength was decreased immediately posttreatment. It steadily increased, beginning at 30 minutes posttreatment, and reached 133% of pretreatment levels at 180 minutes posttreatment. The greatest increases in plantar flexion strength occurred simultaneously with the greatest gains in posttreatment intramuscular temperature. Oliver and Johnson’s subjects stood midthigh in 12 °C water for 30 minutes. Immediate posttreatment strength decreased 2% from pretreatment levels. At 40 minutes posttreatment, strength was 122% of pretreatment, peaked 80 minutes posttreatment at 124%, and was still increased 116% 180 minutes posttreatment. A control group had the same pattern of changes, only the magnitude was less.

Johnson and Leider used a 30-minute forearm bath of 10–15 °C. Immediate posttreatment strength was diminished from pretreatment strength, equal to pretreatment strength at 20 minutes posttreatment, and by 80 minutes posttreatment was significantly greater than any previous measurements, and remained so throughout the remaining 100 minutes of the test. Foldes et al. worked with an in vitro rat nerve. Muscle performance at low (0.1 cycles per second) but not at high (50 cycles per second) rates of direct and indirect stimulation especially, was improved when the temperature was lowered from 37 to 17 °C.

Lind and Samueloff reported that a single contraction to fatigue was longer at water bath temperatures of 18 °C than at 34 °C. Clarke et al. immersed the forearm for 30 minutes in different water baths of temperatures ranging from 2 to 42 °C. The duration of 1/3 maximal contractions was longest for an 18 °C bath. In another study, Clarke had his subjects first perform a 2-minute maximal contraction, then put their hand in 10 °C water for 10 minutes. He found that recovery to pretreatment strength levels took 13% longer than recovery of a control group.

Clendenin and Szumski examined single motor unit control in the biceps brachii. Enough cutaneous icing was applied to produce an even erythema (1–2 min). The result of icing was to facilitate a trained motor unit. Wolf and Letbetter worked with the shaved gastrocnemius-sokleus of decerebrate cats. An 8.6-square centimeter thermoelectric cooling module reduced skin-interface temperatures to as low as 10 °C at a rate of approximately 1 °C per second. All the cats showed a reduction in integrated electromyographic activity following 1–5 seconds of
cutaneous cold stimulation. When cold was removed, electromyographic activity showed a large transient increase 1–10 seconds after removal, before returning to precooling control levels. However, individual motor unit response to skin cooling varied. These effects occurred without significant reduction in intramuscular temperature.

Two studies dealt with the effect of cold application on connective tissue. The Warren et al. study used in vivo rat tail tendon demonstrated that higher therapeutic temperatures at relatively light loads produced the greatest elongations with the least damage. The Lehmann et al. study used in vivo rat tail tendon. It tested at normal in vivo temperature for rat tail (25°C) and at 45°C. It was found that the better way to achieve length increase was by stretching either during or after heating. Lehmann et al. explained that since reorganization of connective tissue was thought to occur during the cooling period, subsequent to the application of stretch and heat, load was maintained while cooling the tendon. This technique was found to be more effective in producing a lasting length increase than the applications in which the load was removed at the end of the heat period.

Cold application has been reported to have varying effects on the heart and on blood pressure. Waylonis reported no change in blood pressure or pulse with a 5-minute ice massage over the calf. Lorenze et al. applied towels which had been soaked in ice water on the shoulder for 10 minutes. No significant clinical or electrocardiographic changes were detected. In one out of 25 subjects with coronary artery disease, there were changes. Glaser and Whittow discovered a habituation effect with hand cooling in 4°C water as measured by a decrease in reactive blood pressure and heart rate rises over a 24-hour period. Murphy reported that the effect of cold on the heart depends on the duration and intensity of the cold stimulus. Virtue described effects on respiration of cold immersion baths.

Much literature dealt with objective temperature changes within various tissues. Regarding changes in intraarticular temperature, the reports were few. Borken and Bierman applied 50–100 grams of ethyl chloride solution along a 5-inch diameter section of the knee in a 15–30 minute period. Knee joint temperature decreases ranged from 1.9 to 3.2°C, while skin temperature fell from 15–27°C. Downey cited Horvath as reporting that the temperature of the knee joint bony structures may be reduced when a superficial form of heating such as hot packs was applied to the joint, or increased with a cold application. In the Cobbold and Lewis study, in which cold was applied to the knee joint of dogs, cold caused vasoconstriction and decreased intraarticular temperature. Wakim et al. applied ice packs of 6–12°C to the knee and leg of dogs for 1 hour, which produced marked reduction in joint temperature of 18.4°C.

Cold application inevitably reduced skin temperature.Four studies involved icing the calf. Two studies produced mean skin temperature drops of 11–12°C in 5–10 minutes, while two produced a 6°C drop during a 2-hour ice application. In the Knight et al. study, it took the fingers studied 30 minutes to regain pretreatment temperature after 40 minutes of immersion in 1.5°C water. Ankles took greater than 30 minutes to regain pretreatment temperature. At 5 minutes into treatment, fingers had cooled to 2.8°C, and ankles to 7.4°C. Zankel produced a mean decrease of 22°C in elbow temperature after a 5-minute ice pack. Borken and Bierman used ethyl chloride to cool the calf or thigh 15–27°C. Boes used ice water towels on hemiplegics' quadriceps for 7 minutes to cause a mean drop of 13°C.

All the studies reporting effects on intramuscular temperature (IMT) found that IMT either remained unchanged or decreased. A variety of cold modalities were used. The greater the depth at which IMT was measured, the less the decrease. In some cases, IMT could remain decreased for minutes to hours after treatment. Also, the greater the depth of IMT measurement, the longer the time required of cold application to affect maximum temperature change, and the less the magnitude of change. The results of Waylonis' study are provided in Table 1 as a representative example of IMT study results. In a modality comparison study, McMaster et al. found that cooling the calf was the superior mode. Where it was addressed, no response difference with respect to sex was found. Many of the studies and this author conjectured variables which could influence IMT response: mode temperature, area, blood flow, local metabolic rate, depth of measurement, sympathetic integrity, modality, duration of application, mass to be cooled, validity and reliability of these studies, effects of ther-
mocouple insertion in the nerve during the experiment. Inactivity of the subject during the experiment and the type of subject. Wolf indicated that local cooling had cooling effects on the contralateral body. No evidence of an IMT hunting reaction was found by this author in any of the sources reviewed.

Occasionally, one finds mention in the literature of other than traditional uses of local cold application. For example, Murphy cited studies indicating that ice placed on the abdomen can influence the gastrointestinal system and other organs, and cited other studies indicating that cancer tissue does not tolerate cold as well as normal tissue. Other uses for local application are admittedly inadequately addressed by this present discussion. An example is the use of cold for rheumatoid arthritis.

The numerous spasticity studies, while using various cryotherapeutic modes, were quite consistent in their results. Two of them found initial increases in spasticity with cold application. All studies encountered by this author reported a general decrease in spasticity. Four noted the delayed return of spasticity after treatment had ceased. Two studies mentioned that cold was not effective for all the spastics upon which it was used. Two reported decreased passive resistance to stretch or increased range of motion. The Houtz and Blakeley study reported increased function. None of these studies mentioned an excessive rebound of spasticity after or while the effects of cold wore off.

In condensing nerve conduction velocity studies results, therapeutic cold decreased motor and sensory nerve conduction velocities in proportion to the amount of cooling, and approximately linearly. Different fiber types responded differently in that nerve conduction velocities decreased fastest for Group A fibers and slowest for Group C fibers.

Studies of cryotherapeutic effects on the monosynaptic reflex found that the amplitude of the monosynaptic reflex in the lower extremity either decreased, or remained unchanged. In reviewing the reported effects on the muscle spindle resulting from decreasing IMT, in the Michalski and Seguin study, cooling from 37 to 24°C had no apparent effect on Group I fibers, but Group II fibers became more sensitive. But Eldred et al. found both Group I and Group II fibers became less sensitive from 38 to 23°C, Group I fibers even more so than Group II. In these two studies, similar temperatures and animals were used. Both did not resemble clinical settings. The Lippold et al. results disagreed with both of these studies, indicating that the isolated spindle in general was most sensitive at 26°C. Only Eldred et al. mentioned an effect on Golgi tendon organ activity, finding that it decreased with cold. Newton and Lehmkuhl measured activity at a different place in the nervous system than did Michalski and Seguin and Eldred et al. Newton and Lehmkuhl's results indicated less reflex and other activity because the frequency of action potentials in the dorsal root filaments decreased with decreasing IMT.

**CONSIDERATIONS**

In considering these studies, some precautions need to be taken. Speculation and extrapolation are desirable, but such need to be differentiated from objective results. Studies need to be controlled and statistically analyzed. Practical clinical study results need to be viewed together with basic physiology knowledge and studies. Generalization can be detrimental if there are inadequate facts to substantiate it. It is not acceptable to state that cold decreases blood flow, diminishes hemorrhage developing after trauma, decreases edema formation, decreases spasm and spasticity, and relieves musculoskeletal pain. It is acceptable, however, to state that based on research results or personal experience that cold can do one or some of these things in this particular situation on this particular structure with this much cold applied for this
much time with this population. It is acceptable to quote a study only if all pertinent details are included in that quote. The utility of any treatment may be wholly or partly attributable to either or both the therapist’s or patient’s conviction that the treatment he is receiving will be effective. In examining IMT studies, it is relevant that a given depth of IMT measurement may be in different structures for different subjects.

The results of the studies presented in this paper were summarized by this author. The two studies on swelling in rabbits and one in pigs indicated that the right kind of cold can be effective in decreasing swelling in mechanically traumatized tissues. The wrong kind of cold can exacerbate swelling. Except for the plethysmography studies, none of these studies documented changes in blood flow to muscle. This author wondered what exactly plethysmography measured. Farry and Prentice found that inflammation can be diminished in an injured ligament by using cold and compression. Many studies found that a hunting reaction can occur in the skin. Much writing about the hunting reaction is based on Thomas Lewis’ work concerning changing skin circulation in a finger immersed in cold water. Cold’s effects on swelling and subcutaneous circulation were not clearly established by these studies.

It was found that cold could be very effective for the relief of musculoskeletal pain. It was found that cold and stretching and exercise were very effective for relieving painful spasms and myofascial pain. Studies indicated that cold could influence muscle performance, often causing depressed immediate posttreatment strength and delayed posttreatment strength increases. The two studies dealing with connective tissue indicated that heat and light load worked to increase length, while cold applied in the stretched position helped to maintain length increases. Sometimes heart rate and blood pressure were affected by cold. Skin and muscle temperature decreased with cold application, and remained decreased for a while after treatment was discontinued. Three of four studies indicated that intraarticular temperature dropped in response to cold application. No evidence of a hunting response in subcutaneous tissue was found. Cold application was mentioned as having potential effects on viscera and as having other-than-traditional uses. Cold applications were reported to cause a general decrease in spasticity, though decrease could be preceded by an initial transient increase. Return of spasticity posttreatment was sometimes reported as delayed. Nerve conduction velocities responded to cold by decreasing proportionately. Different fiber types were reported to differ in degree of response. Amplitude of lower extremity monosynaptic reflex decreased or remained unchanged. The muscle spindle was reported to respond to cold, but the nature of the response varied between reports.

It appeared that response to cold was complex and dependent on a multiplicity of factors, some of which were previously listed. It appeared to this author most appropriate to conclude that the responses to any one specific application scenario be assessed by clinical experience and by examining studies which made use of that same scenario. If studies with the same scenario are not available, one must be very careful in attempting to apply results of incongruous scenarios to the scenario of interest.

Some additional clinical considerations were made. Often the treatment time for cold was recommended to be approximately 20 minutes. This author thought that this duration was likely attributable to reported observed cutaneous hunting reaction vasodilation timing. Kramer and Mendryk described that if deep tissue vasodilation occurred with cutaneous hunting reaction vasodilation, then to minimize the possibility of increasing blood flow to acutely injured tissue, cold should not be applied for more than approximately 20–30 minutes at one time, followed by 20 minutes of rest. This author questioned the validity of this because deep tissue vasodilation was not shown to occur along with cutaneous vasodilation. Abraham indicated that cold increased muscle blood flow and facilitated healing for muscle injuries. Fox stated that the persistent effect of cold vasodilation after removal of cold was to cause rapid rewarming. This may be a clue to treating frostbite and hypothermia. Licht explained that cold was believed to be more penetrative than heat since cold usually decreased blood flow, whereas heat increased blood flow, and increased blood flow would tend to carry away heat. Barnes listed contraindications for cold application.

This author also added that an athlete who is treated on the sidelines should not return to participation because he is more susceptible to injury. Muscle performance, nerve conduction velocity, sensation, and connective tissue flexi-
bility were likely altered by the cold application. This author recommends that physical therapists be attentive to the documented and undocumented effects of cold therapy and related research, so that they can learn to use it to achieve specific objectives consistently.

SUMMARY

An extensive review of cold study results was made and a summary of these results was provided. The consistent findings were reductions in musculoskeletal pain, spasm, connective tissue distensibility, intramuscular temperature, nerve conduction velocity, and spasticity (except upon initial cold contact). The inconsistent findings were effects on swelling, blood flow, heart rate, blood pressure, intraarticular temperature, rheumatoid arthritis, the monosynaptic reflex, and the muscle spindle. The physical therapist should be aware of what has been documented and whether or not he has a valid reason for using cold therapy in the manner in which he uses it.

REFERENCES
