Chapter 16

Superficial Thermal Modalities

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Superficial heat and cold have been used for centuries to manage soft tissue and joint injuries with specific goals of relieving pain, altering the physiologic processes underlying tissue healing, and affecting the plasticity of connective tissue, including muscle, tendon, ligament, and joint capsule. Superficial heat and cold may be delivered through hot or cold packs, hot or cold whirlpools, luminous or nonluminous infrared, ice massage, contrast baths, or cryokinetics. This chapter will focus on the physical principles governing the absorption of heat, the physiologic effects, and the clinical application of heat and cold. The primary goal of any thermal modality is to facilitate the ultimate therapeutic healing modality of exercise.

Electrophysical agents may be used for cryotherapy (the application of cold, using cold packs, ice massage, cold whirlpool, vapor coolant sprays, or cold compression units) or thermotherapy (the application of heat using moist heat or hydrocollator packs, paraffin baths, warm whirlpool, or infrared lamps). Cryotherapy is most effectively used immediately following trauma (accidental or intentional, as in surgical procedures) to provide analgesia, reduce inflammation and its sequelae, control bleeding, and reduce muscle spasm.

Cryokinetics combines cryotherapy with motion (passive, active-assisted, or active) to facilitate normal, pain-free movement, and to reduce edema through muscle pump action to return lymphatic fluid to the vascular system. The primary benefit of cryokinetics is to facilitate the patient's ability to perform pain-free exercise early in the rehabilitation process as long as the level of exercise remains below levels that cause further injury. As signs of acute inflammation begin to subside, the clinician may elect to transition to the use of heat. Contrast baths—alternating hot and cold baths—are most appropriate during the early subacute phase of tissue healing or in cases of chronic edema.

Superficial heat is best applied before performing flexibility exercises to take advantage of the benefits of tissue temperature elevation, including vasodilation that increases tissue oxygenation and transport of metabolites to exercising tissue, increased rate of enzymatic and biochemical reactions that may facilitate tissue healing, and altered viscoelastic properties leading to increased soft tissue extensibility, decreased joint stiffness, and increased range of motion. However, heat applied too early in the healing process may result in increased acute inflammation and possibly increase enzymatic activity detrimental to cartilage (e.g., collagenase and protease).

The Physics of Thermotherapy

Thermotherapy applications fall in the infrared portion of the electromagnetic spectrum just beyond the wavelength and frequency ranges for visible light.[1] The shorter the wavelength, the greater the frequency and depth of penetration. The thermal electrophysical modalities discussed in this chapter fall within the category of "near infrared" and possess shorter wavelengths than electrical stimulating currents. Therefore infrared electrophysical agents penetrate to a shallower depth compared to electrical stimulating currents. The biologic effects of electromagnetic radiation depend on the frequency used, duration of exposure, tissue characteristics, and power density.[1]

Electromagnetic energy and its transmission through the body are governed by several physical laws. The first law is the Arndt-Schultz Principle[2]: Tissue must absorb the energy produced by the thermal agent to stimulate the tissue's normal function. If the energy absorbed is insufficient to stimulate the tissue, there is no effect. If too much energy is absorbed, tissue damage may occur. The second law, related to the first, is the Law of Grotthus-Draper, which determines the fate of the energy. If a tissue does not absorb the energy, it is transmitted to deeper tissue layers. If the energy is absorbed more superficially, less energy will be transmitted to deeper layers and less penetration of the energy occurs. When electromagnetic energy encounters the body's tissues, it has three possible fates: it may be reflected (e.g., reflected from the skin's surface), it may be refracted (e.g., at the interface between the dermis and subcutaneous fat), or it may be absorbed (e.g., by muscle). The estimated depth of penetration for most infrared thermal modalities (cold or hot packs, whirlpools, paraffin baths, luminous infrared devices) is approximately 1 cm.

The application of superficial thermal modalities is governed by the physical laws of heat transfer, primarily conduction and radiation. Most thermal techniques transfer energy by conduction. Energy travels down a thermal gradient, with energy (heat) being removed from tissue, rather than cold being added. During cryotherapy, heat from body tissues is transferred to the cold modality via conduction provided there is direct contact between the two bodies. Heat always travels from the warmer object to the cooler.[3] According to Knight,[4] the rate at which heat transfer occurs depends on the following factors:

- *The temperature difference between the body and the modality:* The greater the difference, the more quickly the transfer of heat occurs.
- *Regeneration of body heat and modality cooling:* As the body tissue gives up heat, the heat lost is replaced by circulating blood and surrounding tissues. Cold penetrates more deeply than superficial heating modalities. For example, after a 20-minute ice pack application to the gastrocnemius muscle, the intramuscular temperature declined more slowly than the subcutaneous temperature (and never reached as cold a temperature as the subcutaneous tissue) (Figure 16-1). When the ice pack was removed, the subcutaneous tissue temperature rose steeply, whereas the intramuscular temperature continued to decline for a period of time until both tissues were within 2° to 3° C of each other.[5]

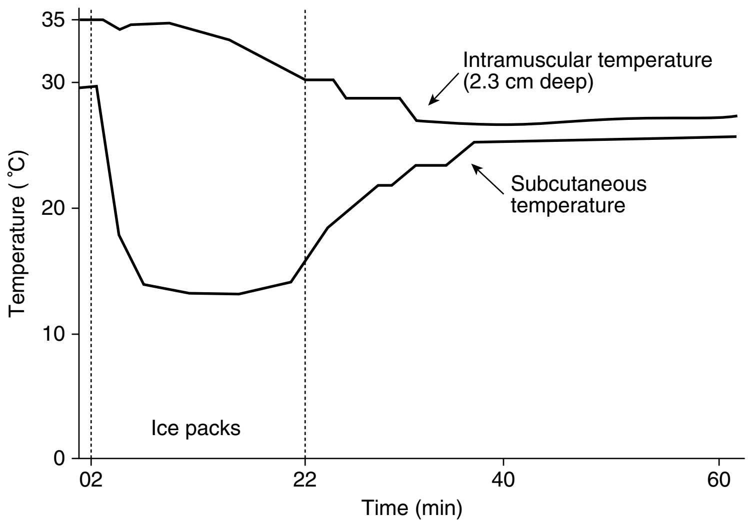

Figure 16-1 Intramuscular versus subcutaneous tissue temperature changes with cryotherapy. Intramuscular (gastrocnemius) and subcutaneous temperatures during and after a 20-min ice pack application. Note that intramuscular temperature declined much more slowly than subcutaneous temperature and continued to decrease after the ice pack was removed. (Redrawn from Hartviksen K: Ice therapy in spasticity, *Acta Neurol Scand* 38(suppl 3):79-84, 1962.)

- *The heat storage capacity of the cold modality:* The more energy it takes to convert a solid to a liquid (e.g., ice to water), the greater its latent heat of fusion and its capacity to remove heat from a tissue. For example, crushed ice packs require more energy for this conversion to occur as compared to semisolid gel packs. Therefore ice packs cool tissues for a longer time and to a greater extent than gel packs.
- *The size of the modality:* The larger the modality (e.g., cold pack), the greater the energy storage capacity.
- *The area of the body in contact with the modality:* For example, cold-water immersion results in the greatest temperature decline compared to other methods of cold delivery because a greater surface area is in contact with the cooling modality.[6] Ethyl chloride vapocoolant sprays result in the least temperature decline and provide only superficial cooling because of the relatively small surface area cooled.
- *The application duration:* The longer the contact time between the two surfaces, the more opportunity for energy exchange to occur and heat to be removed from the body.
- *Individual variability:* Individuals with lower body fat percentage exchange heat more quickly than those with greater amounts of subcutaneous fat.

Regardless of the cold pack type (ice versus commercially available cold packs), the surface temperature drops immediately after application of the cold pack and reaches its maximum effect in approximately 30 minutes in humans. Following removal, the surface temperature rises rapidly, although it may not reach preapplication levels for more than 60 minutes after removal from the skin.[4] Rewarming in animals follows a similar pattern, and it may take several hours after removal of the cold pack for complete rewarming to occur. A 30-minute cold gel pack application to the stifle joint of 10 healthy bulls decreased the intraarticular temperature 6.6° ± 1.0° C for 215 minutes.[7] Studies in dogs have reported similar decreases in intraarticular temperature.[6,8]

Physiologic Effects of Cryotherapy

Cryotherapy is used during the acute phase of tissue injury and healing to mitigate the effects and sequelae of tissue injury, and after exercise during rehabilitation to minimize adverse secondary inflammatory responses. The primary physiologic effects of cryotherapy include vasoconstriction, reduced blood flow, reduced cellular metabolism and permeability, decreased sensory and motor nerve conduction velocity, analgesia, prevention or reduction of trauma-induced edema, decreased muscle spasm, and temporary reduction of spasticity before exercise.[9,10]

During the inflammatory phase of tissue healing, increased permeability of the microvasculature occurs as a result of histamine and bradykinin release. In addition, these chemical mediators cause vasodilation and increased blood flow to the area. These events, coupled with hypoxic cellular changes, are primary factors in the formation of edema. (Centrally mediated sympathetic vasoconstriction helps to reduce edema as a result of decreased hydrostatic pressure.) The primary role of cryotherapy during the inflammatory phase is to reduce the metabolic rate of the injured tissue, which in turn results in decreased metabolite production and metabolic heat.[11] In addition, the decreased metabolic rate limits further injury and aids the tissue in surviving the cellular hypoxia that occurs after injury.[4]

The Hunting reaction, first described by Lewis in 1930, refers to the cyclical temperature oscillation of 2° to 6° C every 8 to 15 minutes after the tissue temperature approaches 2° C. This effect begins 20 to 40 minutes after cryotherapy application. He attributed these oscillations to cold-induced vasodilation (CIVD) as an attempt to protect tissues from cold-induced damage. However, his results have been incorrectly and widely applied to the sports medicine literature in an attempt to explain the success of cryokinetics.[2] Knight et al[12] replicated Lewis' experiment and concluded that Lewis' observation during cold immersion and subsequent rapid increase in temperature after cryotherapy are due to temperature effects, not CIVD and subsequent increased blood flow. Based on these studies, the primary benefits of cryotherapy are twofold: decrease in cellular metabolism and analgesic effects to permit cryoexercise to facilitate rehabilitation.[4,12]

The response to cryotherapy treatment is also mediated by the nervous system. Peripheral thermal receptors are categorized as cutaneous myelinated type III or A delta, which are sensitive to pricking or sharp pain and cold, unmyelinated type IV or C receptors for aching pain, and unmyelinated type IV or C cutaneous receptors for pain and temperature (Table 16-1).

The unmyelinated cutaneous receptors respond to absolute temperature and the rate of temperature change.[13] The cold-sensitive receptors begin firing at 36° C and increase their firing rate until reaching their maximum at approximately 25° C. The firing frequency drops sharply at temperatures below 20° C and is minimal by the time the receptors are cooled to 10° to 12° C. Conversely, the warm receptors also begin firing at 33° to 36° C, rapidly reach their maximum firing frequency at 43° C, and drop to a minimal firing rate at 45° C.[14] Both the hot and cold receptors rapidly adapt to temperature changes.

Central thermosensitive neurons in the preoptic and anterior hypothalamus respond to temperature changes with autonomic responses to stimulate heat retention by the body by altering cutaneous blood flow and thermoregulatory behavior such as panting. Figure 16-2 illustrates this central hypothalamic control of thermoregulation. The anterior hypothalamus also controls thermoinsensitive neurons, such as those that are sensitive to osmolarity and glucose concentration.[15,16] Stimulating the posterior hypothalamus by heating does not result in the autonomic responses characteristic of the anterior hypothalamus, but behavioral responses to the heat load occur. Local warming of the medulla increases respiratory frequency. Autonomic thermoregulatory responses also take place at the spinal cord level.[16] The sympathetic nervous system response to thermal load is also chemically mediated through the release of the neurotransmitters epinephrine and norepinephrine from the adrenal medulla to induce cutaneous vasoconstriction.[15]

A primary effect of cryotherapy is analgesia and the concomitant reduction of reflex muscle spasm. This may be due to the decreased nerve conduction velocity that occurs when nerves are cooled. This relationship, known as the Q10 effect, is thought to be linear until 10° C, when neural transmission is blocked.[17,18] Nerve cooling also increases the duration of the refractory period, the time when a nerve cannot be stimulated by a second impulse.[19]

Table 16-1 Sensory Receptors: Anatomy, Location, and Function

Receptor	Type	Sensory Nerve Classification	Location	Diameter (μm)	Conduction Velocity (m/sec)	Sensory Function
Sensory (afferent) myelinated	A	Ia	Muscle	12-20	72-120	Muscle spindle primary ending (or 1-degree ending)
	A	Ib	Tendon	12-20	72-120	Golgi tendon organ Rate of muscle shortening
	A	II	Muscle	6-12	36-72	Muscle spindle, secondary ending (or 2-degree ending) muscle length changes
	A	II	Skin	6-12	36-72	Vibration, discriminatory touch, pacinian corpuscles
	A	III	Skin	1-6	6-36	Pricking, sharp pain, temperature (cold), light touch
Unmyelinated	C	IV	Muscle	~1	0.5-2.0	Aching pain
	C	IV	Skin	~1	0.5-2.0	Pain, temperature

From Guyton AC: Sensory receptors and their basic mechanisms of action. In *Textbook of medical physiology,* Philadelphia, 1986, WB Saunders, p 578.

Conversely, raising the subcutaneous tissue temperature increases sensory nerve conduction velocity, with the greatest effect occurring during the initial 2° C temperature elevation.[20] Another mechanism postulated for the analgesic effect afforded by cryotherapy is that the cold receptors are overstimulated by cryotherapy, resulting in pain control at the spinal level by preventing pain transmission to higher centers via the spinal gate control theory of pain transmission.

Cryotherapy may also decrease muscle spasm through a number of proposed mechanisms. Decreasing pain may decrease muscle guarding or spasm associated with an injury. The muscle spindle receptors and Golgi tendon organ receptors fire more slowly when cooled, although the effect is less pronounced on the Golgi tendon organs.[21] Sudden cooling has an excitatory effect on the muscle spindle, resulting in increased alpha motoneuron activity and increased muscle guarding. As the temperature continues to decrease, primary spindle afferent activity diminishes.[17] Muscle spasm, resulting from the pain–spasm–pain cycle, stimulates the static stretch response of the type II tissue afferents. Applying superficial heat until the temperature is above 42° C decreases the muscle spindle discharge rate while it increases the firing rate of the Golgi tendon organ.[21] This sequence of events results in a decrease in the firing rate of the alpha motor neuron. Thus cold may raise the threshold stimulus for muscle spindle activity, decreasing muscle spasm.[22]

Thermal effects on strength and endurance have also been observed by a number of authors. The force-velocity curve of muscle contraction shifts downward with decreasing temperature.[23] For a given concentric contraction velocity, cooler muscles have a lower force output. Interestingly, proprioception, joint position, and balance remain largely unaffected by cryotherapy.[24-26] Although most authors agree that changes in muscle torque production occur with cooling, it is less clear whether those effects are specific to a particular contraction mode (concentric acceleration or eccentric deceleration). One group of researchers reported that eccentric muscle action is augmented following cryotherapy,[27] while another group found increases in concentric, but not eccentric, torque.[28] Still others found no effects on peak torque, but increased muscle endurance following cooling.[29] Functionally, vertical jump performance, an indicator of lower-extremity explosive power, is adversely affected by cryotherapy.[30,31] These findings suggest that caution must be used in making recommendations for performance following cryotherapy. Clearly the literature on this subject is undecided as to the specific effects of cold (both immediate and delayed) on muscle strength. These findings have the most implication for dogs who are engaged in work or competitive athletic pursuits. It also

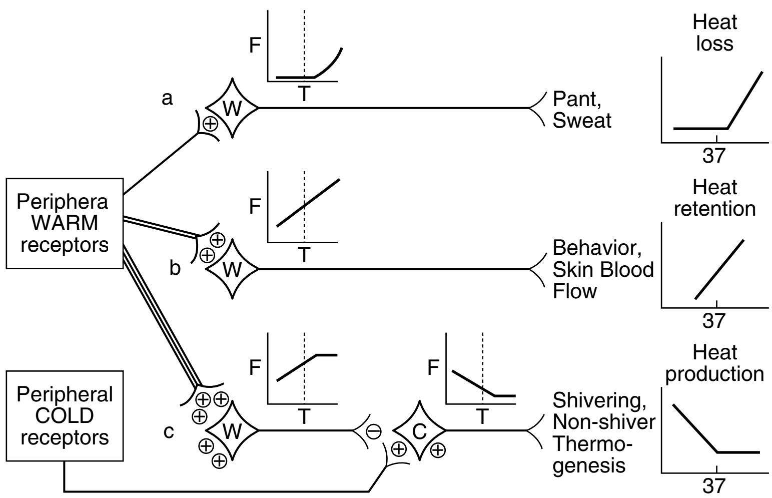

Figure 16-2 Central hypothalamic control of thermoregulation. Diagram shows neuronal control of various thermoregulatory responses. +, Excitatory input; –, inhibitory control; *dashed line*, thermoneutral temperature; *C*, cold-sensitive neuron; *F*, neuronal firing rate; *T*, hypothalamic temperature; *W*, warm-sensitive neuron. (Redrawn from Boulant JA, Dean JB: Temperature receptors in the central nervous system, *Ann Rev Physiol* 48:639-654, 1986.)

requires that the clinician understand the physiology and biomechanics of muscle actions and sport demands. Cold and exercise are an effective combination in the treatment of acute musculoskeletal dysfunction unless restrictions in flexibility are present.[32,33] Combining movement with cold allows for relatively greater pain-free exercise and assists in the muscle pump activity to reduce acute injury-related edema.

Cryotherapy Applications

A variety of methods are available for applying cryotherapy to dogs. Selection of the method depends on the desired effects and is influenced by the stage of tissue repair, physiologic goals (analgesia, edema reduction, lymphatic pumping, and so forth), depth of penetration desired, treatment area, and activity or exercise goals. Cryotherapy is particularly helpful in the management of acute inflammation (bursitis, tenosynovitis, tendinitis, and so forth) where application of heat causes additional pain and edema. Cryotherapy methods include ice packs (homemade, commercial cryogel packs, elastic wraps), cryomassage, ice bath immersion, contrast baths, and vapor coolant (ethyl chloride) spray (Figure 16-3). To prevent frostbite or cold-induced injuries, it is critical to observe the skin for response to cold. Near the end of a 20-minute treatment, the skin may normally be erythematous, but pale or white skin is an indication that cold-induced tissue damage may be occurring. The range of expected sensations during cryotherapy include an initial sensation of cold, followed by burn, sting, and ache, and finally a numb sensation.[12] For most injuries, application times of 20 to 30 minutes may not be sufficient to cool the injured tissues; the notion of "maximum benefit in 20 minutes" has not been substantiated with research.[4] Because animal patients cannot describe these sensations, careful observation of the animal's behavioral responses and skin condition every few minutes during the treatment session is critical.

Ice packs

Several methods may be used to apply superficial cold (see Figure 16-3). The simplest method of ice application is to wrap a freezer bag containing crushed ice in a thin damp cloth (such as a pillowcase) and apply directly over the affected area. Before sealing the bag, remove the excess air. The addition of a compression wrap to secure the bag to the body also insulates the body surface against air, resulting in additional reduction of surface temperature during cooling and slower rewarming following removal of the ice.[34] If crushed ice is not available, cold packs may be prepared by mixing 3 parts water to 1 part rubbing alcohol, double bagging with sealed bags, and placing in a freezer. The resulting slush may then be molded around irregular body parts. If the mixture freezes in a household freezer, more alcohol can be added to the mix. If it is too liquid, more water can be added. To prevent skin damage, apply a towel or cloth to prevent direct contact of the ice pack with the animal's skin. Apply the cryotherapy treatment for 15 to 25 minutes at a time, inspecting the tissue for its response after the first 5 to 10 minutes. Monitor closely for signs of frostbite.

The latent heat of fusion is lower for the alcohol-water mix than for water alone; therefore it performs similarly to crushed ice alone, but a lower temperature. Use caution with the water-alcohol mix because the potential for cold-induced injuries is greater. Never apply this mixture directly to the skin; instead apply using a layer of toweling, either wet or dry

Figure 16-3 Cryotherapy options (clockwise starting top right): Popsicle-type molds for ice massage, alcohol-water slush plastic bags, cotton wraps, commercial cold wraps, flouromethane cold spray.

(wet conducts cold more rapidly). Commercial cold packs may also be applied. Packs that freeze solid (e.g., DuraKold) perform better than frozen gel packs, which contain gelatin or antifreeze to make them more pliable (Figure 16-4).[4] *Cold packs containing ethylene glycol antifreeze should not be used in animals because the contents are toxic if ingested.* As with the alcohol-water mixture, use caution because the risk for frostbite is greater than when using a crushed ice bag (Figure 16-4).

Artificial ice cubes (e.g., Cold Gold), manufactured by the sheet, may be trimmed to fit the body part and secured with elastic wrap or used with commercial custom-designed wraps (e.g., CanineIcer, www.canineicer.com) (Figures 16-5 and 16-6). They offer the advantage of ice cubes without the mess of melting ice. Used often in postoperative cryotherapy applications to minimize postoperative edema and pain, the sheets are somewhat pliable and may be refrozen.

Cold-Compression Units

Cold compression units, which are commercially available, combine compression with cryotherapy. Cold water circulates in a fabricated sleeve which is snugly applied to provide compression to the area. Combined with elevation, this method of treatment is highly effective during the acute phase of tissue inflammation and healing.

Cold Immersion and Contrast Baths

Cold immersion, because it exposes the greatest body surface area to cold, results in the greatest decreases in tissue temperature. The body part is immersed in an ice “slush” bath as part of the immediate first aid following injury (Figure 16-7). The analgesia from the immersion allows the animal to perform cryokinetics with relative ease. Contrast baths, in which the affected body part is immersed in cold water followed by immersion in hot water, have long been used as a method to induce cyclic vasodilation and vasoconstriction to facilitate flushing debris and inflam-

Figure 16-5 Canine stifle icer.

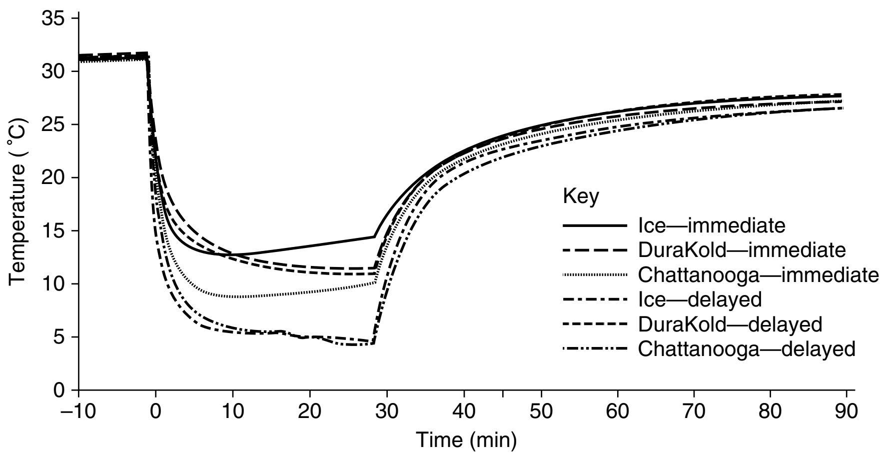

Figure 16-4 The effect of the heat of fusion can be seen in this comparison of several forms of cold packs. The crushed ice and DuraKold packs cool the skin more than the Chattanooga frozen gel pack. The effect is even greater when application is delayed for 20 min after the packs are removed from their cooling devices. (Knight KL et al: A re-examination of Lewis’ cold-induced vasodilation in the finger and ankle, *Athletic Train* 15:238-250, 1980.)

Figure 16-6 Carpal icer.

Figure 16-7 Contrast baths.

Figure 16-8 Ice massage.

matory mediators from the injured area. However, some authors do not agree with this proposed mechanism.[4] Clinically, it may be appropriate to use contrast baths during the transition from acute to subacute injury management. The body part is immersed in alternating cold and hot baths, in a ratio anywhere from 4C:1H (4 minutes cold, 1 minute hot) near the end of the acute phase, to 2H:2C (2 minutes hot, 2 minutes cold). This cycle is repeated three to five times for a total of 15 to 30 minutes. If the injury is relatively acute, the final cycle should be in the cold bath to help reduce edema formation. If contrast baths are used before exercise in subacute or chronic conditions, then the final cycle should be in the hot bath. If used as a transition from the acute to subacute stages of tissue healing, the cold:hot ratio should be weighted more toward a cold emphasis (e.g., 4C:1H) progressing to 2H:2C and 3H:1C depending on the clinical evaluation before treatment. Specific ratios of hot to cold depend on the clinical goals of the treatment.

Ice Massage

Ice massage is a very quick and effective method of applying cryotherapy to the affected area with the muscle in a position of gentle stretch (Figure 16-8). Molds to form a cylinder of ice with an application stick are commercially available. Placing tongue depressors in paper cups filled with water and freezing them is a low-cost alternative for making "ice Popsicles" to perform ice massage. Ice massage is applied parallel to the muscle fibers. The pressure from the ice massage stimulates the mechanoreceptors more than other forms of cryotherapy.[4] This technique is particularly useful for small, irregular areas. Treatment time is generally 5 to 10 minutes or until the affected area is erythematous and numb.

Vapocoolant Sprays

Vapocoolant sprays have long been used to treat trigger points in humans.[35] However, their ability to cool is the least effective of all the methods and results in cooling only of the superficial cutaneous tissue. To use the vapocoolant spray to treat trigger points, place the affected muscle in a position of slight stretch and spray from proximal to distal at a rate of 10 cm/sec from a distance of 30 cm (12 inches) (Figure 16-9). Repeat four or five times until the affected area has been covered. Because of the dog's hair, the effectiveness of this technique is questionable. These sprays can also be potentially dangerous if they accidentally get in the animal's eyes or are ingested.

Figure 16-9 Flourimethane vapocoolant spray.

Indications for Cryotherapy

Cryotherapy is best applied during the acute inflammatory phase of tissue healing and after exercise to minimize any inflammatory response. Cryotherapy is effective in reducing pain, particularly acute postoperative pain. In addition, it is effective in reducing edema when combined with compression and elevation. Cold also decreases the metabolic rate of reactions involved in tissue injury and healing. At joint temperatures of 30° C (86° F) or lower, the activity of cartilage-degrading enzymes, including collagenase, elastase, hyaluronidase, and protease, is inhibited.[36] If cryotherapy is applied during the subacute or proliferative phase of tissue healing, recovery may be impaired. When there are minimal signs of inflammation and the patient tolerates simple range-of-motion and flexibility exercises without an increase in swelling or pain, the treatment may progress to heat.

Treatment Duration and Frequency

The duration and frequency of cryotherapy depend on the severity of the injury, the area of injury, and the desired outcome. Treatment times may be cycled to 30 to 45 minutes on, followed by an equal amount of time off. Practically, cryotherapy is typically administered three to six times daily. It should be continued until the healing tissue moves into the proliferative (subacute) phase of healing. Cryotherapy should be applied to support the goal of pain-free exercise and may also be applied following an exercise session to minimize reactive swelling and pain.

Precautions and Contraindications

Although the application of superficial cold and ice is relatively safe, there are conditions in which the use of cryotherapy is contraindicated. The clinician is cautioned to observe for signs of frostbite during and after cryotherapy application. If the individual has a history of frostbite to the area, further cold application is contraindicated. Cryotherapy should not be used in individuals who are cold-sensitive or demonstrate a response, such as cold urticaria, to the application of cold. Cold urticaria causes wheals and swelling on skin (due to a release of histamine) when the animal is exposed to a reduction in temperature. In dogs with cold sensitivites, care should be taken not to expose large areas of the skin to the cold and should not swim in cold temperatures.

Caution should be exercised when applying cryotherapy around superficial peripheral nerves because cases of cold-induced nerve palsy of the ulnar and superficial peroneal nerves have been reported in people. Knight estimates the incidence of cold-induced neuropathies to be less than 0.0011%.[4] Cold should also not be used in patients with generalized or localized vascular compromise or who possess an impaired thermoregulatory capacity. Use caution in applying cold over open wounds, areas of poor sensation, or in very young or old dogs.

Physiologic Effects of Heat

Heat is used in rehabilitation for its hemodynamic, neuromuscular, metabolic, and connective-tissue effects. Heat is most appropriately applied after the acute inflammatory phase of tissue healing has resolved. Premature application of heat may exacerbate swelling, pain, heat, and functional loss. If in doubt, apply cold or contrast baths until the dog is well into the subacute, or proliferative, stage of tissue healing.

Superficial heating agents such as hot packs or hot baths have the greatest effect on cutaneous blood vessels, resulting in the greatest temperature change within the first 1 cm of tissue depth. Increased superficial tissue temperature results in the release of chemical mediators, such as histamine and prostaglandins, which result in vasodilation. The second mechanism for vasodilation occurs with the stimulation of cutaneous thermoreceptors that synapse on the cutaneous blood vessels, causing the release of bradykinin to relax the smooth muscle walls, resulting in vasodilation. A third mechanism for vasodilation involves the reduction in sympathetic activation via spinal dorsal root ganglia to reduce smooth muscle contraction, resulting in vasodilation at the application site and indirectly to the cutaneous blood vessels of the extremities.[36] These vasodilatory mechanisms do not significantly affect blood flow in skeletal muscle since skeletal muscle blood flow is heavily influenced by other physiologic and metabolic factors. Exercise is the best means to increase blood flow to skeletal muscle.[37]

The neuromuscular effects of heat, in contrast to those of cold, include increased nerve conduction velocity and decreased latency time for both sensory and motor nerves. Nerve conduction velocity increases 2 m/sec for every 1° C (1.8° F) increase in temperature.[36] Muscle relaxation occurs as a result of a decreased firing rate of type II muscle spindle afferents and gamma efferents, and an increased firing rate of type II fibers of the Golgi tendon organs (see Table 16-1). These, in turn, contribute to a decrease in firing of the alpha motoneuron to the extrafusal muscle fiber, resulting in muscle relaxation. Heat lowers the stimulus threshold for muscle spindle activity.[22]

The pain threshold may be elevated with localized heat application. Stimulation of the cutaneous thermal receptors has been proposed to inhibit the transmission of pain at the dorsal horn of the spinal cord via the gate control mechanism. Second, vasodilatation increases the blood flow to reduce ischemia of injured tissue, resulting in decreased activity of the pain receptors. Decreased muscle spasm further relieves pressure of the muscles on blood vessels, reducing ischemia and promoting blood flow.

Heat accelerates biochemical reactions, both enzymatic and metabolic, up to a temperature of 45° C (113° F); increases above this result in decreased activity of these reactions. From 39° to 43° C (102° to 109° F), enzymatic activity increases 13% for every 1° C increase in temperature or doubles for every 10° C increase in temperature.[38] Although heat increases oxygen uptake and accelerates tissue healing, it also increases the activity of destructive enzymes, such as collagenase, and increases the catabolic rate. The oxygen-hemoglobin dissociation curve shifts to the right, making more oxygen available for tissue repair or exercise. Combined with the increased biochemical reaction rate, superficial heat may accelerate tissue healing if the tissue injury is superficial. For thermal effects in deeper tissues, ultrasound or diathermy are most appropriate. The patient's status and tolerance to treatment should be evaluated daily to determine the most appropriate treatment.

Heat causes increased connective tissue extensibility if the tendon, ligament, scar tissue, or joint capsule tissues are superficially located. Deeper musculotendinous or joint capsule structures should be heated using ultrasound or diathermy, which are capable of elevating tissue temperature at greater depths. For the maximum connective tissue plastic deformation to occur, the tissue temperature must be maintained at 40° to 45° C (104° to 113° F) for a minimum of 5 to 10 minutes while applying the stretch.[36] In cases where the viscoelastic properties of connective tissue are to be altered, the tissue must be subjected to adequate concurrent heat and stretch for a sufficiently long period of time to result in permanent tissue elongation.[39] Lower loads applied over a longer period of time during tissue heating and recooling result in less secondary tissue trauma.[40] Superficial heat may be successfully applied to reduce joint stiffness and increase the elasticity of superficial joint capsular structures to facilitate exercise.

Heat Application

Superficial thermal therapy may be applied using commercially available packs containing cornhusks, gel material that can be used for either hot or cold application, or packs containing iron filings (activation of such packs produces heat for several hours following a chemical reaction resulting in oxidation) (Figures 16-10, 16-11, and 16-12). Commercially available wraps may also be used for heat application by placing heat packs inside the wraps.

Treatment Duration and Frequency

The duration and frequency of thermal treatment depends on the severity of the injury, the stage of tissue healing, the area of the injured part, and the desired outcome. Treatment times may be cycled at 30 to 45 minutes on, followed by an equal amount of time off. Thermal modalities should be applied to support the goal of pain-free exercise, the ultimate therapeutic modality, to obtain the best results in the shortest period of time.

Figure 16-10 Superficial hot pack application with commercially available hot pack with straps.

Figure 16-11 Shoulder heat pack with custom wrap (Courtesy CanineIcer, Charlottesville, VA, SofTouch hot/cold pack, PI Medical, Athens, TN).

Figure 16-12 Canine shoulder heat application (www.canineicer.com).

Contraindications and Precautions for Superficial Heat Applications

Superficial heat is contraindicated during acute inflammation because it may exacerbate the inflammatory process, over an area of subcutaneous or cutaneous hemorrhage or thrombophlebitis, or over malignant tissue. Superficial heat should be used with caution in patients with poor thermoregulatory capacity, edema, impaired circulation, or over open wounds. Dogs should be monitored closely because they cannot verbalize their intolerance. A tissue burn may result if the patient is not able to dissipate the heat load via vasodilation or if too much heat (too hot or too long) is applied. Burns can be avoided by using materials that cool as the treatment progresses, by increasing the insulation layer between the patient and the hot pack, or by limiting the initial temperature increase. Monitor the skin condition before, during, and after treatment for any adverse effects.

Conclusion

Thermal heat therapy and cryotherapy are powerful adjuncts in the rehabilitation of musculoskeletal injuries in dogs. Successful management depends on an accurate assessment of the dog's presenting problems at the beginning of each treatment session. Cryotherapy and cryokinetics are most useful during the acute inflammatory stages of tissue healing. As tissue healing is established, with relatively weak hydrogen bonds it is susceptible to injury from exercise that is too aggressive or from changing from cold to heat too early, thus exacerbating the inflammatory response. After new tissue has been established and the tensile strength of the tissue continues to increase as the bonds strengthen into covalent bonds, the emphasis shifts to promoting a mobile scar, normal range of motion, and normal flexibility. In patients with limitations in these areas, concurrent application of superficial heat and flexibility exercises results in beneficial plastic changes to the tissue that may be relatively permanent. Superficial cold and heat modalities may be a very useful adjunct in a rehabilitation program to facilitate nature's ultimate therapeutic modality: controlled exercise. Selection of the appropriate modality depends largely on an understanding and accurate assessment of the stage (acute inflammatory, proliferative, or tissue remodeling) of tissue healing, an accurate clinical assessment of the dog's functional abilities, establishing appropriate treatment goals, and continued reevaluation when the patient status changes as tissue healing progresses. Any therapeutic modality (heat, cold, ultrasound, laser, etc.) should be used to facilitate the ability of the dog to participate with Mother Nature's ultimate therapeutic modality: exercise, first controlled, then free.

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