21 Laser Therapy in Canine Rehabilitation

Darryl L. Millis and Debbie Gross Saunders

Healing properties have been attributed to light for thousands of years. Light provides electromagnetic radiation in the form of photons. A number of forms of light have been used for therapeutic purposes, including sunlight, incandescent light, infrared light, ultraviolet light, light-emitting diodes (LEDs), and, recently, therapeutic lasers. This chapter focuses on therapeutic lasers rather than surgical lasers. Laser therapy has been increasingly incorporated into rehabilitation programs for a variety of conditions, including skin wounds; muscle, tendon, and ligament injuries; neurologic conditions; arthritis; and pain. Many studies have indicated encouraging results with laser therapy. The principles of lasers, research pertaining to the use of laser therapies in rehabilitation, and the basics of laser therapy are addressed.

Laser Therapy

The term *laser* is an acronym for *light amplification by stimulated emission of radiation.* The concept of the use of light for therapeutic purposes, called *phototherapy,* originated from the belief that sun and other sources of light, such as infrared and ultraviolet light, have therapeutic benefit. Many different types of lasers are available for medical and industrial purposes. Low-power laser devices, a form of artificial light, were first used as a form of therapy more than 30 years ago. Today, a variety of lasers are in use for various purposes.

The initial types of lasers used for rehabilitation purposes, commonly known as low-level laser therapy (LLLT), are also called *cold lasers.* In contrast, surgical lasers are high power and capable of thermal destruction of cells and tissues. Recently another form of laser, known as a *therapeutic laser,* has been introduced for rehabilitation purposes and delivers more power than low-level lasers, but less power than surgical lasers. Therapeutic lasers have become increasingly popular in both small and large animal rehabilitation for a variety of conditions.

The lasers used in rehabilitation help to modulate cellular functions. This process is known as *photobiostimulation* and is defined as nonthermal interaction of monochromatic radiation with a target site.[1] Although the physiologic interaction of this type of energy application on tissue is still not completely understood, low-energy lasers have been reported to modulate various biologic processes, such as mitochondrial respiration and adenosine triphosphate (ATP) synthesis, to accelerate wound and joint healing, and to promote muscle regeneration.[2,3] In addition, acute and chronic pain control has been reported using this type of low-energy photon therapy.[4] Treatment of chronic and acute edema, neurologic conditions, and postoperative care are some other popular conditions treated with laser therapy.

Properties of Lasers

Basic light sources emit electromagnetic radiation that is visible to the normal eye. Although natural light sources, such as sunlight, are forms of electromagnetic radiation, lasers are artificial sources that emit radiation in the form of a flow of photons (Figure 21-1). The process of light emission begins with activation of electrons in the laser unit, generally either helium-neon (HeNe), gallium-arsenide (GaAs), or gallium-aluminum-arsenide (GaAlAs) to an excited state.[5] When the electrons drop from their excited state to their ground state, photons are emitted. Although some photons are absorbed by the laser chamber wall, others stimulate the emission of other photons, and together they travel in the chamber, amplifying this stimulated emission, which results in a chain reaction. Some of these photons are released through a semireflective mirror to form a beam of light.

The major difference between laser light and light generated by normal sources is that laser light is monochromatic, coherent, and collimated. *Monochromatic* means that all light produced by the laser is of one wavelength, and therefore a single color. Sunlight, or white light, may be broken into several different colors of different wavelengths by a prism (Figure 21-2). Laser light has electromagnetic radiation of only one wavelength. Commercial lasers occasionally have two or more different wavelengths within a single unit to achieve different effects, but each component within the unit has a single wavelength and is monochromatic. The coherent properties of light mean that the photons travel in the same phase and direction (Figure 21-3). Laser light is also collimated, which means that

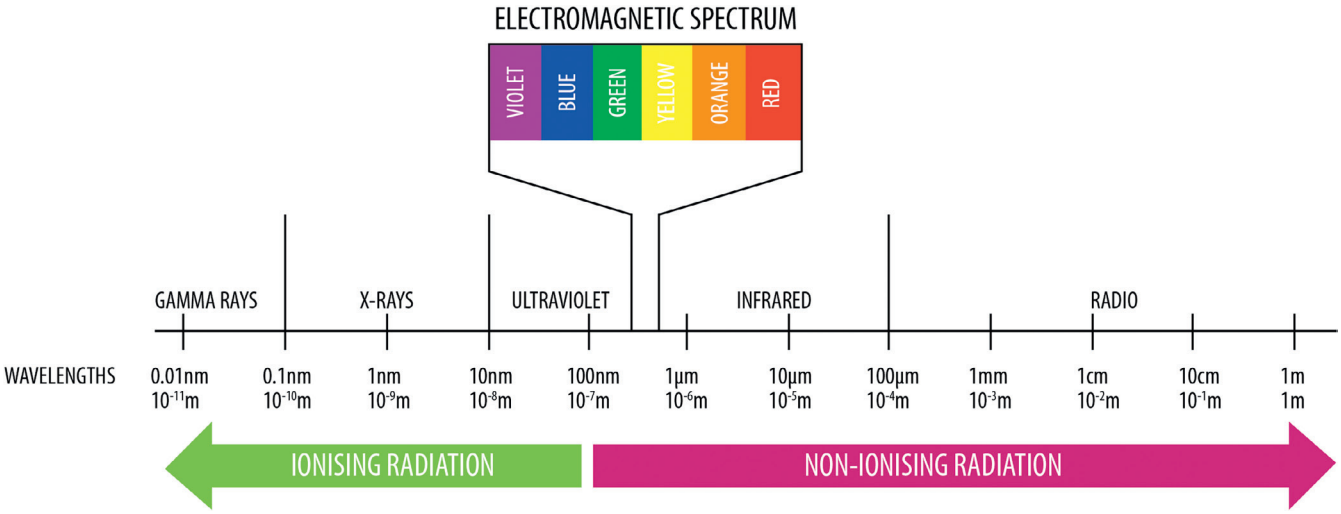

Figure 21-1 Electromagnetic spectrum. Laser light typically falls within the infrared or near red portion of the electromagnetic spectrum. (Photo Courtesy Companion Laser, LiteCure LLC, Newark, Delaware.)

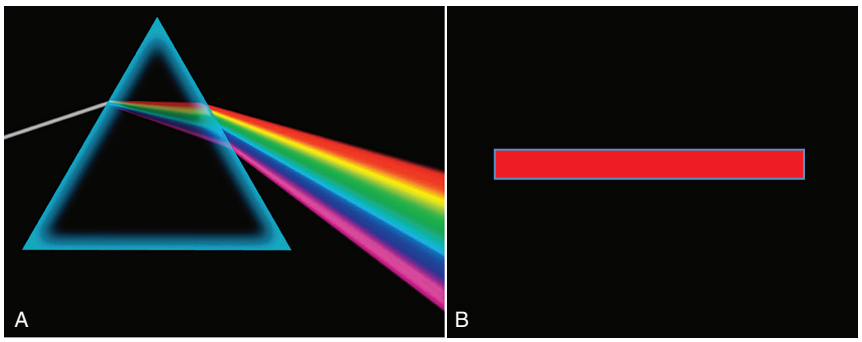

Figure 21-2 **A,** Sunlight, or white light, may be broken into several component colors with different wavelengths. **B,** Laser light is monochromatic and is produced by a single wavelength.

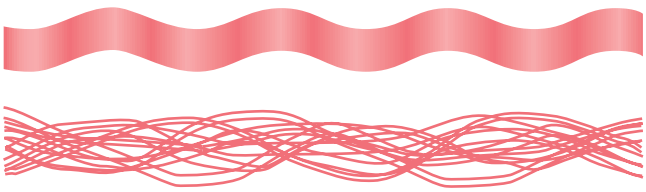

Figure 21-3 Laser light is coherent, with the photons traveling in the same phase and direction, whereas normal light is noncoherent.

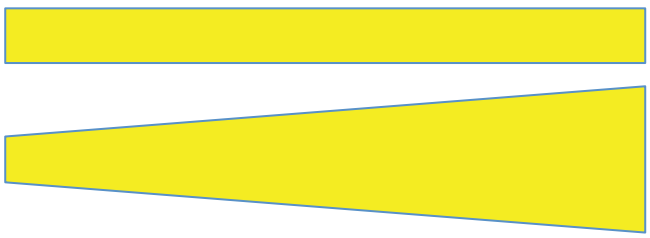

Figure 21-4 Laser light is collimated, which means that there is minimal divergence in the laser beam over a distance. Normal light is not collimated, and the beam diverges over a distance.

there is minimal divergence in the laser beam over a distance (Figure 21-4). Using a monochromatic light source allows the absorption of the light to be targeted to specific wavelength-dependent chromophores, or photon acceptors.[5] The properties of coherence and collimation allow the light to be focused precisely on small areas of the body. These properties allow low-level laser light to penetrate the surface of the skin with no heating effect, no damage to the skin, and few or no side effects when properly used.

Laser light interacts with tissues in various ways. Light may be reflected, scattered, transmitted, or absorbed. Reflected photons have no clinical effect and may be dangerous to tissues that encounter reflected photons, such as the eyes. In addition to surfaces such as watches, tables,

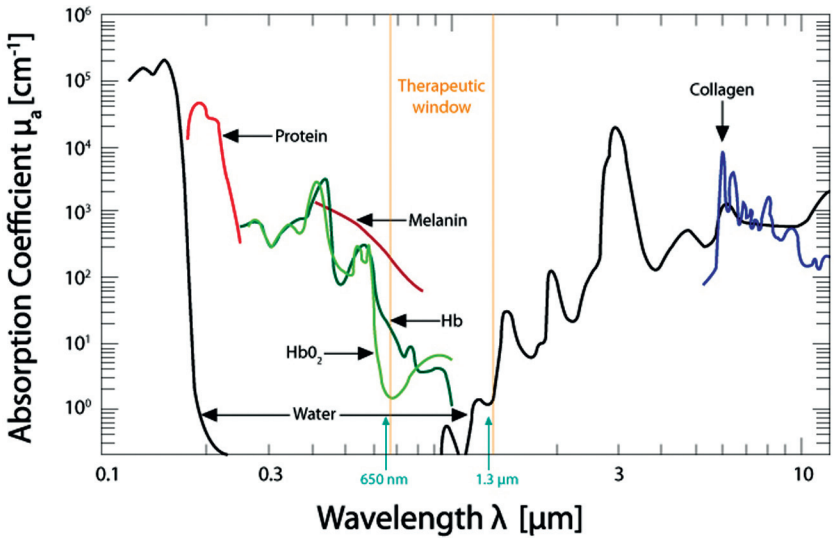

Figure 21-5 The wavelength of the photons is important in laser therapy. Various substances preferentially absorb laser light at different wavelengths. (Photo Courtesy Companion Laser, LiteCure LLC, Newark, Delaware.)

and instruments, the epidermis is responsible for reflecting most of the photons from the skin. To reduce reflection of photons, the laser beam should be directed as nearly to 90 degrees as possible to the skin surface. As photons pass through the tissues, some are scattered. Each photon that is scattered when striking an object reduces the amount of energy that can be directed at the target tissue. Scattering decreases as the wavelength increases because longer wavelengths penetrate deeper into tissues. Transmitted photons pass completely through the tissue without being absorbed. This is rarely a problem in rehabilitation because the tissues are generally thick enough to prevent complete transmission. Finally, photons may be absorbed. Photons are absorbed by chromophores (molecules that absorb certain wavelengths of light) and it is in this manner that laser may affect tissues. The most common chromophores are water, hemoglobin, melanin, cytochrome C system in mitochondria, proteins, and amino acids.[6] The relative amounts of chromophores vary among tissues, and the absorption of photons by chromophores varies, in part, on the wavelength.

The wavelength of the photons is important in laser therapy. Wavelengths are measured in nanometers (nm) and determine, in part, the biologic effect on tissues. For example, ultraviolet light (100-400 nm) is absorbed primarily by melanin, proteins, and nucleic acid; visible light (400-760 nm) is scattered and absorbed, with the absorption primarily by melanin, hemoglobin, and myoglobin; with near infrared light (760-1400 nm), photons are mainly scattered, but a variety of chromophores absorb these photons, although somewhat weakly; in the far infrared zone (1400-10,000 nm), absorption is almost entirely by water (Figure 21-5).[6] Therefore the optimal window to have tissue penetration with less scattering and surface absorption is likely to be in the 600-1200 nm range.

In addition to wavelength, the power of the laser is also a characteristic that is important. Power is a unit of time and is expressed in watts (W) or milliwatts (mW).

$$1 \text{ watt} = 1 \text{ joule/second}$$

The spot size of the unit indicates the surface area the laser covers while held in a stationary position. This is also known as the *power density,* or *intensity,* and indicates the power per surface area unit. It is usually indicated by watts/cm^2. Larger spot areas result in a more homogeneous passage of laser light through tissues with less photon scattering and light dispersion.

The energy is the power emitted over time, and is usually measured in joules. This is also frequently used to report the dosage of laser light.

$$1 \text{ joule} = 1 \text{ watt} \times 1 \text{ second}$$

For example, a 50-mW laser delivers 1 J of energy in 20 seconds of treatment time. A 500 mW laser takes 2 seconds of treatment time to deliver 1 J of energy. A 1-W laser takes only 1 second, and a 10-W laser takes $\frac{1}{10}$ of a second. From a treatment standpoint, a higher watt laser delivers the treatment in a shorter time. If an arthritic stifle is being treated, it may require a total dose of 100 to 500 J depending on the size of the dog and treatment area. So the treatment time may vary greatly depending on the unit used.

The energy density, or radiant exposure, is the energy per surface unit and is typically indicated by joules per cm^2, or J/cm^2. This term is also clinically called the *dose of laser energy* and is important in determining and describing treatment protocols. To date, only the dose of laser energy

Box 21-1 Biologic Effects of Laser Therapy

Activation of respiratory chain enzymes, especially cytochrome C oxidase
Oxygen production
Formation of proton gradients across cell and mitochondrial membranes
Adenosine triphosphate production
DNA production
Cell proliferation
Reduced cyclooxygenase and prostaglandin E_2 production

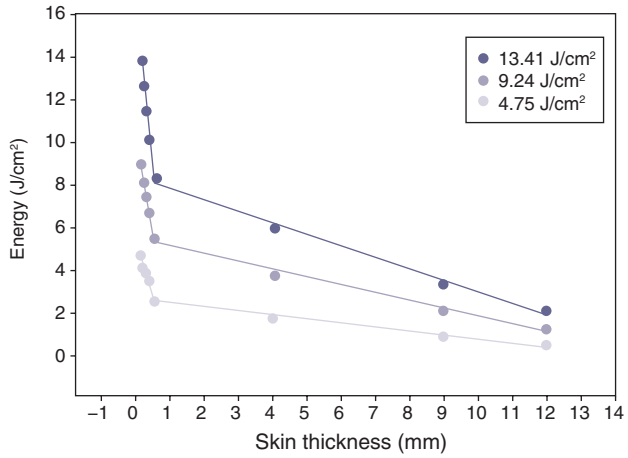

Figure 21-6 Three different doses of laser light and penetration through skin. Greater doses of laser energy penetrate deeper into tissues. (From Topping A, Gault D, Grobbelaar A et al: Does Low Penetration of Human Skin by the Normal Mode Ruby Laser Account for Poor Permanent Depilatory Success Rates? *Lasers Med Sci* 16:224-229, 2001.)

has been shown to have biologic effects as compared with the rate of administering laser energy, or the power of the laser (Box 21-1). Greater doses of laser energy penetrate deeper into tissues (Figure 21-6). The Lambert-Beer law indicates that for homogenous tissues with a constant coefficient of absorption, more photons will reach a given tissue depth with a greater dosage, and the intensity of light passing through tissues decreases exponentially with increasing tissue depth. There is a great deal of difference among lasers related to the power, with those delivering energy at a greater rate generally costing more. Although there is not thought to be an advantage in efficacy regarding low- versus high-power lasers, the dosage (total joules) can be administered in a much shorter time with a high-power laser, therefore reducing labor costs. In addition, high-power lasers are generally administered in a sweeping fashion, whereas lower power lasers are usually held in place until the administration of the dose for a particular spot treatment is complete. The sweeping motion may result in more thorough coverage of the treatment area as compared with the spot treatment of lower power lasers.

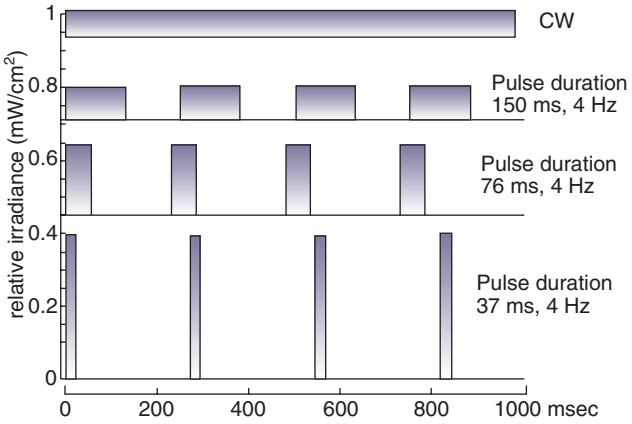

Figure 21-7 Diagram of laser light delivered as continuous wave or pulsed laser light of various pulse durations. (Based on a diagram from Hashmi JT et al: Effect of pulsing in low-level light therapy. *Lasers Surg Med* 42:450-466, 2010.)

The sweeping motion also allows the clinician to cover other surrounding areas that may be causing secondary or tertiary pain. For example, when treating canine hip dysplasia to address pain and inflammation, the coxofemoral joint should be treated from all areas—medial, lateral, caudal, and cranial. With the sweeping motions covering the four areas, the laser may affect the surrounding soft tissues that are often painful in clinical canine hip dysplasia.

Lasers can emit photons continuously or in a pulsed fashion (Figure 21-7). With continuous wave laser, radiation is emitted at a constant power over the entire treatment time. With pulsed wave laser treatment, impulses may be emitted at varied rates, with an on time when energy is emitted (pulse width or pulse duration [PD]) and an off time when there is no energy emitted. The duty cycle (DC) is the percentage of time that radiation is emitted in relation to the total on-off time. The pulse rate, or frequency (F), is measured in Hertz (Hz). The relationships between these measures may be expressed as:

$$DC = F \times PD$$

One report reviewed the literature regarding pulsed versus continuous laser application.[7] Although the authors concluded that there is some evidence that pulsed laser has different effects than continuous laser, further work is necessary to define optimal treatments for various conditions, and to determine the optimal pulse structures. One theory behind the use of pulsed laser is that with relatively short pulses, the laser could be excited to higher levels as compared with continuous wave laser, in which thermal damage to the tissues might limit the maximum amount of energy that can be applied. With short pulses, the thermal effects on tissues might be reduced, limiting tissue damage. Pulsed GaAs and indium-gallium-arsenide (InGaAs) lasers may allow for deeper tissue penetration without thermal damage, as well as allowing for shorter treatment times. In addition to decreasing the thermal effects on tissues, pulsing of the

laser may also have some resonance with certain functions, such as brain waves and opening of cellular ion channels. Pulsing may also have effects on photodissociation of substances, such as nitric oxide (NO) from protein binding sites, allowing multiple episodes of dissociation. Although the actual depth of penetration is probably not that different in pulsed versus continuous wave lasers, for many conditions, depth of penetration is a less important issue, such as with treatment of elbow or stifle arthritis. One author concluded that pulsed lasers (904 nm) were not significantly more effective than continuous-wave lasers (810-830 nm) for treatment of tennis elbow in people.[8] Both types were equally effective, but half the energy was needed with pulsed lasers. However, a review of literature comparing continuous wave laser with pulsed laser identified six of nine studies that found pulsed wave to be more effective.[7] A clinical study of wound healing and experimental studies of pain management and stroke recovery have suggested that pulsed laser has better results than continuous laser. Another study comparing continuous and pulsed laser found both to be equally effective. Only two of the nine studies reported better results with continuous than pulsed laser, although both treatment methods achieved better results than placebo treatments. Some limitations of the studies in this review were that the same parameters of laser wavelength were not used in some instances, making direct comparisons difficult. One study found a combination of pulsed and continuous laser to be more effective than either alone for stimulating nerve regeneration in a median nerve transection and repair study,[9] whereas most studies have shown continuous laser to be more effective than pulsed laser for nerve conduction and regeneration.[7] Studies comparing various rates of pulsed laser treatment show no consistent results, with some demonstrating better results with lower frequencies and some with higher frequencies.[7]

Classification of Lasers

The American National Standards Institute in the United States and the International Electrotechnical Commission have defined classes of lasers based on their ability to damage tissues. In general it is the thermal damage that injures tissues, especially the eyes, and in some cases, skin. Even small amounts of laser light can cause permanent damage to the retina.[10]

Current classifications of lasers are related to the wavelength and the maximum output power (in watts) or energy (in joules). These classifications allow the placement of various lasers into categories based on their ability to cause tissue damage, especially to the eyes. For example, Class 1 lasers are very mild are safe under all conditions of normal use, and include supermarket scanners and post office readers. Class 1M lasers are safe for all uses except when passed through a lens, such as a microscope or telescope. These types of lasers have large-diameter beams or divergent beams and cannot achieve the power to cause damage unless the laser is focused with a lens. The power is less than that of a Class 3B laser, but cannot damage the retina unless the light is focused. Class 2 lasers are in the visible-light spectrum (400-700 nm) and include items such as laser pointers, and occasionally therapy lasers. Because these lasers are visible light, the blink reflex generally limits exposure to less than 0.25 seconds. Class 2 lasers are limited to 1 mW continuous wave, or more if the emission time is less than 0.25 seconds or if the light is not spatially coherent. Class 2M lasers, similar to Class 1M lasers, have a large-diameter light beam or the beam is divergent and is safe unless the light is viewed through an optical instrument.

Figure 21-8 Class IV laser.

Class 3B lasers are either continuous light in the 315 nm to far infrared ranges limited to 500 mW, or pulsed lasers 400-700 nm wavelength limited to 30 mW. When using Class 3B lasers, protective eyewear is required if direct viewing of the light may occur. Class 3R lasers are considered to be safe with restricted exposure and are visible-light continuous lasers with power limited to 5 mW.

Class 4 lasers have the greatest potential to cause tissue damage and include all lasers with power greater than that of Class 3B lasers (Figure 21-8). Surgical, industrial cutting lasers, and some therapeutic lasers are Class 4 lasers. Surgical lasers typically have power between 30 to 100 W, whereas therapeutic lasers may be 1 to 15 W. Class 4 lasers may burn the skin or cause permanent eye damage as a result of direct, diffuse, or indirect beam viewing, such as might occur with reflection of the beam, even from matte surfaces. Therefore, the therapist must use great care to control the beam path and protective eyewear must be worn by all in the immediate area. The U.S. Food and Drug

Administration (FDA) requires all Class 3B and Class 4 lasers in the United States to have safety features, including a key switch, a safety interlock dongle, a power indicator, an aperture shutter, and an emission delay (normally 2-3 seconds). In addition, the U.S. Occupational Safety and Health Administration requires the use of adequate eye protection when eye exposure may occur while operating lasers in these classes.

Lasers Used in Physical Rehabilitation

Most lasers used in physical rehabilitation are Class 3 or 4 lasers and have a finite lifespan that generally varies form 5000 to 20,000 hours. LLLT devices are typically Class 3 lasers and are low power, often less than 100 mW, and they do not heat tissues. The lack of heat generation is significant. If heat is generated by a Class 3 laser, the unit may not be functioning properly or the device may be improperly used. LLLT devices typically have small treatment beam diameters, up to 1 cm. The basic types of lasers used for LLLT are gaseous HeNe and GaAs or GaAlAs semiconductor or diode lasers. HeNe lasers have a visible red light with a wavelength of 632.8 nm, whereas GaAs and GaAlAs have invisible light near the infrared band with a wavelength of 820-904 nm.

The wavelength of the laser is important because it determines, in part, the laser's effect. Longer wavelengths are more resistant to scattering than shorter ones. Therefore, GaAs and GaAlAs lasers penetrate more effectively (direct effect up to 2 cm, indirect effect up to 5 cm) than HeNe lasers (direct effect up to 0.5 cm, indirect effect up to 1 cm) because there is less absorption or scattering in the epidermis and dermis. Light waves in the near infrared ranges penetrate the deepest of all light waves in the visible spectrum (Table 21-1). Although this spectrum of light is not visible, commercial lasers should have an LED that allows the therapist to see where the laser light is aimed.

Lasers can only have an effect if they stimulate cells, and the depth of laser penetration is important to determine if cells at a particular depth may be stimulated. Very few studies have measured the depth of laser penetration through skin, and these studies have been done primarily on human skin samples. Readers should use caution in interpreting the results of these studies and extrapolating them to dogs because of inherent differences in skin thickness, skin composition, cutaneous blood supply, skin color, and thicker hair coats. Lasers with shorter wavelengths are most effective for surface-level conditions because they do not penetrate to deep tissues or large joint capsules. Wound care and wound healing should benefit from lasers with shorter wavelengths. Light that is not absorbed by water, hemoglobin, or melanin is gradually attenuated as it passes through tissues. The level of scattering and absorption is such that HeNe (632.8 nm) laser light loses approximately one third of its intensity during the first 0.5-1 mm of tissue depth.[11] The depth (in centimeters) at which the energy of a laser beam is 36% of its original values is termed the *first depth of penetration.*[12] This attenuation of energy is derived by dividing the original value by a constant, 2.78. Subsequent depths of penetration may be determined by dividing by 2.78 again, so that the level of energy at the second depth of penetration is 13%. However, because biologic effects may be noted with relatively low energy (0.01 J/cm^2), lasers that typically deliver 1 to 4 J/cm^2 may penetrate up to 0.5 to 2 cm before the energy level is so low that they have no effect. These factors apply to human skin, and, although there are many similarities between human and animal skin, there are significant differences caused by hair, pigmentation, and tissues.

One study evaluated the penetration of ruby laser light (694 nm) in human white skin. Doses of 4.75 J/cm^2, 9.24 J/cm^2, and 13.41 J/cm^2 were administered to the skin.[13] (see Figure 21-6). The most likely explanation for the tremendous drop in energy in the first mm is scattering of laser light, which supports the hypothesis that the greatest hindrance to a photon energy beam traversing the skin is from the stratum spinosum of the epidermis, collagen in the dermis, or both. Beyond the depth of the dermis and at the levels of the subcutaneous fat, the energy drop per distance traveled was not as great. The mean maximum depth of penetration was 14.8 mm which appeared to be a function of wavelength and not dosage. The natural chromophore for this wavelength of laser is melanin. Therefore the depth of penetration might be expected to be less in dark-skinned dogs. After passing through the skin, penetration through the muscle becomes easier because muscle has a smaller scattering coefficient.[14] In fact, transmission of laser light between 600 and 800 nm is approximately fourfold greater in skeletal muscle than skin.[15]

Another study with laser of similar wavelengths had similar results. An HeNe laser (632.8 nm, 50 mW power) and a semiconductor laser (675 nm, 21 mW power) were used to measure transmission in human skin and skin with granulation tissue from leg wounds with ulcers.[16] In the thickest sample (epidermis, dermis, and subcutaneous tissue, 2 cm thickness), approximately 0.3% of HeNe laser and 2.1% of semiconductor laser light penetrated through

Table 21-1 Wavelengths of Various Components of the Electromagnetic Spectrum

AM Radio	10,000 cm
TV and FM	100 cm
Microwave	10 cm
Infrared	700 nm
Ultraviolet	10 nm
X-rays	1 nm

all layers. Penetration of laser light was greatly attenuated at 1 to 3 mm of tissue depth. Transmission in granulation tissue was approximately 2.5 times higher than that in normal skin.

In another study of depth of penetration, a GaAlAr laser (wavelength 850 nm, 100 mW power) was applied to human abdominal skin samples.[17] The intensity of laser radiation was reduced by 66% after being transmitted through a 0.784 mm sample of human abdominal tissue. In this study, most laser radiation was absorbed within the first 1 mm of skin. Additional research is needed in small animals to determine the depth of penetration with different hair coats and skin color.

Biologic Effects of Laser Therapy

Most studies of laser use in rehabilitation have centered on wound healing and pain management. However, information regarding their efficacy in reducing pain or promoting tissue repair is incomplete.[18] Recently, interest has been generated in the United States regarding their use in treating people, and a natural extension has been an interest in treating animals. In evaluating the potential usefulness of laser therapy in rehabilitation, the reader is encouraged to be critical of studies that have been performed, and to evaluate these studies in light of recent advances in laser technology and the application of new information. Until recently, low-energy and therapeutic lasers were not approved for medical treatment in this country. However, as more evidence becomes available, they will likely be increasingly used.

Most of the potential responses of cells and tissues to laser energy have been studied in in vitro models. Photons delivered to the cells and tissues trigger biologic changes within the body. Photons are absorbed by chromophores and respiratory chain enzymes (especially cytochrome C oxidase, the terminal enzyme of the mitochondrial respiratory chain) within the mitochondria and at the cell membrane. Copper components of cytochrome C oxidase are photoacceptors.[19] Cellular signaling causes a cascade of cellular reactions resulting in things such as NO dissociation from cytochrome C oxidase.[19] This, in turn, results in further changes down the respiratory chain. Oxygen production and the formation of proton gradients across the cell and mitochondrial membranes may also occur. The enzyme flavomononucleotide is activated and initiates the production of ATP. Even small changes in ATP levels can change cell metabolism. The role of ATP in cellular energetics is well known, but ATP may also act as a signaling molecule to enhance cell to cell communication.[19] ATP may bind with the cell receptor P2X, which opens a channel to allow sodium and calcium to enter cells, resulting in a cascade of intracellular interactions. Increased intracellular calcium positively affects mitochondrial function. ATP may act as a neurotransmitter when released by nerve cells, but may also have other effects when released by other cells, such as bone production and cell proliferation.[20] The changes in ATP may, through its effects as a neurotransmitter, explain some of the effects of laser therapy on pain modulation and the effect of acupuncture.

The effect of laser treatment on various cells in vitro has been evaluated in several studies.[21] HeNe laser (632 nm) with a power of 10 mW and a dose of 0.43 J/cm^2 resulted in greater proliferation and differentiation of human osteoblasts in vitro.[22]

DNA production may also be stimulated. Photons also appear to affect tissues by activating enzymes, which trigger biochemical reactions in the body. Because cellular metabolism and growth are stimulated, lasers have the potential to accelerate tissue repair and cell growth of structures, such as tendons, ligaments, and muscles. Although lower dosages of laser energy appear to stimulate tissues, higher dosages may actually inhibit responses such as tissue healing. The enzyme kinetics may differ between high enzyme/substrate, and low enzyme/substrate conditions.[23]

A great deal remains unknown regarding the mechanisms of laser light in biologic systems. For example, NO and carbon monoxide inhibit cytochrome C oxidase. The effects of near infrared laser radiation in conjunction with NO on cytochrome C oxidase are unknown.[24] Further work is also needed regarding the effects of temperature, pH, exposure times, and frequency of photobiomodulation treatment on cytochrome C oxidase.

Laser therapy may also stimulate stem cell proliferation.[19] In addition to the direct effects of laser at a particular depth of tissue, indirect effects may also be seen. These cellular and tissue effects are decreased in the deeper tissues, and are catalyzed by the energy absorption in the more superficial tissues.

Laser therapy may also have antiinflammatory effects, similar to nonsteroidal antiinflammatory drugs (NSAIDs) and steroids. Studies of laser therapy in cell culture have indicated that inflammation can be reduced by a decrease in prostaglandin E_2 (PGE_2) and cyclooxygenase-2 (COX-2) concentrations.[25,26] This effect has also been demonstrated in an animal model,[27] as well as people with Achilles tendinitis.[28] Frequently, owners seek alternatives to NSAIDs for their animals, and laser therapy may offer alternative care. Animals that are unable to consume NSAIDs may also benefit from laser therapy as an alternative for inflammation.

Research Regarding Laser Therapy

Wound Healing

Laser light stimulates fibroblast development and may affect collagen production to repair tissues. Laser light may also accelerate angiogenesis and increase the formation of new capillaries in damaged tissues, possibly improving the rate of wound healing (Box 21-2). Therefore laser therapy may aid healing of open wounds and burns. There is an increased growth factor response within cells and tissues, which may

Box 21-2 Laser Therapy Research

Wound Healing
- Fibroblast stimulation
- Capillary formation and angiogenesis
- Collagen formation
- Enhanced adenosine triphosphate, protein, and growth factor production
- Vasodilation
- Lymphatic drainage
- Potential inhibition of wound healing at high doses

Bone and Cartilage
- Enhanced early bone repair
- Increased collagen deposition and bone trabeculae
- Adjunct to treatment of osteomyelitis
- Fibrous healing of cartilaginous defects
- Improved maintenance of cartilage in immobilized joints

Arthritis
- Inhibition of inflammation
- Inhibition of cyclooxygenase-2 enzyme and prostaglandins
- Reduced pain
- Possible reduction of morning stiffness in rheumatoid arthritis

Ligament and Tendon Conditions
- Pain reduction in acute tendonitis
- Improvement with lateral epicondylitis
- Reduced pain and inflammation in Achilles tendonitis
- Improved collagen organization
- Improved biomechanical properties

Analgesia
- Reduced pain in postoperative incisions

Inhibits Nociceptors
- Potential reduction in transmission of pain signals to pain centers in the brain
- Increased release of endorphins and enkephalins
- Stimulation of trigger points and acupuncture points
- Slowing of nerve conduction velocity
- Reduced action potential
- Suppressed substance P
- Disruption of axonal flow

Peripheral Nerves and Spinal Cord
- Promotion of nerve recovery after injury
- Increased axonal sprouting and growth
- Increased myelinization
- Reduced degeneration of neurons
- Increased growth-associated protein-43 and calcitonin gene–related peptide

be related to increased ATP and protein synthesis. Laser light therapy causes vasodilation and also may improve lymphatic drainage. This may result in decreased edema and swelling caused by bruising or inflammation.

In cell culture, doses of 0.5 to 16 J/cm^2 were evaluated in vitro as a single exposure on two consecutive days.[29] A single dose of 5 J/cm^2 resulted in increased proliferation and viability of injured fibroblasts. Higher doses (10 and 16 J/cm^2) had reduced cell proliferation and viability, with damage to the cell membrane and DNA. The results of this in vitro study do not necessarily imply that similar findings would be present in vivo, but do suggest that there may not be a linear dose-response effect.

A review of experimental studies related to laser treatment of wounds in 8 mouse and 39 rat model studies has been reported.[30] Wound healing in rodent models differs from wound healing in people because of the loosely attached skin in rodents as compared with people, making wound contraction a significant factor in healing in rodents. The loosely attached skin of rodents may be similar to dogs and cats, and therefore mice and rats may be a useful model of wound healing to evaluate treatments for dogs and cats. Many studies continue to inadequately report laser parameters used in treatment protocols. In spite of these shortcomings, the results of these studies suggest that laser or monochromatic light is effective as a treatment for wounds when applied at appropriate doses. Coherence of light may not be an important factor when treating surface wounds. LEDs with monochromatic light appear to have effects on topical wounds, similar to those obtained with laser light. Wavelengths in both the visible red (630-685 nm) and infrared (700-1000 nm) typically stimulated wound healing in a variety of models. Some studies suggested that the best results were obtained when using 660-nm laser light in the early stages of wound healing, whereas 780 nm produced positive results throughout all stages of wound healing.[31,32] In general, there was no clear association between outcomes and power levels used in the studies evaluated in this review.[30] However, lack of standard experimental design, including total dose administered, made it difficult to draw conclusions. In those studies that reported energy density or when calculation was possible, there appeared to be a dose-response relationship.[30] However, there may be a biphasic response, with positive effects seen with lower dosages, and inhibitory effects at higher dosages.[30] Treatment with a total dose of 20 J/cm^2 divided between 638 and 830 nm light produced better outcomes than using either wavelength alone, suggesting a possible effect of both superficial and deep treatments.[33] However, two studies with infrared laser treatment using higher dosages had reduced stimulation[34] or inhibitory effects.[35] In one study of rats with circular wounds receiving a single 830-nm laser treatment with 1.3 J/cm^2, more rapid epithelialization and wound contraction resulted compared with 3 J/cm^2, although both treatments resulted in stimulation of healing compared with controls, and there was no difference between the treated groups by day 14.[34] In a mouse wound model, 18 J/cm^2 of 980-nm laser treatment had a beneficial effect on wound healing, whereas 36 J/cm^2 was too aggressive and resulted in decreased healing.[35]

Laser therapy may also be beneficial for difficult wounds in metabolically compromised patients. Laser

photostimulation accelerated wound healing in diabetic rats in one study.[1] Diabetes was induced in male rats by streptozotocin injection and two 6-mm diameter circular wounds were created on either side of the spine. The left wound of each animal was treated with a 632.8 nm HeNe laser at a dose of 1 J/cm^2 5 days per week until the wounds closed (3 weeks). There was a marginal increase of biomechanical properties of the laser-treated wounds, including an increase in maximum load (16%), stress (16%), strain (27%), energy absorption (47%), and toughness (84%) compared with control wounds. The amount of total collagen was significantly increased in laser-treated wounds. It was concluded that laser photostimulation promoted tissue repair by accelerating collagen production and promoting overall connective tissue stability in healing wounds of diabetic rats. HeNe lasers also improved wound healing by increasing collagen synthesis when corticosteroids or nonsteroidal antiinflammatory agents were administered to rats with surgical abdominal wounds.[36] Laser treatment significantly increased collagen synthesis.

One study reported 100 clinical cases with healing wounds treated with LLLT.[37] There was a marked increase in collagen formation, increased vasodilation, and accelerated DNA synthesis. This researcher recommended 1 J/cm^2 of laser treatment.

A statistical metaanalysis was performed to determine the overall treatment effects of laser phototherapy on tissue repair.[18] After performing a literature search, the effectiveness of laser treatment was calculated from each study using standard procedures. Thirty-four peer-reviewed papers met the inclusion criteria for tissue repair. There was a positive effect of laser phototherapy on tissue repair. Collagen formation, rate of healing, tensile stress and strength, time needed for wound closure, number and rate of degranulation of mast cells, and flap survival were improved with laser therapy. Laser treatment with a wavelength of 632.8 nm had the greatest effect, and 780 nm had the least. This metaanalysis concluded that laser therapy was an effective treatment for tissue repair.

Another study reviewed the literature regarding the in vitro and in vivo effects of low-intensity laser therapy on the wound healing process, especially in diabetic patients.[38] Although many of the in vivo studies lacked specific information on dosimetric data and appropriate controls, the data from appropriately designed studies indicated that LLLT should be considered as an adjunctive adjuvant therapy for refractory wound-healing disorders, including those experienced by diabetic patients.

However, results from other controlled and blinded studies have been less clear regarding the efficacy of LLLT for the treatment of wounds.[11] Studies in laboratory animals have suggested that LLLT may improve healing during the early stages of wound healing, but the effect may not result in improved total healing time.[39,40] Another large review paper did not find unequivocal evidence that LLLT was beneficial for the treatment of wound healing.[41]

Bone and Cartilage Effects

Bone and cartilage may also be affected by laser treatment. In one study of bone healing, rats received a defect in a femur.[42] Rats were treated for either 12 sessions (4.8 J/cm^2 per session, 28-day follow up) or three sessions (4.8 J/cm^2 per session, 7-day follow up) with 40 mW 830 nm laser light. Treatments were applied three times per week, and two other groups served as untreated controls. Rats were sacrificed on either day 7 or 28 after surgery. Although there were significant differences between treated and control animals regarding the area of mineralized bone at 7 days, there were no differences at 28 days. The authors suggested that LLLT may have some effect on early bone repair.

Another study of bone healing in rats compared ultrasound with laser.[43] A GaAlAs laser (780 nm) was applied using 30-mW power and a dose of 112.5 J/cm^2. The ultrasound group was treated with 1.5 MHz, at 30 mW/cm^2. Both groups received 12 total treatments, with 5 treatments administered per week. Bones were harvested on day 20. Maximum load at failure was greatest in the laser-treated group. Ultrasound resulted in promotion of bone resorption at the osteotomy site, whereas laser caused bone formation in comparison with control osteotomies.

The use of GaAlAs laser was compared with bone morphogenetic protein (BMP) and bovine organic bone graft in a rat femoral bone healing model.[44] Rats were assigned to four groups: control; laser treatment; BMPs plus organic bovine bone graft; and BMPs plus organic bovine bone graft plus laser treatment. The laser-irradiated groups received treatments every 48 hours for seven treatments, beginning immediately after the surgical procedure. The laser therapy (830 nm, 40 mW) consisted of 16 J/cm^2 per session divided equally over four points (4 J/cm^2 each) around the defect. The subjects were sacrificed after 15, 21, and 30 days. There was increased deposition of collagen at 15 and 21 days, as well as increased bone trabeculae at the end of the experimental period in the irradiated animals versus the nonirradiated controls. The greatest healing was seen in the group treated with organic bovine bone graft, BMP, and laser treatment.

LLLT has also been investigated as an adjunctive treatment for infections of the musculoskeletal system. In one study, the effect of various doses of 808 nm (100 mW continuous laser, at doses of 7.64 J/cm^2, 15.29 J/cm^2, and 22.93 J/cm^2) laser therapy was evaluated in induced chronic osteomyelitis of rat tibias, created with methicillin-resistant *Staphylococcus aureus*.[45] Rats had either surgical debridement, surgical debridement plus laser therapy, or no treatment. Infection levels decreased by 37%, 67%, 81%, and 93% in groups treated by debridement only, or debridement plus laser at 7.64 J/cm^2, 15.29 J/cm^2, or 22.93 J/cm^2, respectively, compared with the nontreated control group. The authors

concluded that laser therapy may be an adjunctive treatment for the management of osteomyelitis. Laser has also been used to create a laser shockwave to clear biofilm from medical devices in vitro.[46] Bacteria surrounding medical devices, such as stents and orthopedic implants, may make a biofilm coating that prevents penetration of antibiotics. In this study, the biofilm was disrupted by a pulsed Nd:YAG laser that produced laser-generated shockwaves, making the bacteria susceptible to conventional treatment.

A more complete review of the effects of laser therapy for bone repair has been published.[47] Most of the research regarding bone healing has been performed in cell culture or in rodent models. However, the authors acknowledge that more study on the laser properties, wavelength, and energy dosage is needed, along with improved study design.

The safety of laser therapy on epiphyseal cartilage has been evaluated in rats.[48] Young rats had either no laser irradiation, 5 J/cm^2, or 15 J/cm^2 of 830 nm GaAlAs laser application to the proximal tibial epiphyseal cartilage every other day for a total of 10 sessions. Laser irradiation increased epiphyseal cartilage thickness and the number of chondrocytes, but these effects were not great enough to increase bone length.

Another study evaluated osteochondral lesions of the knee treated intraoperatively with laser therapy in rabbits.[49] Bilateral osteochondral lesions were created in the femoral medial condyles. All of the left lesions underwent immediate stimulation using a GaAlAs laser (780 nm), and the right knees were left untreated as a control group. After 24 weeks, the condyles were examined histomorphometrically. The condyle treated with laser had better cell morphologic findings and repair of osteocartilaginous tissue.

The effect of laser therapy on cartilage was further investigated in another study that evaluated whether intraoperative laser biostimulation can enhance healing of cartilaginous lesions of the knee in rabbits.[50] Bilateral chondral lesions were created in the medial femoral condyles. The lesion in the left knee of each animal was treated intraoperatively using a diode GaAlAs 780-nm laser (300 J/cm^2, 1 W, 300 Hz, 10 minutes), and the right knee was left untreated. Cartilage was then examined 2, 6, or 12 weeks after surgery. The rabbits receiving laser therapy had progressive filling with fibrous tissue of the cartilaginous lesion, whereas no changes were apparent in the untreated group.

Although laser therapy may have some benefit to treat cartilage injury, it may also have benefit to help maintain the health of cartilage during periods of disuse and immobilization. The influence of laser therapy (632.8 nm, HeNe, 13 J/cm^2, three times a week) on the articular cartilage of rabbit stifles immobilized for 13 weeks was examined in one study.[51] The number of chondrocytes and depth of articular cartilage of the treated rabbits were significantly higher than those of the sham-treated group. The cartilage surface of the sham-treated group was rough and fibrillated, whereas the surface of the experimental group was intermediate between a nonimmobilized control group and the sham-treated group. The authors of this study concluded that low-power HeNe laser irradiation reduced the adverse effects on the articular cartilage of rabbits immobilized for 13 weeks. Another study evaluated the use of 810 nm laser therapy on bone and cartilage during joint immobilization of rat knees.[52] Three groups of rats received either 3.9 W/cm^2, 5.8 W/cm^2, or sham treatment. After 6 treatments over a 2-week period, tissues were harvested for testing. Results indicated that cartilage stiffness, assessed by indentation testing, was preserved in both laser groups.

Treatment of Arthritis with Low-Level Laser Therapy

There is much interest in treating various forms of arthritis with laser therapy, including osteoarthritis (OA) and various forms of inflammatory arthritis, such as rheumatoid arthritis. Models of various forms of arthritis have also been studied in animal models. Zymosan was injected into knee joints of rats to create inflammatory arthritis in one study.[53] LLLT (830 and 635 nm, 20 mW) or LED (628 nm) was applied to animals immediately and 1 and 2 hours after injection, using the same dose of 2.5 J/cm^2. A positive control group was pretreated with a dexamethasone injection into the knee 1 hour before zymosan injection. Laser treatment significantly reduced edema by 23%, vascular permeability by 24%, and pain by 59%, whereas LED treatment had no effect on any of the outcome parameters. Laser treatment may inhibit inflammation by reducing PGE_2 levels by inhibiting the COX-2 enzyme. Another inflammatory joint model also suggested that laser treatment may reduce inflammatory changes.[54] Hydroxyapatite and calcium pyrophosphate crystals injected into rat knee joints resulted in inflammatory changes in the non–laser-treated control animals, but HeNe laser (633 nm, 5 mW, 8 J/cm^2 daily for 5 days) reduced the intensity of the inflammatory changes.

Laser therapy has been used for the treatment of OA in people. The effect of laser therapy in OA of the knee was investigated in one double-blind study.[55] One treated group that received infrared laser (GaAlAs) and the other that received HeNe laser treatment were compared with a group that received placebo treatment. Patients were treated for 15 minutes twice daily for 10 days. Total dose for each session was 10.3 J for HeNe and 11.1 J for GaAlAs. The laser-treated groups were significantly less painful compared with the placebo groups, but there was no difference between the HeNe and the GaAlAs groups. The Disability Index Questionnaire also revealed an improvement in the laser groups. Patients receiving laser treatment had less pain for 2 months to 1 year after treatment.

Laser treatment was also performed on 20 human patients with OA of the knee, ranging from 42 to 60 years of age.[3] All patients had previously received conservative treatment with poor results. The laser device used for this

treatment was a pulsed infrared diode laser, 810 nm wavelength, once per day for 5 consecutive days, followed by a 2-day rest interval. The total number of applications was 12 sessions. Laser treatment was performed on five periarticular tender points, for 2 minutes each. Pain relief and functional ability were assessed using a numerical rating scale, self-assessment by the patient, index of severity for OA of the knee, and analgesic requirements for comfort. There was significant improvement in pain relief and quality of life in 70% of patients, compared with their previous status, but there was no significant changes in range of motion (ROM) of the knee. Although the authors of this study indicated that laser treatment was beneficial, there was not an untreated control group. Therefore the results should be interpreted with caution.

A double-blind randomized study was conducted in 90 patients with OA of the knee to evaluate a GaAs laser in combination with 30 minutes of exercise.[56] One group received 5 minutes of laser therapy, with 3 J delivered. Another group was treated for 3 minutes and received 2 J, and a third group received placebo laser and exercise. Patients received a total of 10 treatments and were studied for 14 weeks. Patients receiving laser treatment had significantly improved pain, function, and quality of life measures after treatment and had improved scores as compared with the placebo laser group.

The analgesic and microcirculatory effects of LLLT were evaluated in a recent study of people with knee OA.[57] Laser therapy (830 nm, continuous wave, 50 mW, 6 W per treatment site) or placebo treatments were administered twice weekly for 4 weeks. Pain, circumference, pressure sensitivity, and flexion were all improved in the laser treatment group, whereas the placebo group had no improvement in flexion or pain. Thermographic measurements showed a 0.5° C increase in temperature in the laser group, suggesting an increase in circulation.

A similar randomized, placebo-controlled study of 60 patients with knee OA indicated no significant improvement with 50 mW 830 nm GaAlAs LLLT at 3 weeks or 6 months.[58] In this study, patients received 3 or 1.5 J per painful joint, or placebo laser treatment, five times per week, with 10 total treatments.

Finally, a metaanalysis review was conducted on the efficacy of laser therapy on OA in people.[59] Seven trials were included, with 184 patients randomized to laser, and 161 patients to placebo groups, using a variety of lasers and treatment protocols. Treatment duration ranged from 4 to 12 weeks. Pain was assessed in four trials. The pooled estimate of three trials showed no effect on pain measured using a scale, and two demonstrated very beneficial effects with laser. In another trial, with no scale-based pain outcome, significantly more patients reported pain relief (yes/no) with laser. One study found knee ROM was significantly increased. Other outcomes of joint tenderness and strength were not significant. Lower dosages of laser were found to be as effective as higher dosages for reducing pain and improving knee ROM. The authors concluded that for OA, the results are conflicting in different studies and may depend on the method of application and other features of laser application, including wavelength, treatment duration, dosage, and site of application over nerves instead of joints.

The efficacy of laser therapy for the treatment of rheumatoid arthritis in people has also been reviewed.[60] Five placebo-controlled trials evaluating 222 patients met inclusion criteria of the review. Treatments were typically administered two to three times per week for 4 weeks. Compared with a control group, laser therapy reduced pain by 1.10 points on a 10-point visual analogue scale (VAS) relative to placebo, reduced morning stiffness duration by 27.5 minutes, and increased tip to palm flexibility by 1.3 cm. Other outcomes such as functional assessment, ROM, and local swelling did not differ between groups. There were no differences based on laser therapy dosage, wavelength, site of application or treatment length. The authors concluded that laser therapy could be considered for short-term treatment for relief of pain and morning stiffness for patients with rheumatoid arthritis. Further evaluation of wavelength, treatment duration, dosage, and site of application over nerves instead of joints is needed. A recent study, however, generally showed no effect of laser therapy (GaAlAr laser, 785 nm, 3 J/cm^2, and mean power of 70 mW) on the hands of patients with rheumatoid arthritis.[61]

Treatment of Tendon and Ligament Conditions with Laser Therapy

Low-level and therapeutic laser has been recommended for the treatment of various tendon and ligament conditions, but the clinical efficacy of this treatment remains controversial. Laser therapy has been used in people for tendinopathies of the Achilles tendon, patella tendon, medial and lateral elbow tendons, and shoulder rotator cuff tendons.

The effect of GaAs laser therapy (904 nm, 4000 Hz, 0.5 to 1 J/cm^2) for tendinitis was evaluated in 74 treated people and 68 people receiving placebo treatment in a randomized, blinded fashion.[62] All patients received six treatments during a period of 3-4 weeks. Pain was estimated objectively using a pain threshold meter, and subjectively with a VAS before treatment, at the end of treatment, and 4 weeks after the end of treatment. Laser therapy generally had a significant, positive effect compared with placebo measured from the first assessment to 4 weeks after the end of treatment. Laser treatment appeared to be most effective for acute tendinitis.

Another study evaluated the effect of laser therapy in seven people with bilateral Achilles tendinitis to see if laser treatment has an antiinflammatory effect.[63] Laser therapy (904 nm, 5.4 J per point, 20 mW/cm^2) or placebo was applied to either Achilles tendon in random fashion. PGE_2 was reduced 75 to 105 minutes after laser therapy, and pain

pressure threshold values increased after laser therapy. The authors concluded that laser therapy reduces pain and inflammation in people with acute Achilles tendinitis.

A rat model of partial calcaneal tendon lesions also evaluated the effects of laser therapy.[64] Sixty rats were assigned to five groups: standard control (no lesion induced and no laser therapy); control (lesion induced, but no laser therapy); and groups 3, 4, and 5, which suffered the lesion and underwent laser therapy for 3, 5, and 7 days, respectively. Laser therapy was delivered with a GaAsAl laser (830 nm), power of 40 mW, power density of 1.4 W/cm^2 with continuous waveform, with a dose of 4 J/cm^2, and total energy of 0.12 J every day during treatment, always in the same period, for 3, 5, or 7 days starting on the day the lesion was produced. Control lesions had significantly less collagen fiber organization compared with the standard controls. There were no differences in collagen organization between group 4 and standard control. Groups 3 and 5 were similar to each other and had greater collagen fiber organization than the animals with control lesions. Laser therapy was effective in the improvement of collagen fibers organization of the calcaneal tendon after undergoing a partial lesion in this study, and early treatment for 5 days appeared to give the optimal response in this study.

Lateral epicondylitis can be a challenging condition to treat in people. A GaAs laser (904 nm, 12 mW, 70 Hz, 0.36 J/point with four or five points treated over the most painful area, two to three treatments per week for a total of 10 treatments) or placebo treatment was applied to people with lateral epicondylitis.[65] Laser treatment resulted in significant improvement in some objective parameters, but not subjective parameters, perhaps because the subjective scales were not sensitive enough to detect small differences.

One recent review and metaanalysis evaluated the use of low-level laser for tendinopathies in people.[66] The results of 25 studies were conflicting, with roughly half showing a positive effect and half being inconclusive or showing no effect. Positive results from studies of lateral epicondylitis and Achilles tendinopathy appear to be related to the dosage of laser applied. Studies suggesting efficacy of laser treatment used doses similar to those recommended by the World Association of Laser Therapy, which suggests doses of 1-8 J and power less than 100 mW/cm^2 for superficial tendons. For deeper tendons, such as the rotator cuff, power up to 600 mW/cm^2 and total dosages of 3-9 J have been recommended.

Laser therapy may also be useful for other forms of soft-tissue injury, such as ligament healing. In one study, 24 rats received surgical transection to their right medial collateral ligament and eight received sham operation.[67] After surgery, 16 received a single dose of GaAlAs laser to their transected ligament for 7.5 minutes or 15 minutes, and eight served as control with placebo laser, whereas the sham group did not receive any treatment. The ligaments were biomechanically tested either 3 or 6 weeks following surgery. The ultimate tensile strength and stiffness of laser and sham groups were larger than controls. The laser and sham groups had improved stiffness from 3 to 6 weeks. It was concluded that a single dose of laser therapy improved the biomechanical properties of healing medial collateral ligaments 3 and 6 weeks after injury. However, a randomized clinical trial of laser therapy for the treatment of ankle sprains in people indicated that laser treatment was not effective.[68]

Analgesia and Pain Management

Interest in the use of laser therapy to treat acute and chronic pain has increased in recent years. In fact, the World Health Organization's Committee of the Decade of the Bone and Joint has recently incorporated laser therapy into guidelines for the treatment of neck pain in people.[69] Knowledge of the effects of laser irradiation on pain has increased in recent years.[69] Nociceptors, which are Aδ and C peripheral nerve fibers, lie just beneath the surface of the skin. Because these nerve fibers are relatively superficial, they are within the depths of laser stimulation. In addition, neurons that supply blood vessels and contribute to vasoconstriction and vasodilatation associated with inflammation are also within the depth of laser penetration. Therefore laser has the potential to influence pain perception by direct or indirect actions on nociceptors, as well as modulation of inflammation, which may contribute to pain. In fact, one study showed a reduction in postoperative pain and drug intake in people after immediate postoperative laser treatment to a surgical incision.[70] Laser therapy may suppress central sensitization and result in long-term depression of persistent pain with repeated application. The exact mechanisms by which laser therapy results in analgesia are unknown, but are the focus of active research. Although both nociceptors and motor nerves may be affected by laser irradiation, sensory nerves appear to be preferentially affected. It is likely that application of laser results in mainly inhibitory effects on aspects of nerve function, especially pain receptors.

The results of studies regarding pain management with the use of laser have been somewhat controversial. However, studies performed have resulted in the approval by the FDA of 635 nm low-level lasers for the management of chronic, minor pain, such as OA and muscle spasms. Laser therapy may have some analgesic effects by blocking pain transmission to the brain. Some studies have shown changes in the conduction latencies of the radial and median nerve after laser therapy,[71,72] but others have shown no effect.[73] Laser treatment may also increase the release of endorphins and enkephalins, which may further provide analgesic benefits. Laser therapy has been used to stimulate muscle trigger points and acupuncture points, which may provide pain relief.[74]

Although the precise mechanism by which laser therapy may provide analgesia is unknown, several studies have

investigated other possible mechanisms. One study evaluated the effects of diode laser irradiation of peripheral nerves.[75] The response was evaluated by monitoring neuronal discharges from the L5 dorsal nerve roots elicited by application of various stimuli to the hindpaw of rats, including brush, pinch, cold, heat stimulation, and chemical stimulation by injection of turpentine. Diode laser irradiation (830 nm, 40 mW, 3 min, continuous wave) of the saphenous nerve significantly inhibited neuronal discharges elicited by pinch, cold, heat, and chemical stimulation, but not discharges induced by brush stimulation. These data suggest that laser irradiation may selectively inhibit nociceptive neuronal activities.

Another study evaluated the effect of laser therapy on the head of rats.[76] Rats received various combinations of laser (0, 6.4, and 12 J/cm^2) and naloxone (0, 5, and 10 mg/kg) prior to a hot plate test. Laser therapy (820 nm, pulsing) was applied to the rats' skulls. Hindpaw lick latencies (in seconds) in response to the hot plate test were recorded immediately, 30 minutes, and 24 hours after the administration of treatment. When animals were tested immediately following laser irradiation at 12 J/cm^2, significant analgesia resulted. Treatment with naloxone at either dose antagonized this effect, but naloxone produced no significant hyperalgesia when given alone. This suggests that opioid peptide mechanisms may mediate the analgesic action of laser therapy of the cranium.

Recently, the effects of laser irradiation on peripheral nerves and their potential effects on analgesia have been reviewed.[77] A total of 44 studies were included in this review. In 13 of 18 human studies, pulsed- or continuous-wave visible and continuous-wave infrared laser irradiation slowed nerve conduction velocity and reduced the amplitude of compound action potentials. In 26 animal studies, infrared laser irradiation suppressed evoked action potentials, pain-related neurotransmitters, such as substance P, and proinflammatory mediators, such as bradykinin. Disruption of axonal flow and microtubule arrays may be responsible for neural inhibition. The varicosities that form as a result of laser therapy inhibit axonal flow and block the transport of ATP, which is necessary to generate action potentials. The authors concluded that a range of inhibitory effects on peripheral nerves has been demonstrated, which may reduce acute pain by inhibiting peripheral nociceptors. In chronic pain, spinal cord changes induced by laser irradiation may result in depression of pain. Laser therapy seems to be most effective in reducing nerve conduction velocity when it is applied to several points over the nerve, causing an additive effect as compared with irradiation of a single point. In addition, continuous-wave laser therapy appears to be more effective than pulsed-wave application.

Laser acupuncture is another potential method of achieving pain control that has recently generated interest.[74] Laser acupuncture is the stimulation of traditional acupuncture points with low-level laser. Most animal models of laser acupuncture studies have shown no benefit over placebo treatment, although the power used in those studies was generally very low. The results of many studies of laser acupuncture in people are hampered by inappropriate or poor description of laser application. Many of these studies have shown no positive benefits, but they used very low power. One study of laser-mediated acupuncture anesthesia (2.8-6 mW, 632.8 nm) for tooth extraction or minor facial surgery reported a 95% success rate. However, the characteristics determining the success rate were not defined.

A randomized, double-blind, placebo-controlled study of laser therapy in 90 subjects with chronic neck pain was conducted to determine the efficacy of 300 mW, 830 nm laser.[4] Subjects were randomized to receive 14 treatments over 7 weeks with either active or sham laser to painful regions of the neck. Assessments were made at baseline, week 7, and week 12. Mean VAS pain scores improved by 2.7 in the treated group and worsened by 0.3 in the control group. However, the treated group began the study with higher mean VAS scores, despite randomization. Significant improvements were also seen in the laser therapy group compared with placebo for other total outcome measures, but some component portions of assessments did not differ significantly between the two groups. Laser therapy, at the parameters used in this study, was efficacious in providing pain relief for patients with chronic neck pain over a period of 3 months.

The results of laser therapy on acute and chronic back pain may differ from those obtained from treatment of neck pain. A randomized, double-blind, placebo-controlled study compared the effectiveness of laser therapy on pain and functional capacity in people with acute and chronic low back pain caused by lumbar disk herniation (LDH).[78] Patients were randomly allocated into four groups. Group 1 (acute LDH, n = 20) received hot pack plus laser therapy; group 2 (chronic LDH, n = 20) received hot pack plus laser therapy; group 3 (acute LDH, n = 20) received hot pack plus placebo laser therapy, and group 4 (chronic LDH, n = 20) received hot pack plus placebo laser therapy, for 15 sessions over 3 weeks. Pain, ROM, and disability were evaluated using standard techniques, such as VAS and global assessment scores, before and after 3 weeks of treatment. After treatment, there were significant improvements in pain severity, patients' and physicians' global assessment, ROM, and disability scores in all groups. However, no significant differences were detected between the four treatment groups with respect to all outcome parameters. There were no differences between laser and placebo laser treatments on pain severity and functional capacity in patients with acute and chronic low back pain caused by LDH.

A randomized, double-blind study of 100 patients with neck and shoulder pain indicated that 90% of the patients in the treated group had at least a 30% improvement in the degree of pain relief, as compared with only 14% of the patients in the placebo group.[79] Most patients had reduction of their pain immediately after treatment, and the improvement was typically maintained for 24 hours. A follow-up

study of another 100 patients indicated that 65% of the treated patients had improvement in their pain, but only 12% of untreated patients improved.[79]

A metaanalysis evaluated the effect of laser therapy on pain relief.[18] Nine papers met the inclusion criteria for pain control. The overall treatment effect for pain control was positive. Another review of laser therapy with location-specific doses for pain from chronic joint disorders suggested that some benefit may be derived from the use of lasers.[80] A literature search identified 88 randomized, controlled trials, of which 20 trials included patients with chronic joint disease. Laser therapy was applied within the suggested dose-range to the knee or temporomandibular joint capsule to reduce pain in chronic joint disorders. The results showed a mean difference in change of pain using a VAS by 45.6% in favor of laser therapy. Global status was also improved 33.4% more in patients in the laser therapy group. Although laser therapy appeared to reduce pain in patients with chronic joint diseases, the heterogeneity in patient samples, treatment procedures, and trial design calls for cautious interpretation of the results.

Peripheral Nerves and Spinal Cord

Peripheral nerve and spinal cord injuries can be devastating to patients of all species. Studies have been recently conducted which, along with the few known side effects of laser therapy, make this an exciting potential treatment for nerve and spinal cord injuries.

Initial studies evaluated the use of laser therapy on peripheral nerve regeneration in a crushed sciatic nerve model in rats. Most of the studies indicated that laser therapy was effective in promoting nerve recovery.[81-83] Laser therapy was applied directly to the nerve or transcutaneously. With direct stimulation, wavelengths of 540, 633, and 780 nm were found to be effective. Subsequent studies indicated that laser therapy applied to the nerve injury and the corresponding segments of the spinal cord with 633 nm laser at a dose of 10 J/cm^2 seems to improve the outcome. Although it appears that laser therapy is most effective when applied during the early posttraumatic period,[84] laser therapy may also be beneficial for chronic nerve conditions. A study of human patients with incomplete peripheral nerve or brachial plexus injuries present for 6 months to several years indicated that laser therapy resulted in progressive improvement of peripheral nerve function.[85]

Studies of rat sciatic nerve injuries indicated that there was increased functional activity, decreased scar tissue formation, decreased degeneration of motor neurons, and increased axonal growth and myelinization with laser therapy applied to the spinal cord immediately after wounding, and for 30 minutes daily for 21 days using 16 mW 632 nm HeNe laser.[86] This study suggested that laser therapy applied directly to the spinal cord may improve the recovery of corresponding peripheral nerve injuries. Additional studies on laser therapy applied to surgically repaired peripheral nerves have also shown promise in studies of rats.[87-89]

Laser therapy appears to enhance axonal sprouting, resulting in accelerated healing. Laser therapy applied to the corresponding segments of the spinal cord also helps to reduce the degenerative changes in the neurons and helps induce proliferation of astrocytes and oligodendrocytes, which may result in an increased ability to produce myelin.[89] In addition, laser therapy may enhance the production of proteins and growth factors associated with axonal sprouting, such as growth-associated protein-43 and calcitonin gene-related peptide, and may stimulate the proliferation of Schwann cells.

In an initial study, laminectomy and transection of the spinal cord at T12-L1 were performed in 17 dogs.[85] An autograft of the sciatic nerve was implanted in the injured area. Ten dogs received laser therapy for 20 days, and the others did not. The 7 that did not receive laser therapy were paralyzed, whereas the 10 treated dogs stood between 7 and 9 weeks, and walked between 9 and 12 weeks. Treated dogs did not have prominent scar tissue, and there were new axons and blood vessels originating in the spinal tissue and extending into the graft. However, the study did not report the results of neurologic testing to know whether or not the dogs were spinal walking or had functional walking ability.

More recently, a prospective study was performed to determine if low-level laser therapy and surgery would result in earlier ambulation than surgery alone for intervertebral disk herniation.[90] Thirty-six dogs with acute paralysis or nonambulatory paraparesis were randomly assigned to a surgery or surgery plus laser group. A 5 × 200-mW 810-nm cluster array laser was used to deliver 25 W/cm^2 to the skin over the spinal segment associated with the hemilaminectomy and the two adjacent ones (one cranial and one caudal). However, the dose in joules per cm^2 was not clear. The laser array was applied to each area for 5 days or until dogs became ambulatory with paraparesis or ataxia. The time to achieve this level of recovery was significantly lower in the low-level laser therapy group (median 3-5 days) than the control group (median 14 days). The authors concluded that low-level laser therapy in combination with surgery decreases the time to ambulation in dogs with T3-L3 myelopathy secondary to intervertebral disk herniation.

The use of transcranial laser or LED therapy has recently been reviewed for the treatment of stroke, traumatic brain injury, and neurodegenerative diseases in people.[91] There is some apparent transmission of near infrared light through the scalp and skull to stimulate the cortical surface of the brain. Because cortical neurons are rich in mitochondria, these cells may be responsive to light therapy. There may be upregulation of cytoprotective antioxidant enzymes, heat shock proteins, and antiapoptotic

proteins with light therapy, perhaps helping to preserve neurons afflicted with hypoxic or traumatic events.[91] In addition, light therapy may increase neurogenesis, which has been demonstrated in rat models of stroke.[92,93] In particular, there may be newly formed neuronal cells in the area ipsilateral to the lesion; however, there may be no new cells in the area of the lesion. Transcranial laser therapy may increase ATP in cortical neurons.[91] In human stroke patients, transcranial laser therapy may improve outcome when applied approximately 18 hours after moderate stroke over the entire head.[94] Transcranial laser treatment has also been investigated in mild traumatic brain injury in mice and has beneficial effects. There are also cases of treatment of people with reduced cognitive function after brain injury in which cognition was improved after laser treatment.[91]

Application of Laser Therapy to Dogs

Before applying laser therapy to a patient, there are two fundamental attributes that must be established. First, the type of laser must be known, as well as the wavelength. The wavelengths of most lasers used for laser treatment are typically in the infrared or near-infrared range of 600-1000 nm. Wavelengths of low-power lasers commonly used are 632.8 nm (HeNe, gas) in the visible light range, 810 nm (GaAlAs, diode), and 904 nm (GaAs, diode) in the infrared region of the light spectrum. The wavelength is the prime determinant of tissue penetration. Lasers that do not penetrate as deeply (630 to 740 nm) are suitable for acupuncture point stimulation and wound healing but have not proved their clinical effectiveness with deep-seated musculoskeletal conditions. Infrared lasers (750 to 1500 nm) penetrate more deeply and are used to treat trigger points, ligaments, joint capsules, and intraarticular structures. The output power (watts or milliwatts) must also be known. Based on this, and the condition to be treated, the dose of laser light (J/cm^2) is determined. For most conditions, a dose of 1 to 8 J/cm^2 is typically applied. The time the laser must be applied to an area to deliver the dose must be calculated. For example, if a 904-nm laser with a maximum output power of 250 mW is used, it will take 4 seconds to deliver 1 J.

$$0.250\ \text{W} = 1\ \text{J}/\text{X seconds}$$

$$(0.250\ \text{W})(\text{X seconds}) = 1\ \text{J}$$

$$\text{X seconds} = 1\ \text{J}/0.250\ \text{W}$$

$$\text{X} = 4\ \text{seconds}$$

With this particular laser, it will be necessary to hold the laser on one point for 4 seconds to deliver 1 J of energy. With a 1-W laser, this takes 1 second. It is crucial to always understand what the particular laser unit possesses with regard to power and wavelengths, and the dose, in J/cm^2, a condition requires. From there, it should be easy to determine how much time is needed for laser application. Some laser units compute this with preprogrammed software, whereas others require the therapist to calculate how many joules are needed and how many joules are emitted per second. Some units may take 1 second or less to deliver 1 J, whereas other units may take up to 20 seconds to deliver 1 J.

The greater the power density and longer the wavelength, the deeper the penetration is through tissues. Unfortunately, the optimal wavelengths, intensities, and dosages have not been adequately studied in dogs, and information in people is difficult to interpret because of different conditions and treatment regimens. More laser dosage is not necessarily better, because overdosing may retard the desired effect. A common mistake in using laser therapy, especially in wound healing, is to experience a positive result and automatically assume more will be better. The healing process can only progress at a certain rate.

Laser therapy is generally administered with a handheld probe, with a small beam area that is useful to treat small surfaces; other lasers have several beam areas in the same unit to treat larger areas (Figure 21-9). Laser energy may be applied with the laser probe in contact with the skin, which eliminates reflection from the skin and minimizes beam divergence, or with the probe not held in contact. With the noncontact method, it is necessary to hold the probe perpendicular to the treatment area to minimize wave reflection and beam divergence. Noncontact application is recommended for wound treatment. The appropriate dosage may be applied to larger areas by administering the calculated dose to each individual site in a grid fashion, or by slowly moving the probe over the entire surface, being certain to evenly distribute the energy to each site. In any case, the probe should be held perpendicular to the skin. A coupling medium is not necessary, as in ultrasound, because the laser beam is not attenuated by air.

To maximize laser application, the hair should be clipped because 50% to 99% of the light may be absorbed by hair. Little is known about the transmission of laser light to deeper tissues in darker dogs, but HeNe laser energy is likely to be absorbed because of the pigment. It has been recommended that the dose be increased by 25% in treatment areas with dark pigmentation. Any iodine or povidone iodine should be washed off the area. Any topical medications, especially corticosteroids and other photosensitizing agents, should be removed. The therapist should wear protective eye wear, because damage may occur to the retina if the laser shines into the eyes, and the patient's eyes should also be protected (Box 21-3).

Figure 21-9 Laser therapy is generally administered with a handheld probe, with a small beam area that is useful to treat small surfaces.

Box 21-3 Key Points for Laser Usage in Dogs

1. Clip hair.
2. Measure area to be treated (a playing card is 57 cm^2).
3. Determine treatment dose.
4. Increase dose for dogs with dark skin by 25%.
5. Determine the number of J/cm^2, total joules, and the length of treatment time for laser application. If treating an area the size of a playing card with 10 J/cm^2, the total treatment is 600 J. If using a 10-W laser, the treatment time is 60 seconds.
6. Place safety goggles on all in the immediate area.
7. Hold laser perpendicular to the skin (direct contact minimizes laser light reflection; noncontact application is recommended for wounds).
8. Apply laser treatment using an overlapping grid technique to be certain that the treatment is applied equally to all areas.

Application for Various Conditions in Dogs

Laser therapy has been used for the treatment of wounds; pain; inflammation; OA; and muscle, ligament, and tendon injuries. In general, Class IV laser energy is applied in an overlapping grid or fanning fashion, always moving the laser to avoid heating the area. Other lasers may be applied using a point-to-point application of a dose per unit area. One can imagine the area covered by a grid with square centimeters, and the laser treatment is given in the squares. The following doses have been suggested for treating various conditions. However, there is currently little or no research available regarding dose or frequency of treatment in dogs for different conditions; the information is extrapolated from research in other species and anecdotal information and should be used with caution (Box 21-4).

Open Wounds

Clinically, laser therapy has been applied to both traumatic and surgical wounds, lick granulomas, abrasions, and skin conditions associated with allergies. The causes and sources of lick granulomas should be treated appropriately to complement the laser treatments. Laser therapy assists with the reduction of inflammation and wound healing, as indicated previously. Pain should also be considered in wound management as well, and laser therapy may be helpful to provide some pain control. Traumatic wounds also need to be treated appropriately with regard to infections, wound dressings, and other related issues. Debriding and cleaning should be performed before laser therapy is performed. When treating wounds, it is beneficial to document the size of the wound with photographs and measurements. The wound should be measured at each treatment session to document progress or lack of progress. Corresponding medications and bandage changes should be documented as well.

Traumatic wounds, such as degloving injuries, are understandably very painful and the animal may not tolerate direct contact. The laser head should be held above the wound to avoid contamination of the wound. The head should be cleaned thoroughly with rubbing alcohol prior to and after treatment. Most laser heads have a small lip or surface on them, preventing direct contact with the lens and the wound. Laser treatment is applied directly to the wound at a treatment dosage of 2 to 8 J/cm^2. Acute wounds may be treated with a lower dosage daily for the first 7 to 10 days. The entire wound area should be treated, including the periphery of the wound.

Postsurgical Wounds

Postsurgical wounds may be treated immediately after the surgical procedure to assist with healing. The postsurgical wounds appropriate for laser are not limited to orthopedic and neurologic cases. General postsurgical wounds, including spays, other abdominal surgeries, dewclaw removals, benign soft tissue removals, and other soft tissue surgeries, may respond to laser therapy. Laser treatments assist with cell proliferation, antiinflammation, and DNA synthesis. Because of this, surgical wounds following removal of neoplasia should not be treated with laser.

Box 21-4 Dose Guidelines for Various Uses in Dogs

Analgesic Effect

- Muscle pain: For acute pain apply 2 to 4 J/cm^2; for chronic pain, apply 4 to 8 J/cm^2.
- Joint pain: Apply 4 to 6 J/cm^2 for acute pain, and 4 to 8 J/cm^2 for chronic pain.

Antiinflammatory Effect

- Acute and subacute: Apply 1 to 6 J/cm^2.
- Chronic: Apply 4 to 8 J/cm^2.

Open Wounds

- Acute wounds: Apply 2-6 J/cm^2 sid for 7-10 days.
- Chronic wounds: Apply 2-8 J/cm^2 sid.
- Laser head should not be applied directly to the wound.
- Clean laser head before and after treatment.
- Do not apply laser to wounds following removal of neoplasia.

Postsurgical Wounds

- A daily dose of 1-3 J/cm^2 is recommended for the first 7 to 10 days if possible, followed by a 1- to 2-day break, continued until the wound is healed. If daily treatment is not possible, then treatment three times per week may be performed.

Lick Granulomas

- Administer 1-3 J/cm^2, directly over the entire granuloma and at least 1 cm from the periphery. Depending on the size of the granuloma, the wound should be treated as frequently as possible; daily to a few times a week is beneficial. The granuloma should be treated until the wound is healed and hair growth has resumed.

Osteoarthritis

- Administer 8-10 J/cm^2.
- Treat along the joint lines and surrounding area.
- Hip: Start treatment at the greater trochanter, then direct around the cranial, medial, and caudal surfaces of the hip in a circumferential pattern.
- Stifle: Start at the patella. The joint line may then be followed either medially or laterally to complete the full circumference.
- Hock and digits: Start below the point of the hock and circle around the hock while applying treatment. It is important that the anatomy of the tarsus be considered, with its distal extent at the tarsometatarsal junction, to be certain that the appropriate areas are treated. The calcaneal tendon may also be treated. Individual toes may be treated but it is recommended that a small laser apparatus be used.
- Shoulder: Start at the greater tubercle, continuing circumferentially around the joint. Because of the tissue depth in this area, a longer wavelength laser source is necessary. If the biceps tendon or other tendons are involved, the treatment should include the length of the tendon.
- Elbow: Start below the olecranon process and continue around the entire joint in a circumferential manner. Treating distally and proximally from the elbow also benefits the surrounding soft tissue.
- Carpus and digits: Start at the accessory carpal pad and then treat in a circumferential manner. Sweeping motions may be performed distally and proximally to cover the distal and proximal aspects of the joint as well as the surrounding soft tissue. The digits may be approached the same way, although it is sometimes difficult to move in a circumferential manner. The dorsal and palmar aspects of the digits may be treated.
- Cervical spine: Treat the entire cervical spine from the suboccipital area down to the upper thoracic region. The laser may be applied directly over the dorsal cervical spine, and then moved over the epaxial musculature on both sides. Do not apply the laser for a prolonged period over the carotid arteries.
- Thoracic and lumbar spine: Treat directly over the area as well as the epaxial and surrounding musculature.
- Tendon conditions (biceps tenosynovitis, supraspinatus tendonitis, patellar tendonitis, and other tendon inflammatory conditions): The length of the superficial aspect of the tendon should be treated along with the surrounding soft tissues.

sid, Once daily.

The laser apparatus should be held directly over the wound and either moved in a sweeping fashion or held directly over the wound. The recommended treatment schedule is 1-3 J/cm^2 daily for the first 7-10 days, with a 1- to 2-day break, then continuing laser treatment until the wound is healed. Realistically, if the animal is not in the hospital, it may be difficult to laser the wound daily. Therefore as frequent treatments as possible should be pursued, with a minimum of three times per week. Laser therapy should continue a few times per week until the wound has closed and healthy tissue has formed. Clinically, steps should be taken to avoid self-mutilation by the dog, such as application of an Elizabethan collar.

Lick Granulomas

Lick granulomas are a common problem seen in small animal practice and may be treated with laser therapy. The source of the lick granuloma must be initially identified and treated appropriately, and then the wound may be addressed. There are often underlying causes of the lick granuloma. The lick granuloma should be treated with 1-3 J/cm^2, directly over the granuloma and at least 1 cm from the periphery. Laser treatment contributes to wound healing, decreases inflammation, and also contributes antihistamine effects. Depending on the size of the granuloma, the wound should be treated frequently. Daily to a few

times a week is beneficial. The granuloma should be treated until the wound is healed and hair growth has resumed. However, the underlying cause must be determined and treated, whether it is anxiety, neurologic, orthopedic, or the result of other causes.

Osteoarthritis

As in human medicine, OA is very common in dogs. The initial step when addressing the arthritic patient is a thorough assessment of ROM, weight-bearing status, girth measurements, palpation, overall function and owner perception of problems with home activities. A pain scale may be used to determine the level of pain. Weight-bearing status may be determined through dynamic or static forceplates, or scales. The overall function and goals of the owner should be determined in the evaluation, and progress using the various assessment tools should be monitored.

After the problem list and the goals have been determined, treatment with laser therapy may be implemented as part of a multimodal treatment program. The specific goals of laser therapy often include decreased pain, inflammation, and improved circulation. Arthritic joints should be thoroughly treated along the joint lines and surrounding area (Figure 21-10). Recommendations for arthritic joints have ranged from 4 J/cm^2 up to 30 J/cm^2, but more appropriate doses may be 8-10 J/cm^2. The apparatus may either be held directly over the area for the designated number of joules, or used in a sweeping fashion depending on the unit.

Hip

Canine hip dysplasia and resultant OA are very common. The coxofemoral joint should be completely treated. A good landmark to start treatment is the greater trochanter. The treatment should then be directed around the cranial, medial, and caudal surfaces of the hip. The treatment is directed in a circumferential pattern. Referred pain or secondary pain should also be addressed. The lumbosacral area and the musculature of the hip are often painful because of compensations and may also be treated.

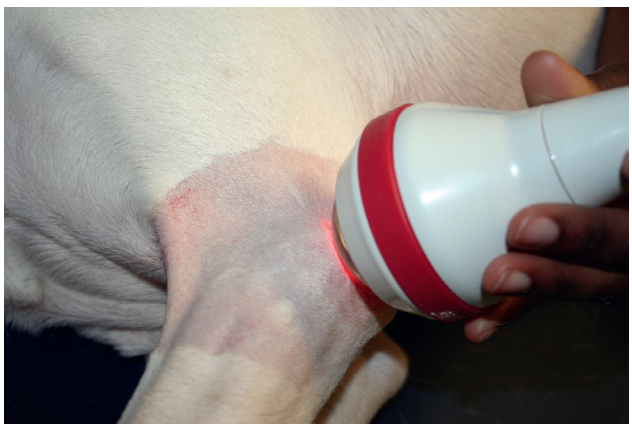

Figure 21-10 Treatment of an arthritic joint with a therapeutic laser.

Stifle

Arthritic stifles are easily treated with therapeutic laser. A nice starting point is the patella. The joint line may then be followed either medially or laterally to complete the full circumference. The patella ligament may be treated proximally and distally. Cranial cruciate repairs or deficient stifles often have soreness in the distal hamstring muscles and patients may benefit from treating this area as well.

Hock and Digits

Hock and digit joints are often difficult to treat with modalities such as cryotherapy or moist heat because of their size and irregular contour. Laser therapy is an easy treatment for these areas. Arthritic conditions of the hock may be treated by beginning below the point of the hock and circling around the hock while applying treatment. It is important that the anatomy of the tarsus be considered, with its distal extent at the tarsometatarsal junction, to be certain that the appropriate areas are treated. The calcaneal tendon may also be treated. Individual toes may be treated, but it is recommended that a small laser apparatus be used. If only a large unit is available, it may be used in a sweeping motion over the affected digits.

Shoulder

The shoulder and affected areas are easily treated. A good starting point is the greater tubercle, with the laser continuing circumferentially around the joint. Because of the tissue depth in this area, a longer wavelength laser source is necessary. If the biceps tendon or other tendons are involved, the treatment should include the length of the tendon. The cervical region and the cervical strap muscles may benefit from treatment because of possible secondary compensations that may occur from shoulder issues and lameness.

Elbow

The elbow is a very common area for arthritic changes and may benefit from laser therapy. The laser should be directed around the entire joint in a circumferential manner. A good starting point is below the olecranon process; treatment should then proceed around the area. Treating distally and proximally from the elbow also benefits the surrounding soft tissue, in particular the triceps muscles. Secondary and tertiary soreness and pain may be noted in the shoulder and the carpal region, and they may benefit from laser treatment.

Carpus and Digits

The carpal joint usually responds well to laser therapy to help reduce the inflammation and pain associated with

arthritic changes. Arthritic digits may also be aided by therapeutic effects of laser, in addition to sesamoiditis. The carpal joint should be treated in a circumferential manner. The accessory carpal pad is a good starting point; the laser should then be directed around the joint. Sweeping motions may be performed distally and proximally to cover the distal and proximal aspects of the joint as well as the surrounding soft tissue. The digits may be approached in the same way, although it is sometimes difficult to move in a circumferential manner. The dorsal and palmar aspects of the digits may be treated, however.

Cervical Spine

The entire cervical spine should be treated from the suboccipital area down to the upper thoracic region. The laser may be applied directly over the dorsal cervical spine, and then moved over the epaxial musculature on both sides. Caution should be exercised to be certain that the laser is not applied for a prolonged period over the carotid arteries. The cervical musculature is thick and arthritic conditions of the cervical spine may benefit from the effects of laser.

Thoracic Spine

The lower thoracic spine is especially affected with arthritic changes and compensations. Treating directly over the area as well as the epaxial and surrounding musculature may be very beneficial.

Lumbar Spine

The lumbar spine, surrounding areas, and musculature may be treated the same as the thoracic spine.

Tendon Conditions

Biceps tenosynovitis, supraspinatus tendonitis, patellar tendonitis, and other inflammatory conditions involving tendons may be treated with laser therapy. The length of the superficial aspect of the tendon should be treated along with the surrounding soft tissues. The biceps tendon communicates with the shoulder joint capsule; therefore the shoulder joint capsule should be treated as well.

Precautions Regarding the Use of Laser Therapy

In general, the thermal effects of laser may injure tissues, especially the eyes, and in some cases, skin. Even small amounts of laser light can cause permanent damage to the retina.[10] Because lasers have coherent light, even a small amount of laser light may be focused on the retina through the eye, and as little as 10° C increase in temperature may cause permanent damage to the retinal photoreceptor cells. The visible and near-infrared regions of the electromagnetic spectrum may penetrate into the eye, but because there is visible light, the blink reflex helps protect against damage. Infrared laser light is not visible, and therefore a blink reflex does not occur as with bright visible light. A person exposed to laser light in an eye may not experience any pain or discomfort until a pop is heard as a result of explosive boiling and damage to the retina.[10] Caution must be used to select appropriate eyewear to be certain that the particular wavelength will be blocked and that an appropriate optical density is used to attenuate the beam power (Figure 21-11).

Figure 21-11 Protective eyewear should always be used when using a laser therapy.

Box 21-5 Precautions Regarding Laser Therapy

- Use protective eye wear.
- Do not direct laser treatment to the eye.
- Use caution with laser beam reflection from metal surfaces.
- Use caution with treatment in the presence of the following conditions:
  - Pregnancy
  - Open fontanels
  - Growth plates of immature animals
  - Malignancies
  - Photosensitive areas of the skin
- Dark colored skin, tattoos, and hair can absorb laser light and undergo excessive heating, resulting in discomfort.

Other contraindications and precautions to laser therapy include pregnancy, treatment over open fontanels or growth plates of immature animals, over malignancies, and over photosensitive areas of the skin.[5] Dark-colored skin, tattoos, and hair can absorb laser light and undergo excessive heating when a Class IV laser is applied, resulting in discomfort (Box 21-5).

Summary of Laser Therapy

Lasers are a potentially useful tool in veterinary rehabilitation. Although their use remains controversial, several studies have demonstrated benefit to using laser therapy.

Especially promising for their use in veterinary rehabilitation are studies showing preservation of cartilage properties with treatment, improvement in peripheral nerve injuries, and as a possible adjunct to managing pain, such as in patients with OA. Laser therapy also appears to have benefit in early wound healing. Laser therapy is noninvasive and there are no reported side effects when used properly.

REFERENCES

1. Reddy GK, Stehno-Bittel L, Enwemeka CS: Laser photostimulation accelerates wound healing in diabetic rats, *Wound Repair Regen* 9(3):248-255, 2001.
2. Stelian J, Gil I, Habot B et al: Laser therapy is effective for degenerative osteoarthritis. Improvement of pain and disability in elderly patients with degenerative osteoarthritis of the knee treated with narrow-band light therapy, *J Am Geriatr Soc* 40:23-26, 1992.
3. Djavid GE, Mortazavi SMJ, Basirnia A et al: Low level laser therapy in musculoskeletal pain syndromes: pain relief and disability reduction, *Lasers Surg Med* 152(Suppl 15):43, 2003.
4. Chow RT, Heller GZ, Barnsley L: The effect of 300 mW, 830 nm laser on chronic neck pain: a double-blind, randomized, placebo-controlled study, *Pain* 124:201-210, 2006.
5. Bélanger A-Y: Laser. In Bélanger A-Y, editor: *Evidence-based guide to therapeutic physical agents*, Philadelphia, 2002, Lippincott Williams & Wilkins.
6. Zati A, Valent A: Laser light. In *Laser Therapy in Medicine*, Torino, Italy, 2008, Edizioni Minerva Medica.
7. Hashmi JT, Huang YY, Sharma SK et al: Effect of pulsing in low-level light therapy, *Lasers Surg Med* 42:450-466, 2010.
8. Bjordal JM, Lopes-Martins RA, Joensen J et al: A systematic review with procedural assessments and meta-analysis of low level laser therapy in lateral elbow tendinopathy (tennis elbow), *BMC Musculoskelet Disord* 9:75, 2008.
9. Gigo-Benato D, Geuna S, de Castro Rodrigues A et al: Low-power laser biostimulation enhances nerve repair after end-to-side neurorrhaphy: a double-blind randomized study in the rat median nerve model, *Laser Med Sci* 19:57-65, 2004.
10. Chuang LH, Lai CC, Yang KJ et al: A traumatic macular hole secondary to a high-energy Nd:YAG laser, *Ophthalmic Surg Lasers* 32(1):73, 2001.
11. Ramey DW, Rollin BE: Scientific aspects of CAVM. In Ramey DW, Rollin BE, editors: *Complementary and alternative veterinary medicine considered*, Ames, Iowa, 2004, Iowa State Press.
12. Baxter GD, Walsh DM, Allen JM et al: Effects of low-intensity infrared laser irradiation upon conduction in the human median nerve in vivo, *Exp Physiol* 79:227-234, 1994.
13. Topping A, Gault D, Grobbelaar A et al: Does low penetration of human skin by the normal mode ruby laser account for poor permanent depilatory success rates? *Lasers Med Sci* 16:224-229, 2001.
14. Simpson CR, Kohl M, Essenpreis M et al: Near-infrared optical properties of ex vivo human skin and subcutaneous tissues measured using the Monte Carlo inversion technique, *Phys Med Biol* 43:2465-2478, 1998.
15. Wilson BC, Jeeves WP, Lowe DM: In vivo and post mortem measurement of the attenuation spectra of light in mammalian tissues, *Photochem Photobiol* 42:153-162, 1985.
16. Kolárová H, Ditrichová D, Wagner J: Penetration of the laser light into the skin in vitro, *Lasers Surg Med* 24:231-235, 1999.
17. Esnouf A, Wright PA, Moore JC et al: Depth of penetration of an 850 nm wavelength low level laser in human skin, *Acupunct Electrother Res* 32:81-86, 2007.
18. Enwemeka CS, Parker JC, Dowdy DS et al: The efficacy of low-power lasers in tissue repair and pain control: a meta-analysis study, *Photomed Laser Surg* 22(4):323-329, 2004.
19. Karu T: Mitochondrial mechanisms of photobiomodulation in context of new data about multiple roles of ATP, *Photomed Laser Surg* 28:159-160, 2010.
20. Khakh BS, Burnstock G: The double life of ATP, *Sci Am* 12:84-92, 2009.
21. Da Salva JP, da Salva MA, Almeida APF et al: Laser therapy in the tissue repair process: a literature review, *Photomed Laser Surg* 28:17-21, 2010.
22. Stein A, Benayahu D, Malts L et al: Low-level laser irradiation promotes proliferation and differentiation of human osteoblasts in vitro, *Photomed Laser Surg* 23:161-166, 2005.
23. Patore D, Greco M, Passarella S: Specific helium-neon laser sensitivity of the purified cytochrome C oxidase, *Int J Radiat Biol* 76:863-870, 2000.
24. Quirk BJ, Whelan HT: Near-infrared irradiation photobiomodulation: the need for basic science, *Photomed Laser Surg* 29:143-144, 2011.
25. Honmura A, Lshii A, Yanase M et al: Analgesic effect of GaAlAs diode laser irradiation on hyperalgesia in carrageenin-induced inflammation, *Lasers Surg Med* 13:463-469, 1993.
26. Sakurai Y, Yamaguchi M, Abiko Y: Inhibitory effect of low-level laser irradiation on LPS-stimulated prostaglandin E_2 productions and cyclooxygenase-2 in human gingival fibroblasts, *Eur J Oral Sci* 108:29-34, 2000.
27. Medrado AR, Pugliese LS, Reis SR et al: Influence of low level laser therapy on wound healing and its biological action upon myofibroblasts, *Lasers Surg Med* 32:239-244, 2003.
28. Bjordal JM, Lopes-Martins RAB, Iversen VV: A randomized, placebo controlled trial of low level laser therapy for activated Achilles tendinitis with microdialysis measurement of peritendinous prostaglandin E_2 concentrations, *Br J Sports Med* 40:76-80, 2006.
29. Hawkins D, Abrahamse H: Effect of multiple exposures of low-level laser therapy on the cellular responses of wounded human skin fibroblasts, *Photomed Laser Surg* 24:705-714, 2006.
30. Peplow PV, Chung TY, Baxter GD: Laser photobiomodulation of wound healing: a review of experimental studies in mouse and rat animal models, *Photomed Laser Surg* 28:291-325, 2010.
31. Meirelles GC, Santos JN, Chagas PO et al: A comparative study of the effects of laser photobiomodulation on the healing of third-degree burns: a histological study in rats, *Photomed Laser Surg* 26:159-166, 2008.
32. Meirelles GC, Santos JN, Chagas PO et al: Effectiveness of laser photobiomodulation at 660 or 780 nanometers on the repair of third-degree burns in diabetic rats, *Photomed Laser Surg* 26:47-54, 2008.

33. Mendez TM, Pinheiro AL, Pacheco MT et al: Dose and wavelength of laser light have influence on the repair of cutaneous wounds, *J Clin Laser Med Surg* 22:19-25, 2004.
34. Rezende SB, Ribeiro MS, Nunez SC et al: Effects of a single near-infrared laser treatment on cutaneous wound healing: biometrical and histological study in rats, *J Photochem Photobiol B, Biol* 87:145-153, 2007.
35. Kawalec JS, Hetherington VJ, Pfennigwerth TC et al: Effect of a diode laser on wound healing by using diabetic and nondiabetic mice, *J Foot Ankle Surg* 43:214-220, 2004.
36. Concalves WLS, Souza FM, Conti CL: Influence of He-Ne laser therapy on the dynamics of wound healing in mice treated with anti-inflammatory drugs, *Braz J Med Biol Res* 40:877-884, 2007.
37. Mester E, Spiry T, Szende B et al: Effect of laser rays on wound healing, *Am J Surg* 122:532-538, 1971.
38. Schindl A, Schindl M, Pernerstorfer-Schoen H et al: Low intensity laser therapy in wound healing: a review with special respect to diabetic angiopathies, *Acta Chirurgica Austriaca* 33(3):132-137, 2001.
39. Surinchak JS, Alago ML, Mellamy RF et al: Effects of low-level energy lasers on the healing of full-thickness skin defects, *Lasers Surg Med* 2(3):267-274, 1983.
40. Braverman B, McCarthy RJ, Ivankovich AD et al: Effect of helium-neon and infrared laser irradiation on wound healing in rabbits, *Lasers Surg Med* 9(1):50-58, 1989.
41. Lucas C, Criens-Poublon LJ, Cockrell CT et al: Wound healing in cell studies and animal model experiments by low level laser therapy: were clinical studies justified? A systematic review, *Lasers Med Sci* 17(2):110-134, 2002.
42. Pinheiro ALB, Oliveira MG, Martins PPM et al: Biomodulatory effects of LLLT on bone regeneration, *Laser Ther* 13:73-79, 2001.
43. Lirani-Galvão AP, Jorgetti V, da Silva OL: Comparative study of how low-level laser therapy and low-intensity pulsed ultrasound affect bone repair in rats, *Photomed Laser Surg* 24(6):735-740, 2006.
44. Gerbi ME, Marques AM, Ramalho LM et al: Infrared laser light further improves bone healing when associated with bone morphogenic proteins: an in vivo study in a rodent model, *Photomed Laser Surg* 26(1):55-60, 2008.
45. Kaya GS, Kaya M, Gürsan N et al: Use of 808-nm light therapy to treat experimental chronic osteomyelitis induced in rats by methicillin-resistant *Staphylococcus aureus*, *Photmed Laser Surg* 29:405-412, 2011.
46. Kizhner V, Krespi Y, Hall-Stoodley L et al: Laser-generated shockwave for clearing medical device biofilms, *Photomed Laser Surg* 29:277-282, 2011.
47. Barber A, Luger JE, Karpf A et al: Advances in laser therapy for bone repair, *Laser Ther* 13:80-85, 2001.
48. Cressoni MDC, Giusti HHKD, Piao AC et al: Effect of GaAlAs laser irradiation on the epiphyseal cartilage of rats, *Photmed Laser Surg* 28:527-532, 2010.
49. Guzzardella GA, Tigani D, Torricelli P et al: Low-power diode laser stimulation of surgical osteochondral defects: results after 24 weeks, *Artif Cells Blood Substit Immobil Biotechnol* 29(3):235-244, 2001.
50. Guzzardella GA, Morrone G, Torricelli P et al: Assessment of low-power laser biostimulation on chondral lesions: an "in vivo" experimental study, *Artif Cells Blood Substit Immobil Biotechnol* 28(5):441-449, 2000.
51. Bayat M, Ansari A, Hekmat H: Effect of low-power helium-neon laser irradiation on 13-week immobilized articular cartilage of rabbits, *Indian J Exp Biol* 42(9):866-870, 2004.
52. Akai M, Usuba M, Maeshima T et al: Laser's effect on bone and cartilage change induced by joint immobilization: an experiment with animal model, *Laser Surg Med* 21(5):480-484, 1997.
53. de Morais NCR, Barbosa AM, Vale ML et al: Anti-inflammatory effect of low-level laser and light-emitting diode in zymosan-induced arthritis, *Photomed Laser Surg* 28:227-232, 2010.
54. Rubio CR, Cremonezzi D, Moya M et al: Helium-neon laser reduces the inflammatory process of arthritis, *Photomed Laser Surg* 28:125-129, 2010.
55. Stelian J, Gil I, Habot B et al: Laser therapy is effective for degenerative osteoarthritis. Improvement of pain and disability in elderly patients with degenerative osteoarthritis of the knee treated with narrow-band light therapy, *J Am Geriatr Soc* 40:23-26, 1992.
56. Gur A, Cosut A, Sarac AJ et al: Efficacy of different therapy regimes of low-power laser in painful osteoarthritis of the knee: a double-blind and randomized-controlled trial, *Lasers Surg Med* 33:330-338, 2003.
57. Hegedüs B, Viharos L, Gervain M et al: The effect of low-level laser in knee osteoarthritis: a double-blind, randomized, placebo-controlled trial, *Photomed Laser Surg* 27:577-584, 2009.
58. Tascioglu F, Armagan O, Tabak Y et al: Low power laser treatment in patients with knee osteoarthritis, *Swiss Med Wkly* 134(17-18):254-258, 2004.
59. Brosseau L, Robinson V, Wells G et al: Low level laser therapy (Classes I, II and III) for treating osteoarthritis, *Cochrane Database Syst Rev* Issue 3. Art. No.: CD002046. DOI: 10.1002/14651858.CD002046.pub2, 2004.
60. Brosseau L, Welch V, Wells GA et al: Low level laser therapy (Classes I, II and III) for treating rheumatoid arthritis, *Cochrane Database of Systematic Reviews* Issue 4. Art. No.: CD002049. DOI: 10.1002/14651858.CD002049.pub2, 2005.
61. Meireles SM, Jones A, Jennings F et al: Assessment of the effectiveness of low-level laser therapy on the hands of patients with rheumatoid arthritis: a randomized double-blind controlled trial, *Clin Rheymatol* 29:501-509, 2010.
62. Lögdberg-Andersson M, Mützel S, Hazel Å: Low level laser therapy (LLLT) of tendinitis and myofascial pains—a randomized, double-blind, controlled study, *Laser Therapy* 9:79-86, 1997.
63. Bjordal JM, Lopes-Martins RAB, Iversen VV: A randomized, placebo controlled trial of low level laser therapy for activated Achilles tendinitis with microdialysis measurement of peritendinous prostaglandin E2 concentrations, *Br J Sports Med* 40:76-80, 2006.
64. Oliveira FS, Pinfildi CE, Parizoto NA et al: Effect of low level laser therapy (830 nm) with different therapy regimes on the process of tissue repair in partial lesion calcaneous tendon, *Lasers Surg Med* 41:271-276, 2009.
65. Haker E, Lundeberg T: Is low-energy laser treatment effective in lateral epicondylalgia? *J Pain Symptom Management* 6:241-246, 1991.

66. Tumilty S, Munn J, McDonough S et al: Low level laser treatment of tendinopathy: a systematic review with meta-analysis, *Photomed Laser Surg* 28:3-16, 2010.
67. Fung DT, Ng GY, Leung MC et al: Therapeutic low energy laser improves the mechanical strength of repairing medial collateral ligament, *Lasers Surg Med* 31:91-96, 2002.
68. De Bie RA, de Vet HC, Lenssen TF et al: Low-level laser therapy in ankle sprains: a randomized clinical trial, *Arch Phys Med Rehabil* 79(11):1415-1420, 1998.
69. Chow R: Phototherapy and the peripheral nervous system, *Photomed Laser Surg* 29:591-592, 2011.
70. Moore KC, Naru H, Broome IJ: The effect of infra-red diode laser irradiation on the duration and severity of postoperative pain: a double blind trial, *Laser Therapy* 4:145-149, 1993.
71. Snyder-Mackler L, Bork CE: Effect of helium-neon laser irradiation on peripheral sensory nerve latency, *Phys Ther* 68:223-225, 1988.
72. Lowe AS, Baster GD, Walsh DM et al: The effect of low-intensity laser (830 nm) irradiation upon skin temperature and antidromic conduction latencies in the human median nerve: relevance of radiant exposure, *Lasers Surg Med* 14:40-46, 1994.
73. Basford JR, Daube JR, Hallman HO et al: Does low-intensity helium-neon laser irradiation alter sensory nerve action potentials or distal latencies? *Lasers Surg Med* 10:35-39, 1990.
74. Whittaker P: Laser acupuncture: past, present, and future, *Lasers Med Sci* 19:69-80, 2004.
75. Tsuchiya K, Kawatani M, Takeshige C et al: Laser irradiation abates neuronal responses to nociceptive stimulation of rat-paw skin, *Brain Res Bull* 34(4):369-374, 1994.
76. Wedlock PM, Shephard RA: Cranial irradiation with GaAlAs laser leads to naloxone reversible analgesia in rats, *Psychol Rep* 78(3):727-731, 1996.
77. Chow R, Armati P, Laakso E-L et al: Inhibitory effects of laser irradiation on peripheral mammalian nerves and relevance to analgesic effects: a systematic review, *Photo Med Laser Surg* 29:365-381, 2011.
78. Ay S, Dogan SK, Evcik D: Is low-level laser therapy effective in acute or chronic low back pain? *Clin Rheumatol* 29:905-910, 2010.
79. Kleinkort JA: Low-level laser therapy: new possibilities in pain management and rehab, *Orthopaedic Prac* 17(1):48-51, 2005.
80. Bjordal JM, Couppè C, Chow R et al: A systematic review of low level laser therapy with location-specific doses for pain from chronic joint disorders, *Austr J Physiother* 49:107-116, 2003.
81. Rochkind S, Nissan M, Razon N et al: Electrophysiological effect of HeNe laser on normal and injured sciatic nerve in the rat, *Acta Neurochir* 83:125-130, 1986.
82. Rochkind S, Barr-Nea L, Razon N et al: Stimulatory effect of He-Ne low dose laser on injured sciatic nerves of rats, *Neurosurgery* 20:843-847, 1987.
83. Rochkind S, Nissan M, Lubart R et al: The in-vivo nerve response to direct low-energy-laser irradiation, *Acta Neurochir* 94:74-77, 1988.
84. Shin DH, Lee E, Hyun JK et al: Growth-associated protein-43 is elevated in the injured rat sciatic nerve after low power laser irradiation, *Neurosci Lett* 344:71-74, 2003.
85. Rochkind S: The role of laser phototherapy in nerve tissue regeneration and repair: research development with perspective for clinical application. In Proceedings of the World Association of Laser Therapy, São Paulo, Brazil, 2004, pp 94-95.
86. Rochkind S, Nissan M, Alon M et al: Effects of laser irradiation on the spinal cord for the regeneration of crushed peripheral nerve in rats, *Lasers Surg Med* 28(3):216-219, 2001.
87. Shamir MH, Rochkind S, Sandbank J et al: Double-blind randomized study evaluating regeneration of the rat transected sciatic nerve after suturing and postoperative low-power laser treatment, *J Reconstr Microsurg* 17:133-137, 2001.
88. Miloro M, Halkias LE, Mallery S et al: Low-level laser effect on neural regeneration in Gore-Tex tubes, *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 93:27-34, 2002.
89. Gigo-Benato D, Geuna S, Rochkind S: Phototherapy for enhancing peripheral nerve repair: a review of the literature, *Muscle Nerve* 31:694-701, 2005.
90. Draper WE, Schubert TA, Clemmons RM et al: Low-level laser therapy reduces time to ambulation in dogs after hemilaminectomy: a preliminary study, *J Small Anim Pract* 53:465-469, 2012
91. Naeser MA, Hamblin MR: Potential for transcranial laser or LED therapy to treat stroke, traumatic brain injury, and neurodegenerative disease, *Photomed Laser Surg* 29:443-446, 2011.
92. Oron A: Low-level laser therapy applied transcranially to rats after induction of stroke significantly reduces long-term neurological deficits, *Stroke* 37:2620-2624, 2006.
93. Zhang L, Chopp M, Zhang ZG: A rat model of focal embolic cerebral ischemia, *Brain Res* 766:83-92, 1997.
94. Zivin JA, Albers GW, Bornstrin N et al: Effectiveness and safety of transcranial laser therapy for acute ischemic stroke, *Stroke* 40:1359-1364, 2009.