

Cryotherapy

Review of physiological effects and clinical application¹

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Cryotherapy, the therapeutic use of cold in the management of injuries and painful conditions, can be a valuable technique for the medical practitioner. The physiologic effects of cold are vasoconstriction, which helps to decrease swelling and inflammation; decreased tissue hypoxia; decreased pain; and decreased muscle spasm. Integrating cold in both the acute and rehabilitation stage can promote quick and effective results. Combining cold with exercise (cryokinetics) has significant clinical implications for the treatment of many musculoskeletal problems, athletic injuries, and inflammatory conditions such as tendonitis, bursitis, and arthritis. Application of ice provides a safe, convenient, and inexpensive method of treatment for the patient, especially in the home setting.

Index term: Cryotherapy

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The therapeutic use of cold in the management of acute and chronic musculoskeletal pain is not new. The use of ice has traditionally been accepted as the standard method for treating common sprains and strains immediately following an injury. Basic first aid texts or emergency room instructions would often advise the use of ice for initially 24 hours, followed by heat.¹ A more effective treatment regimen might use cold therapy in later phases of the injury cycle, during the rehabilitation phase, and even in the chronic stage of injury.²⁻⁴

Cryotherapy can be defined as the use of some modality such as ice for the purpose of lowering temperature to attain therapeutic effects. The purpose of the review of literature is to provide the reader with a thorough under-

standing of the physiologic effects of cold, to clarify practical methods of application of various cold therapy techniques, and to demonstrate integration of cryotherapy into effective treatment planning by the medical practitioner.

When an injury occurs in a sports setting, vigorous attempts are often made to return athletes to competition as quickly and safely as possible. Athletic trainers, sports therapists, and physicians working in sports medicine settings have realized the successful potential of ice as an effective treatment modality for many years. Clinical and empirical evidence appears to demonstrate that early and frequent cold application during the acute and rehabilitative phases can result in more successful management of the injury. Similar techniques and application of cryotherapy with the nonathletic patient can also be applied. Ice can be a valuable therapeutic agent for the treatment of arthritis, low back pain, bursitis, common musculoskeletal problems, and other inflammatory conditions.

Physiological effects of cold

The physiological effects of cold most commonly noted are:

1. Vasoconstriction to decrease swelling and inflammation,
2. Decreased tissue hypoxia,
3. Decreased pain, and
4. Decreased muscle spasm.

Vasoconstriction

Vasoconstriction is the initial response of the cells to the application of ice.⁵⁻⁹ Cold elicits an immediate and direct constriction of surface blood vessels through an axon reflex arc that is a projection of the peripheral autonomic system controlling sympathetic vasoconstriction.¹⁰ Vasoconstriction also occurs through reflexive action via the spinal reflexes.⁶ Cooled venous blood returning to the general circulation activates the posterior hypothalamus to further increase vasoconstriction.⁸

Cold is thought to be therapeutically effective because it decreases vascular permeability, which draws the cell wall together.⁵ The decrease in permeability is beneficial because it reduces the amount of fluid that leaks into the extracellular spaces. Edwards and Burton¹¹ noted that cold increases blood viscosity, which also helps to decrease blood flow into the injured area. Addi-

tional vasoconstriction is achieved because of slower blood flow into the injured area.

This initial response of vasoconstriction produced by cold application is considered to be the principal mechanism to reduce swelling and bleeding after trauma and to decrease edema in inflammatory reactions.¹²

Knight⁵ suggested that controlling and reducing the hematoma formation in an injury is vitally important for adequate progression of the healing process. Control of excessive swelling, hemorrhage, and exudate formation decreases the initial severity of the injury, promoting successful rehabilitation.

Garrick¹³ stated that what one does during the first 24 hours of treatment may have as much to do with healing six months later as anything else that is done.

Guyton¹⁴ stated that when cold was applied directly to the skin the vessels progressively constrict and are lowered to a temperature of about 15 °C, at which point they reach their maximum degree of constriction. At temperatures below 15 °C, the vessels appear to dilate. This dilation is a direct local effect of the cold on the vessels themselves, and is thought to be a paralysis of contractile mechanism of the vessel wall or block of nerve impulses coming to the vessels. This vasodilation, which occurs in severe cold, can protect against freezing, especially of the hands and ears.

Lewis¹⁵ first noted that when subjects removed their fingers from ice water, skin temperature rose above preimmersion level. A similar type of reflex vasodilation appears to occur on the facial region. During Lewis's study, a thermocouple was attached to the finger to measure temperatures before and after a period of immersion. Results showed an initial increase postimmersion and then fluctuations in temperature caused by alternating vasodilation and vasoconstriction. This characteristic feature of vasodilation caused by cold has become known as the "Lewis hunting reaction."

Decreased tissue hypoxia

Ice markedly decreases tissue hypoxia. Knight⁵ explained that cold induces a temporary hibernation state of the tissue and therefore decreases the possibility of extensive secondary damage. Following an injury, tissue disruption reduces available oxygen supply, and therefore the met-

abolic needs of the uninjured tissue may not be met. Secondary tissue hypoxia often develops. Ice application decreases the metabolic demands of the area and subsequently decreases the actual need for oxygen. It has been suggested that the rate of chemical reaction is reduced by one half with 10 °C drop in temperature.⁸

The protective effect of ice is critical in the early management of injuries, as often a simple contusion or a sprain is aggravated because of secondary complications of bleeding and exudate formation.

Decreased pain

Decrease in pain is frequently accomplished through a direct and indirect mechanism. Several studies have demonstrated that ice may cause a temporary decrease in nerve conduction velocity. Clarke et al⁹ noted that cooling below 20 °C caused significant reduction in the production of acetylcholine along cooled nerve, which varied according to the size of the fiber. This seemed to produce an asynchrony of impulses and therefore decreased pain.

Olson and Stravino⁸ suggested that cold may produce a temporary limited anesthesia due to decreased nerve conduction velocity or to competitive inhibition within the central nervous system. DeJong et al¹⁶ similarly demonstrated an effect on nerve conduction velocity caused by cold. He showed a linear association between conduction velocity and temperature above 25 °C.

DeJesus et al¹⁷ reported that cold caused a decrease in velocity of conduction in nerve fibers, but suggested that certain classes of fibers are more sensitive to cold than others. The conduction velocity of large group-A fibers decreased most rapidly with cold, followed by group-B and group-C fibers.

Lehmann and DeLateur¹² reported that the sensitivity of nerve fibers to cold appears to depend largely upon myelination and upon fiber diameter. Douglas and Malcolm¹⁸ in experiments with cats studied the differential effect of cold on fibers, and finally unmyelinated fibers. Specifically, they found that small γ efferent fibers were more sensitive to cold than larger α efferent fibers. Lee et al¹⁹ noted a reduction in nerve conduction velocity of 11.6% in the ulnar nerve when an ice pack was applied over the flexor carpi ulnaris muscle. They then demonstrated an

even greater drop in nerve conduction velocity when the ice pack was applied directly to the elbow region. This appeared to indicate that icing where the nerve is more superficial produced a greater and more rapid reduction in nerve conduction velocity.

Abramson et al²⁰ reported that changes in nerve conduction velocity are thought to be caused by a fall in tissue temperature adjacent to the nerve rather than to a marked change in the blood flow to the area. DeJong et al¹⁶ concluded that changes in conduction velocity during cooling and rewarming can be due to thermal effects on the nerve fiber membrane. Bugaj²¹ analyzed the effectiveness of the ice massage technique in reducing the localized skin temperature and maintaining analgesia. His study demonstrated that an analgesic effect began when localized skin temperature was lowered to approximately 13.6 °C. Analgesia began one minute and 45 seconds after ice application and terminated two minutes and 57 seconds following removal of the cold agent.

Stimulation of sensory fibers may relieve pain through a bombardment mechanism similar to Melzack's gate control theory of pain.²² An indirect decrease of pain occurs through alteration of muscle spasm, spasticity, and control of swelling. The pain-spasm cycle can be arrested through the use of cold.

Decreased muscle spasm

Haines²³ revealed that local cryotherapy can produce a temporary damping of spasticity, probably by decreasing responsiveness of muscle spindles to stretch. Eldred et al²⁴ demonstrated that a cooler muscle had a lower rate of firing from the afferents arising from flower-spray annulo-spiral endings. Changes in discharge of the muscle spindle may result from the extrafusal muscle, the intrafusal fibers, or the sensory endings.

Hartviksen²⁵ reported a generalized decrease in spasticity in the gastrocnemius in patients (quadriplegics, paraplegics, hemiplegics) treated with cold therapy. The most significant reduction in spasticity occurred while the ice packs were applied; however, changes were noted for several hours afterwards.

Knutsson²⁶ studied the effect of topical cryotherapy in spasticity by analyzing the resistance to passive movements, clonus, and maximal contraction forces in the spastic muscles. This study

concluded that cold may reduce activity in the spastic muscle and enhance the contraction of the antagonist muscle. Knutsson and Mattsson²⁷ showed a mean (34%) amplitude decrease in tendon jerks following a 20-minute cooling period of the triceps surae muscle. They concluded that both peripheral and central excitability changes had potential effects on the muscle spindle.

Hedenberg²⁸ functionally tested the upper extremity of 24 spastic hemiplegics before and after immersion in cold water. A significant improvement in functional capacity was noted after the cooling, having positive implications for better performance throughout the active hours of the day.

The general temporary change in muscle spindle activity may be additionally responsible for the overall decrease in muscle spasm often associated with many painful conditions. Griffen and Karselis²⁹ noted that "when pain is present, there is often concomitant local circulatory impairment. One known cause of such impairment is skeletal muscle spasm, which can significantly limit venous return. Such flow deficit can give use to additional pain because the deficit leads to inadequate local removal of metabolic waste products."

Methods of application of cold therapy

Three of the most common methods of applying cold are ice packs, ice massage, and ice immersion. Each appears to be effective at different phases in the program, on different problems, and in different regions of the body. Successful results can be enhanced through selection of the most appropriate method.

Ice pack

The treatment of choice, in the acute state of injury, is some form of ice pack. The familiar mnemonic *ICE* has traditionally been used to refer to *Ice*, *Compression*, and *Elevation*. All three components must be incorporated to achieve optimal results. One of the simplest but most effective methods is the use of cubed or crushed ice in a plastic bag. This is usually readily available and therefore self-treatment can easily be administered. The plastic bag method provides quick and optimal cooling, which can be uniformly maintained throughout the treatment. Chemical ice packs should be avoided. On many occasions, they have broken open and caused

serious chemical burns. Ice can easily be stored in a cooler and therefore be accessible for picnics, travel, or sports events.

When applying ice, a wet elastic bandage should be applied to the injured area. This provides the additional benefit of uniform pressure to the area, and wetting the wrap facilitates penetration of cold. A dry wrap or towel under the ice decreases cold penetration. To gain additional compression and uniformity of cooling, another wrap can be used to secure the ice pack. If an elastic wrap is not available, the ice bag may be placed directly on the skin.

Twenty-minute periods of application of ice packs at one-hour intervals is recommended for optimal treatment benefit and tissue safety. The one-hour interval permits the tissue temperature to reach pretreatment level.

Compression and elevation should be continued between ice applications. The most successful management of an acute injury requires repeated applications of cold. If possible, the body segment of the injured area should be completely surrounded with ice to provide uniform cooling, e.g., an ice pack on both sides or front and back of the knee.

Ice massage

Ice massage, the second method of cryotherapy is often used after the acute stage of injury; however, it may safely be initiated immediately following an injury. Water frozen in a paper or Styrofoam cup is gently massaged or rubbed onto the injured area, with circular or longitudinal strokes. This technique appears to work best over a muscular area as the quadriceps, gastrocnemius, or low back; however, it can be used effectively over a joint surface like the knee. Treatment in this case, is generally 10 minutes, but can be extended for as long as 20 minutes.

The practitioner should understand and carefully explain to the patient the sensations that will be experienced with this method of treatment. The initial response is a feeling of cold, followed by a burning sensation, and then, often, pain. This frequently makes the beginning phase of the treatment difficult to tolerate. It should be pointed out that this is only a temporary response and will be followed by numbness or mild anesthesia. Clinical evidence suggests that the patient will experience these four stages of cold, burning, pain, and numbness much more quickly with ice

massage than with an ice pack.²¹ The anesthesia phase becomes an integral part of the rehabilitation program.

Lowdon and Moore³⁰ demonstrated that ice massage produced a rapid decrease in intramuscular temperature of 15.9 °C in five minutes. He related, however, that subcutaneous tissue thickness and limb circumference should be taken into account when determining treatment time for ice massage. This method of treatment is convenient and can achieve valuable therapeutic effects quickly.

Ice immersion

Ice immersion, the third method of cryotherapy, is most frequently used for treatment of the distal extremities such as the hands or feet. The patient can fill a tub, bucket, wastebasket, or whirlpool with ice and water to reach a water temperature of 40 to 60 °C. The patient can easily exercise or move the injured part while immersed to help increase range of motion. Ice immersion has the advantages over the other methods when treating fingers or toes of completely enveloping the injured part. A disadvantage of ice immersion is that the extremity is in a dependent position. However, it can be elevated immediately following the treatment if necessary.

The initial pain associated with application of ice is most evident with ice immersion. Clinical impressions indicate that patients are able to adapt to this initial painful response. It often appears with frequent applications of long-term treatment that an increased tolerance is established. Glaser and Whittow's study³¹ showed that following repeated ice immersions, a rise in blood pressure and heart rate during localized cooling was significantly diminished, and pain from cooling was abolished. They concluded that localized adaptation to cold is due to habituation, which plays an important part in acclimatization.

Several studies evaluated temperature changes superficially and intramuscularly. Abramson et al²⁰ noted that tissue temperature fell rapidly with the application of ice with the greatest effect noted in the skin and the least in the muscle. In the later part of cooling, the fall in tissue temperature slowed and eventually plateaued despite continued cooling. Wolf and Basmajian³² analyzed the reduction in deep intramuscular temperatures when the skin overlying the left medial gastrocnemius was cooled for five minutes. The

results of their study showed that the reduction in intramuscular temperature varied from 0.4 to 1.9 °C (mean, + 1.2 °C) when recorded at 4.3 cm below the skin surface. Johnson et al³³ concluded that intramuscular temperature of the lower leg decreased 12.0 °C by submersion in cold-water bath of 10 °C. Reduction of intramuscular temperature by direct application of cold was directly related to the percentage of body fat of the subject. Also, intramuscular temperature of the lower leg, after 30 minutes of submersion in 10 °C water, remained lower than presubmersion level up to four hours when the subject did not contract those muscles.

Bierman and Friedlander³⁴ studied the penetration of cold by placing an ice bag on each side of the human gastrocnemius for a period of two hours. During that time, skin temperature and the muscle temperature 5.08 cm below the skin surface was recorded. Skin temperature dropped quickly upon application of cold and was maintained at approximately 6.1 °C whereas intramuscular tissue did not begin to show a significant drop in temperature for at least 30 minutes and then only to levels slightly below 32.3 °C. Waylonis³⁵ studied the effect of ice massage to the thigh and calf for five to ten minutes. Skin temperatures dropped as much as 19.2 °C, with the smaller drops in deeper structures.

Thermal receptors for cold and warmth appear to be simple unencapsulated nerve endings or nerve nets found profusely throughout the skin.^{7,14} The sensitivity of nerve fibers to cold appears to depend largely upon myelination and fiber diameter. Small medullated fibers appear to be affected first.¹² Lehmann and DeLateur¹² state that pain is relieved by elevating the pain threshold as a direct effect of temperature reduction on nerve fibers and receptors.

Cold receptors become highly sensitive when stimulated by a sudden fall in temperature. This immediate occurrence fades rapidly during the first minute, and progressively more slowly during the next half hour. It also appears that cold receptors display a certain degree of adaptation causing a change in frequency of discharge.¹⁴

Guyton¹⁴ reports that thermal receptors are stimulated by changes in metabolic rates. Temperature alters the rate of intracellular chemical reaction about 2.3 times for each 10 °C change. It is suggested that thermal detection results not from direct physical stimulation, but instead from

chemical stimulation of endings as modified by the temperature change.

Clinical applications of cryotherapy

Many authors have reported the clinical advantages of cryotherapy in the management of both acute and chronic conditions.

It is generally accepted that the primary rationale for cryotherapy in the acute stage is vasoconstriction and pain reduction. Following standard guidelines for applying ice packs, one might achieve better control of bleeding and swelling into the injured area. Rest of the injured area is also of critical importance to protect the damaged structures during the immediate phase of healing.

Greater use of cryotherapy beyond treatment of acute injuries may be significantly helpful for the medical practitioner. Using cold as an effective rehabilitation tool is not commonly discussed in the literature. However, integrating cold therapy into various phases of the rehabilitation program can be an extremely valuable technique. The key goal during the healing and rehabilitation phase is to increase circulation to enhance the healing process. Exercise becomes the most important component at this stage in rehabilitation.

The term *cryokinetics* can simply be defined as the combination of cold and exercise. It is generally felt that increasing blood flow speeds up the removal of cellular debris from the injury site and increases delivery of nutrients to be used in rebuilding the damaged area.

Knight et al³⁶ studied the effects of cryotherapy on vasodilation. Their results suggest that cryotherapy must be combined with exercise to effectively achieve long-term vasodilation or increased circulation benefits. Knight and Londeree³⁷ compared blood flow in the ankle during the therapeutic applications of heat, cold, and exercise. Their data suggest that exercise following cryotherapy is most successful in increasing blood flow. Cryotherapy appears to allow easy and more comfortable active motion of painful joints. Early mobilization of the injured area allows quick return of full range of motion and restoration of strength.

A 10- to 15-minute icing period might be used before exercise. This should achieve significant anesthesia adjacent to the injured area, which might allow the patient to begin active range of

motion exercises with less difficulty. The patient can still use pain as a guide for the exercise. Integration of exercise with cryotherapy can often help prevent tissue tightness and adhesions. The ice becomes a dynamic component because it decreases pain and accompanying muscle spasm in the injured area.

McMaster⁴ stated that cold may decrease the excitability of free nerve endings and peripheral nerve fibers, thus increasing the pain threshold. This may support the concept of utilizing cold therapy in chronic conditions. This temporary reduction in pain appears to be effective in the management of some arthritic conditions and other common painful musculoskeletal disorders.

Clinically, pain reduction following cryotherapy appears to be greater than that following superficial heat treatment, such as hot packs and whirlpools. There may also be a long-lasting reduction in pain following the treatment.

Cryotherapy after activity can be effective in reducing postexercise pain. This can have valuable implications for many individuals who experience muscular or joint discomfort after recreational activities. Arthritics often complain of pain following prolonged weight bearing or with increased physical activity such as working in the garden. Prentice³⁸ used electromyographic analysis to determine the effectiveness of heat or cold and stretching for inducing relaxation in injured muscles. He concluded that cold combined with static stretching seemed superior to other forms of treatment in reducing postexercise discomfort. The cold and stretching appeared to suppress muscle spindle activity, which helps to decrease muscle pain. The use of ice on a regular basis after activity or at the end of the day may reduce pain and inflammation.

Cryotherapy for patients with frozen shoulders, cervical myalgia, low back pain, and bursitis who complain of night pain may often provide the necessary initial relief to allow sleep.

Knott and Barufaldi³⁹ demonstrated success in treating whiplash injuries by combining cryotherapy and a series of controlled isometric exercises.

The study of Hocutt et al⁴⁰ assessed the recovery from ankle sprains showing that cryotherapy started within 36 hours after the injury was statistically more effective than heat therapy for complete and rapid recovery. Early initiation of cryotherapy appeared to yield earlier recovery from ankle sprains. Basur et al⁴¹ similarly found

that recovery from ankle sprains occurred earlier in the group treated with cryotherapy.

Hayden⁴² reported the success of cryokinetics in an early treatment program of 1,000 patients in a military setting who had common acute and painful musculoskeletal conditions. He urged patient responsibility for treatment because of the ease of compliance with cryotherapy.

Grant³ reported beneficial results of ice massage in more than 7,000 outpatients. Although his study did not include adequate control, the magnitude of his population suggests credibility. He also used combined ice massage and exercise.

The study of Yackzan et al⁴³ pointed out that ice massage alone was not effective in relieving delayed muscle soreness. However, clinical evidence may support the advantage of combining ice with exercise.

Cornelius and Jackson⁴⁴ indicated that cryotherapy and proprioceptive neuromuscular facilitation (PNF) is an effective method of increasing hip extensor flexibility.

The application of ice to acute and subacute rheumatoid joints is supported by the work of Harris and McCroskery.⁴⁵ They found that destructive enzymes are more active at higher temperatures. It would seem that cold applications could be extremely valuable for the rheumatoid patient, especially in a flare-up stage. Temporary relief of pain via cryotherapy may allow important range of motion exercises.⁴⁶⁻⁴⁸

The number of well-controlled studies comparing heat versus cold treatment of various musculoskeletal problems are limited. However, there appears to be valid justification for incorporating cryotherapy into the treatment of chronic problems and throughout all phases of rehabilitation. Potential increases in the inflammatory reaction could occur if heat is applied too early in the postinjury phase. Also, heat applied to an injured joint or muscular area after exercise or activity may actually increase swelling. Ice might have some advantages over heat because of this inflammatory factor.

Contraindications

The occurrence of severe adverse reactions to cold are rare; however, several studies have reported contraindications and precautions. Juhlin and Shelley⁴⁹ classified three types of cold hypersensitivity. The first type is the result of release of histamine or histaminelike substances, fre-

quently presented as classical cold urticaria. The second type is the result of the presence of cold hemolysins and agglutinins, primarily producing general symptoms such as malaise, chills, and fever with significant anemia. The third type is the result of the presence of cryoglobulins, which in turn produce chills and fever and seriously affect both vision and hearing to the point of blindness and deafness.

The clinician should be aware of the possibility of these hypersensitivities especially in patients with associated diseases such as lupus erythematosus, atypical pneumonia, rheumatoid disease, progressive symptomatic sclerosis, or multiple myeloma.

Raynaud's phenomenon often associated with rheumatic conditions may preclude cold application. One should be especially careful when treating the distal extremities because of the pathological increase in arterial tone and the potential for closure of the digital arteries.¹²

Additional precaution should be exerted for those individuals with severe peripheral vascular disease with arterial insufficiency. The vasoconstricting effects of cold may be potentially harmful.^{4,12}

The practitioner should also exhibit added care for individuals with insensitive skin or unstable cardiac patients.^{4,12}

A frequent question is about the occurrence of frostbite from ice treatment. Tissue damage from frostbite is possible though rare if standard cryotherapy guidelines are followed. Prolonged exposure to cold, water, and low environmental temperature may increase the risk of frostbite. Extreme caution should however be exercised in using a vapocoolant such as ethyl chloride since rapid cooling of the skin occurs and possible freezing of the tissue might result.¹²

Proper use of cold is important to eliminate potential problems due to extreme cooling. One case report of cold-induced nerve palsy was reported following a two-hour application of ice to the knee of an injured high school athlete.⁵⁰ This type of adverse reaction should be prevented by limiting the treatment time to 20 minutes.

Conclusions

The effectiveness of cryotherapy in the treatment of acute injuries appears to be well accepted in the clinical setting. Incorporating cryotherapy into other phases of rehabilitation can be sup-

ported because of the natural physiologic response from ice. Decreased swelling and inflammation, decreased pain, and decreased muscle spasm, which occur with cryotherapy clearly should help to rationalize its value in the treatment of subacute and chronic problems. Additional well-controlled studies would be helpful in clarifying the effectiveness of cryotherapy in the rehabilitation program. Ice therapy appears to be a safe, convenient, and successful mode of therapy.

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References

- Knight KL. Ice for immediate care of injuries. *Physician and Sports Medicine* 1982; **10**:137.
- Moore RJ, Nicolette RL, Benke RS. The therapeutic use of cold (cryotherapy) in the care of athletic injuries. *J National Athletic Trainers Association* 1967; **2**:6-13.
- Grant AE. Massage with ice (cryokinetics) in the treatment of painful conditions of the musculoskeletal system. *Arch Phys Med Rehabil* 1964; **45**:233-238.
- McMaster WC. A literary review of ice therapy in injuries. *Am J Sports Med* 1977; **5**:124-126.
- Knight K. The effects of hypothermia on inflammation and swelling. *Athletic Training* 1976; **11**:7-10.
- Fox RH. Local cooling in man. *Br Med Bull* 1961; **17**:14-18.
- Wise DD. Ice and the athlete. *Physiotherapy* 1973; **25**:213-218.
- Olson JE, Stravino VD. A review of cryotherapy. *Phys Ther* 1972; **52**:840-853.
- Clarke RS, Hellon RF, Lind AR. Vascular reactions of the human forearm in cold. *Clin Sci* 1958; **17**:165-179.
- Licht S. Physiologic responses to heat and cold. [In] Licht S, ed. *Therapeutic Heat and Cold*. 2nd ed. Baltimore, Williams and Wilkins, 1965, pp 137-159.
- Edwards M, Burton AC. Correlation of heat output and blood flow in the finger especially in cold-induced vasodilation. *J Apply Physiol* 1960; **15**:201-208.
- Lehmann JF, DeLateur BJ. Therapeutic cold. [In] Lehman JF, ed. *Therapeutic Heat and Cold*. 3rd ed. Baltimore, Williams and Wilkins, 1982, pp 563-602.
- Garrick J. Treatment of ankle injuries. *Cleveland Clinic Foundation Sports Medicine Symposium*, 1983.
- Guyton AC. *Textbook of Medical Physiology*. 5th ed. Philadelphia, WB Saunders, 1976, pp 380-381, 675-677.
- Lewis T. Observations upon the reactions of the vessels of the human skin to cold. *Heart* 1930; **15**:177-208.
- DeJong RH, Hershey WN, Wagman IH. Nerve conduction velocity during hypothermia in man. *Anesthesiology* 1966; **27**:6, 805.
- DeJesus PV, Hausmanowa-Petrusewicz I, Barchi RL. The effect of cold on nerve conduction of human slow and fast nerve fibers. *Neurology* 1973; **23**:1182-1189.
- Douglas WW, Malcolm JL. The effect of localized cooling on conduction in cat nerves. *J Physiology* 1955; **130**:53-71.
- Lee JM, Warren MP, Mason SM. Effects of ice on nerve conduction velocity. *Physiotherapy* 1978; **64**:2-6.
- Abramson DI, Chu LSW, Tuck S Jr, Lee SW, Richardson G, Levin M. Effect of tissue temperature and blood flow on motor nerve conduction velocity. *JAMA* 1966; **198**:1082-1088.
- Bugaj R. The cooling, analgesic, and rewarming effects of ice massage on localized skin. *Phys Ther* 1975; **55**:11-19.
- Melzack R, Wall PD. Pain mechanisms: a new theory. *Science* 1965; **150**:971-979.
- Haines J. A survey of recent developments in cold therapy. *Physiotherapy* 1967; **53**:222-229.
- Eldred E, Lindsley DF, Buchwald JS. The effect of cooling on mammalian muscle spindles. *Exp Neurol* 1960; **2**:144-157.
- Hartviksen K. Ice therapy in spasticity. *Acta Neurol Scand* 1962; **38**(suppl 3):79-84.
- Knutsson E. Topical cryotherapy in spasticity. *Scand J Rehabil Med* 1970; **2**:159-163.
- Knutsson E, Mattsson E. Effects of local cooling on mono-synaptic reflexes in man. *Scand J Rehabil Med* 1969; **1**:126-132.
- Hedenberg L. Functional improvement of the spastic hemiplegic arm after cooling. *Scand J Rehabil Med* 1970; **2**:154-158.
- Griffen JE, Karselis TC. *Physical Agents for Physical Therapists*. Springfield, Ill, Charles C Thomas, 1978, p 4.
- Lowdon BJ, Moore RJ. Determinants and nature of intramuscular temperature changes during cold therapy. *Am J Phys Med* 1975; **54**:223-233.
- Glaser EM, Whittow CC. Adaptions to cold. *J Physiol* 1957; **136**:98-111.
- Wolf SL, Basmajian JV. Intramuscular temperature changes deep to localized cutaneous cold stimulation. *Phys Ther* 1973; **53**:1284-1298.
- Johnson DJ, Moore S, Moore J, Oliver RA. Effect of cold submersion on intramuscular temperature of the gastrocnemius muscle. *Phys Ther* 1979; **59**:1238-1242.
- Bierman W, Friedlander M. Penetrative effect of cold. *Arch Phys Ther* 1940; **21**:585-592.
- Waylonis GW. The physiologic effects of ice massage. *Arch Phys Med Rehabil* 1967; **48**:37-42.
- Knight K, Aquino J, Urban C. A re-examination of Lewis's cold-induced vasodilatation—in the finger and ankle. *Athletic Training* 1980; **15**:248-250.
- Knight KL, Londeree BR. Comparison of blood flow in the ankle of uninjured subjects during therapeutic applications of heat, cold, and exercise. *Med Sci Sports Exercise* 1980; **12**:76-80.
- Prentice WE. An electromyographic analysis of the effectiveness of heat or cold and stretching for inducing relaxation in injured muscle. *J Ortho Sports Phys Ther* 1982; **3**:133-140.
- Knott M, Barufaldi D. Treatment of whiplash injuries. *Phys Ther Rev* 1961; **41**:573-577.

40. Hocutt JE Jr, Jaffe R, Rylander R, Beebe JK. Cryotherapy in ankle sprains. *Am J Sports Med* 1982; **10**:316-319.
41. Basur RL, Shephard E, Mouzas GL. A cooling method in the treatment of ankle sprains. *Practioner* 1976; **216**:708-711.
42. Hayden CA. Cryokinetics in an early treatment program. *J Am Phys Ther Assoc* 1964; **44**:990-993.
43. Yackzan L, Adams C, Francis KT. The effects of ice massage on delayed muscle soreness. *Am J Sports Med* 1984; **12**:159-165.
44. Cornelius W, Jackson A. The effects of cryotherapy and PNF on hip extensor flexibility. *Athletic Training* 1984; **19**:183-185.
45. Harris ED Jr, McCroskery PA. The influence of temperature and fibril stability on degradation of cartilage collagen by rheumatoid synovial collagenase. *N Engl J Med* 1974; **290**:1-6.
46. Pegg SMH, Littler TR, Littler EN. A trial of ice therapy and exercise in chronic arthritis. *Physiotherapy* 1969; **55**:51-56.
47. Kirk JA, Kersley GD. Heat and cold in the physical treatment of rheumatoid arthritis of the knee: a controlled clinical trial. *Ann Phys Med* 1968; **9**:270-274.
48. Rembe EC. Use of cryotherapy on the postsurgical rheumatoid hand. *Phys Ther* 1970; **50**:19-23.
49. Juhlin L, Shelley WB. Role of mast cell and basophil in cold urticaria with associated systemic reactions. *JAMA* 1961; **177**:371-377.
50. Parker JT, Small NC, Davis PG. Cold-induced nerve palsy. *Athletic Training* 1983; **18**:76.