Chapter 12

Electromagnetic Radiation: Lasers and Light

OUTLINE

TERMINOLOGY

It is recommended that the first time reader and student carefully review the glossary of useful terms and concepts before reading the text because much of the terminology used to describe **laser** and light therapy is unique to this area.

INTRODUCTION TO ELECTROMAGNETIC RADIATION

Electromagnetic radiation is composed of electric and magnetic fields that vary over time and are oriented perpendicular to each other (Fig. 12-1). Physical agents that deliver **energy** in the form of **electromagnetic radiation** include various forms of visible and invisible light and radiation in the shortwave and microwave ranges. All living organisms are continuously exposed to electromagnetic radiation from natural sources, such as the magnetic field of the earth and **ultraviolet (UV) radiation** from the sun. We are also exposed to electromagnetic radiation from manufactured sources, such as light bulbs, domestic electrical appliances, computers, and power lines.

This chapter serves as an introduction to the application of electromagnetic radiation in rehabilitation and provides specific information on the therapeutic application of lasers and other light therapy. The therapeutic use of electromagnetic radiation in the UV, radiowave, and microwave ranges are covered in Chapters 13 and 14. Because infrared (IR) radiation produces superficial heating, the clinical application of IR lamps and other superficial heating agents is described in Chapter 6.

PHYSICAL PROPERTIES OF ELECTROMAGNETIC RADIATION

Electromagnetic radiation is categorized according to its **frequency** and **wavelength**, which are inversely proportional to each other (Fig. 12-2). Lower-frequency electromagnetic radiation, including extremely low-frequency (ELF) waves, shortwaves, microwaves, IR radiation, visible light, and UV, is nonionizing, cannot break molecular bonds or produce ions, and can therefore be used for therapeutic medical applications. Higher-frequency electromagnetic radiation, such as x-rays and gamma rays, is ionizing and can break molecular bonds to form ions.[1,2] **Ionizing radiation** can also inhibit cell division and is therefore either not used clinically or is used in very small doses for imaging, or in larger doses to destroy tissue. Approximate frequency ranges for the different types of electromagnetic radiation are shown in Fig. 12-3 and are provided in the sections concerning each type of radiation. Approximate ranges are given because the reported values differ slightly among texts.[3]

The intensity of any type of electromagnetic radiation that reaches the patient from a radiation source is proportional to the energy output from the source, the inverse square of the distance of the source from the patient, and the cosine of the angle of incidence of the beam with the tissue. The intensity of energy reaching the body is greatest when the energy output is high, the radiation source is close to the patient. and the beam is perpendicular to the surface of the skin.

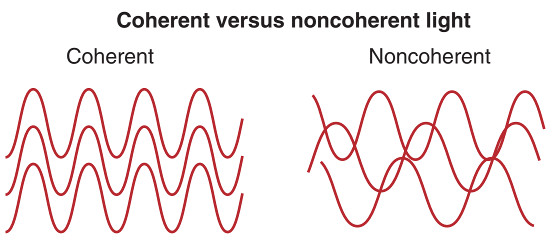

FIG 12-1 Coherent versus noncoherent light.

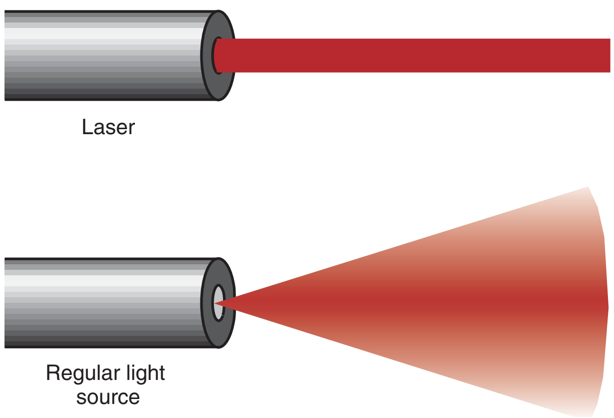

FIG 12-2 Directional light produced by a laser, in contrast to the divergent light produced by other sources.

Clinical Pearl

The intensity of any type of electromagnetic radiation reaching the body is greatest when the energy output is high, the radiation source is close to the patient, and the beam is perpendicular to the surface of the skin.

As the distance from the skin, or the angle with the surface, increase, the intensity of the radiation reaching the skin falls.

Electromagnetic radiation can be applied to a patient to achieve a wide variety of clinical effects. The nature of these effects is determined primarily by the frequency and wavelength range of the radiation[4] and to some degree by the intensity of the radiation.

Clinical Pearl

The clinical effects of electromagnetic radiation are determined primarily by the radiation's frequency and wavelength range.

The frequencies of electromagnetic radiation used clinically can be in the IR, visible light, UV, shortwave, or microwave range. Far IR radiation, which is close to the microwave range, produces superficial heating and can be used for the same purposes as other superficial heating agents. It has the advantage over other superficial heating agents of not requiring direct contact with the body. UV radiation produces erythema and tanning of the skin and epidermal hyperplasia and is essential for vitamin D synthesis. It is used primarily for the treatment of psoriasis and other skin disorders. Shortwave and microwave energy can be used to heat deep tissues and, when applied at a low-average intensity using a pulsed signal, may decrease pain and edema and facilitate tissue healing by nonthermal mechanisms. Low-intensity lasers and other light sources in the visible and near IR frequency ranges are generally used to promote tissue healing and control pain and inflammation by nonthermal mechanisms.

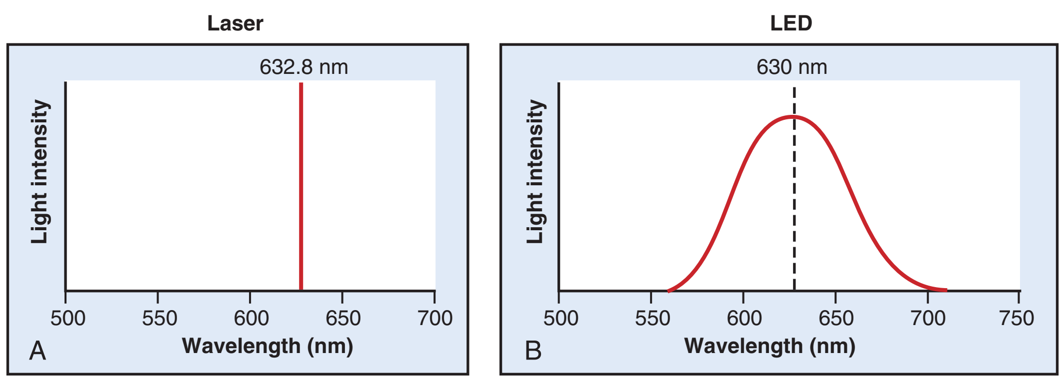

FIG 12-3 Wavelength distribution of different red light sources. **A,** Light from a He-Ne laser with a wavelength of 632.8 nm. This monochromatic light has a single wavelength. **B,** Light from a red LED. This light concentrates around a wavelength of 630 nm but has a range of wavelengths.

With the exception of lasers and light, electromagnetic agents are currently not in widespread use by therapists in the United States (US). However, most are commonly used in other countries and some are effective for the treatment of disorders not related to the musculoskeletal system and are therefore more commonly used by other health professionals. For example, **diathermy** is commonly used in other countries as a thermal agent to heat larger deeper areas but is unpopular in the US because of the risks associated with its misuse and the size of most devices. UV radiation has proven beneficial in the treatment of many skin disorders and is therefore most frequently used by dermatologists.

HISTORY OF ELECTROMAGNETIC RADIATION

Electromagnetic agents have been used for therapy to varying degrees at different times. Until recently, most electromagnetic agents were used in a limited manner by therapists. However, since 2002, when the Food and Drug Administration (FDA) cleared the use of a laser device for the treatment of carpal tunnel syndrome, the use of lasers and other forms of light for therapy has gained much popularity.

Sunlight was the earliest form of electromagnetic energy therapy. As noted previously, sunlight includes electromagnetic radiation in the UV, visible and IR range of the spectrum. Prehistoric man believed that sunlight could drive out the evil spirits that caused disease. The ancient Greeks praised Helios, their god of light, sun, and healing. It is from the word Helios that the term for treatment with sunlight, *heliotherapy*, is derived. Although the exact purpose and effectiveness of heliotherapy, as recommended by the ancient Greeks and Romans, are hard to judge, their prominent physicians, Celsus and Galen, recommended sunbathing for a many conditions including seizures, arthritis, and asthma, as well for preventing a wide range of problems and disorders.

Sunlight exposure, with a particular emphasis on exposure to UV light, regained therapeutic popularity in the 19th century when its value for preventing rickets (a bone disorder caused by vitamin D deficiency) in people exposed to a small amount of light because of dark living and working conditions, and its effectiveness in the treatment of tuberculosis, were recognized.[5] Today, although rickets and tuberculosis are rare, UV therapy remains popular for the treatment of psoriasis and other skin disorders, and lasers and similar forms of light, generally in the red and IR range, are used clinically, particularly for the treatment of pain and to promote tissue healing.

Other forms of treatment with electromagnetic radiation gained popularity in the 20th century when electrically driven devices that could deliver controlled wavelengths and intensities of electromagnetic energy were produced. These included diathermy devices that output energy in the shortwave or microwave wavelength range to produce heat in patients and fluorescent and incandescent lights that output energy in the UV, visible, and IR parts of the spectrum. Diathermy was a popular heating device worldwide but has fallen out of favor in the US since the advent of ultrasound, which is a deep heating device that is safer, smaller, and easier to use. UV light continues to be used for the treatment of certain skin disorders, but this area of practice is now generally the domain of dermatologists rather than therapists. IR lamps were popular in the mid-20th century as heating devices. Although they have the advantage of not requiring contact with the body, their safety is limited by the fact that the amount of heat delivered to an area varies with the distance of the body from the lamp, so that closer placement may produce too much heating and burns and further placement may be ineffective. This is a particular challenge when trying to treat contoured body areas. Therefore conductive heating devices, such as hot packs, have become a much more popular thermal agent.

Today, laser and other light devices are probably the most common form of electromagnetic therapy. The section on the history of light and laser therapy later in this chapter includes additional details about the development of this physical agent.

PHYSIOLOGICAL EFFECTS OF ELECTROMAGNETIC RADIATION

When electromagnetic radiation is absorbed by tissues it can affect them via thermal or nonthermal mechanisms. Because IR radiation and continuous shortwave and microwave diathermy delivered at sufficient intensity can increase tissue temperature, these agents are thought to affect tissues primarily by thermal mechanisms. IR lamps can be used to heat superficial tissues, whereas continuous shortwave and microwave diathermy heat deep and superficial tissues. The physiological and clinical effects of these thermal agents are generally the same as those of the superficial heating agents (see Chapter 6), except that the tissues affected are different.

UV radiation and low levels of pulsed diathermy or light do not increase tissue temperature and are therefore thought to affect tissues by nonthermal mechanisms. It has been proposed that these types of electromagnetic energy cause changes at the cellular level by altering cell membrane function and permeability and intracellular organelle function.[6] Nonthermal electromagnetic agents may also promote binding of chemicals to the cell membrane to trigger complex sequences of cellular reactions. Because these agents are thought to promote the initial steps in cellular function, this mechanism of action could explain the wide variety of stimulatory cellular effects that have been observed in response to the application of nonthermal levels of electromagnetic energy. Electromagnetic energy may also affect tissues by causing proteins to undergo conformational changes to promote active transport across cell membranes and to accelerate adenosine triphosphate (ATP) synthesis and use.[7]

Many researchers have invoked the Arndt-Schulz law to explain the effects of low, nonthermal levels of electromagnetic radiation (Fig. 12-4). According to this law, a certain minimum stimulus is needed to initiate a biological process. In addition, although a slightly stronger stimulus may produce greater effects, beyond a certain level, stronger stimuli will have a progressively less

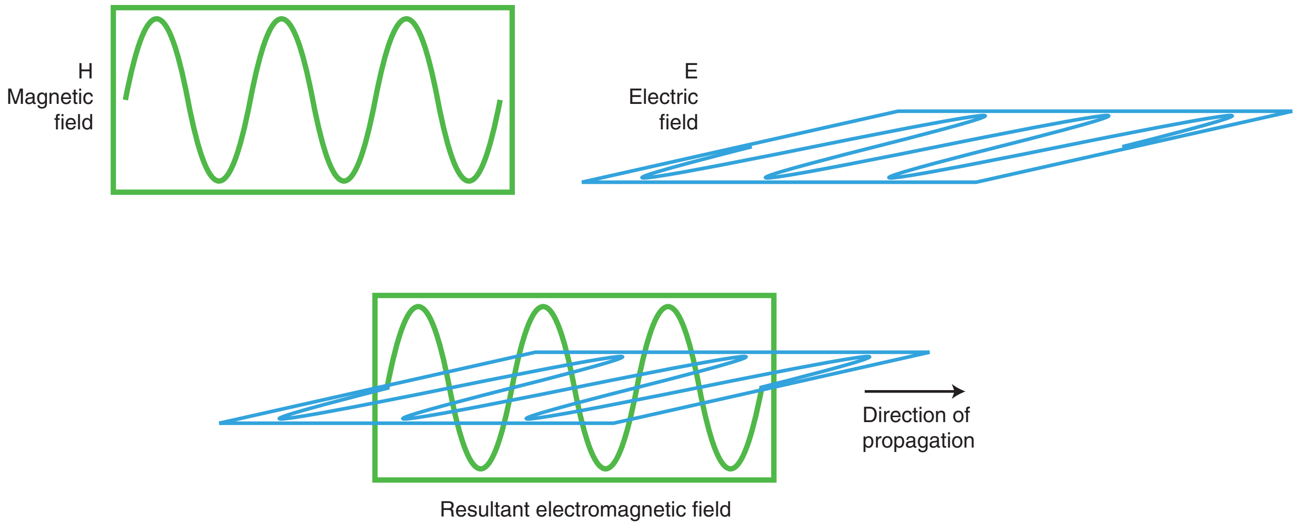

FIG 12-4 Perpendicular orientation of the electric and magnetic components of an electromagnetic field.

positive effect and higher levels will become inhibitory. For example, a low level of mechanical stress during childhood promotes normal bone growth, whereas too little or too much stress can result in abnormal growth or fractures. Similarly, with some forms of electromagnetic radiation, such as diathermy or laser light, although too low a dose may not produce any effect, the optimal dose to achieve a desired physiological effect may be lower than that which produces heat. If excessive doses are used, they may cause tissue damage.

INTRODUCTION TO LASERS AND LIGHT

Light is electromagnetic energy in or close to the visible range of the electromagnetic spectrum. Most light is polychromatic, or made up of light of various wavelengths within a wide or narrow range. Laser (an acronym for *l*ight *a*mplification by *s*timulated *e*mission of *r*adiation) light is also electromagnetic energy in or close to the visible range of the electromagnetic spectrum. Laser light differs from other forms of light in that it is **monochromatic** (made up of light that is only a single wavelength), **coherent** (i.e., in phase [Fig. 12-5]), and **directional** (Fig. 12-6).

BRIEF HISTORY OF LASERS AND LIGHT

The earliest records of using light for clinical purposes involved the use of sunlight as described earlier in this chapter. Light therapy gained modern popularity with the advent of the laser and **light-emitting diodes (LEDs)**. The history of the laser begins in 1916 when Albert Einstein introduced the concept of **stimulated emission** and proposed that it should be possible to make a powerful light amplifier. He improved on a fundamental statistical theory of heat that predicted that as light passed through a substance it could stimulate the emission of more light. This effect is at the heart of the modern laser. Einstein moved on to other things, and it was not until 1954 that the first stimulated emission device was made.

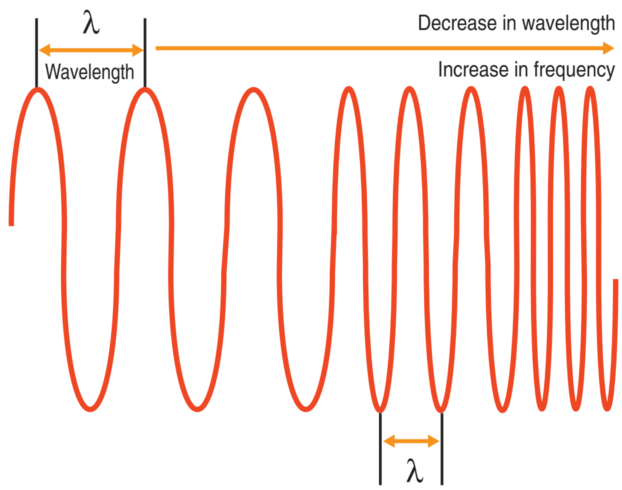

FIG 12-5 The frequency and wavelength of an electromagnetic wave are inversely related. As the frequency increases, the wavelength decreases.

In 1954, Arthur Schawlow and Charles Townes at Columbia University in New York, and Nicolay Basov and Aleksandr Prochorov at the Lebedev Institute in Moscow, all winners of the Nobel prize in physics, simultaneously made the first stimulated emission device, a **maser**. This device used ammonia gas as its medium to produce stimulated emission of radiation in the microwave frequency range.

Shortly thereafter, in 1960, Theodore Maiman made the first laser using ruby as the lasing medium. This laser output red light with a wavelength of 694 nm. Later in the same year, Ali Javan invented the first gas laser, the helium-neon (He-Ne) laser. This also output red light but with a wavelength of 632.8 nm. Laser technology evolved rapidly in the following few years, using different lasing media to produce laser light of different colors and wavelengths and of different **powers**.

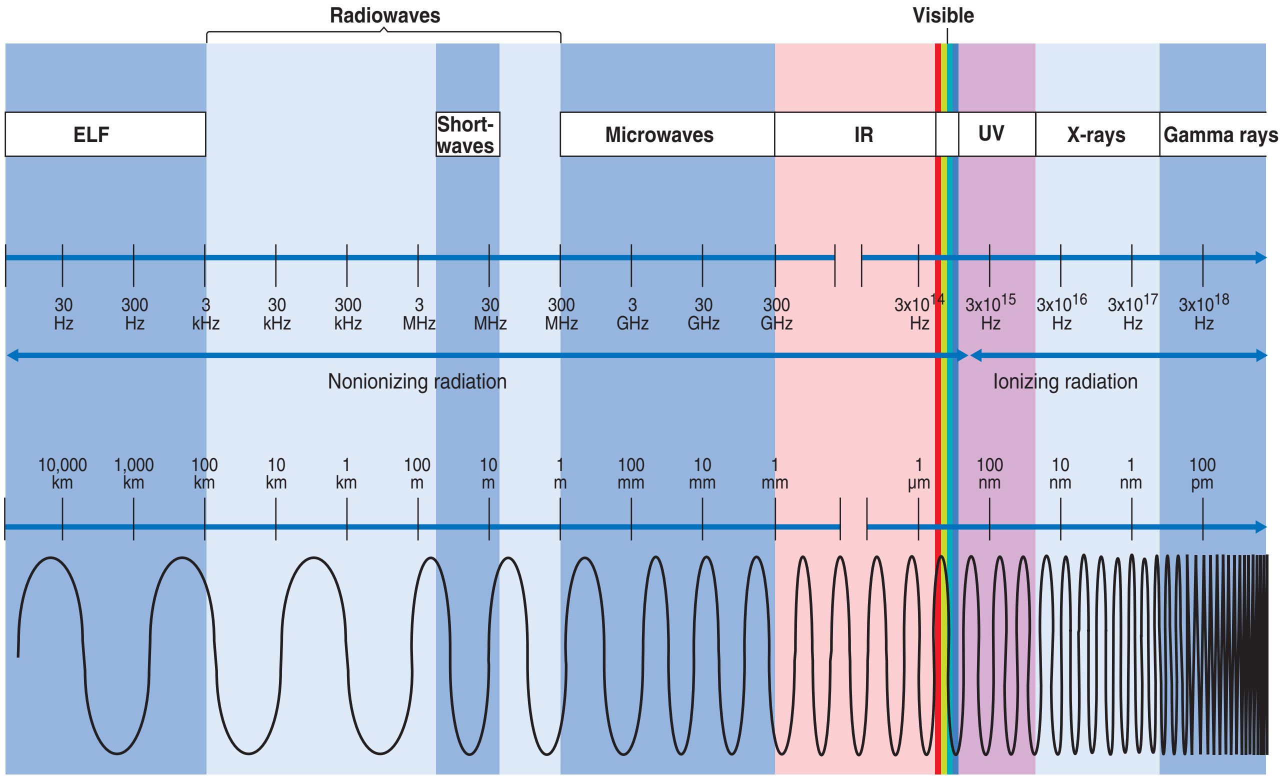

FIG 12-6 The electromagnetic spectrum ranges from low frequencies in the hertz range to over 1023 Hz, with wavelengths varying from over 10,000 km to less than 1 pm.

High-power lasers were quickly adopted for a range of medical applications. Lasers were first used in medicine by ophthalmologists to “weld” detached retinas back in place, and are now used by ophthalmologists for many other applications as well as by surgeons where finely controlled cutting and coagulation is required, and by dermatologists for treating vascular lesions. The high-intensity “hot” lasers used for surgery heat and can destroy tissue. Because the laser has a narrow beam, and because laser light is absorbed selectively by **chromophores,** it generates heat in and destroys only the tissue directly in the beam while avoiding damage to surrounding tissues.[8] **Hot lasers** have a number of advantages over traditional surgical implements: the beam is sterile, it allows fine control, it cauterizes as it cuts, and, it produces less scarring. Because hot lasers destroy tissue, they are not used for rehabilitation.

In the late 1960s and early 1970s, Endre Mester began to explore potential clinical applications of the nonthermal effects of laser light on tissue. He found that low-level irradiation with the He-Ne laser appeared to stimulate tissue healing.[9-12] Based on Mester’s early work, others started to study the effects of low-level laser irradiation, primarily with the He-Ne laser, and the He-Ne laser was promoted throughout Eastern Europe and much of Asia as the treatment of choice for a wide range of conditions.

The He-Ne gas tube lasers enjoyed limited popularity in the West because of their cost, bulk, fragility, and the limited evidence regarding effectiveness. However, in the late 1980s, with the advent of relatively inexpensive semiconductor technology-based photodiodes and mounting research evidence, low-intensity laser therapy and later, other forms of light therapy, including treatment with light from LEDs and then **supraluminous diodes** (SLDs), started to gain popularity in the West and were widely studied.[13]

Because of conflicting and limited research data, until 2002 the FDA limited the clinical use of low-intensity lasers in the US to investigational use only. In June 2002, the use of one laser device was cleared for the treatment of carpal tunnel syndrome. Since then, laser devices have received FDA clearance for the treatment of head and neck pain, knee pain, and postmastectomy lymphedema, and many other light therapy devices that include infrared output have been introduced to the US market and cleared by the FDA as heating devices based on the known effects of IR lamps.

The laser light therapy market in the US is evolving rapidly at this time, with a constantly changing array of devices and features becoming available. In general, these devices include one or more probes (applicators), each of which contains one or more diodes. The diodes may be LEDs, SLDs, or **laser diodes**, each producing light in the visible or IR range of the electromagnetic spectrum. Applicators with more than one diode, generally called **cluster probes**, usually contain various diodes of different types, wavelengths, and power.

PHYSICAL PROPERTIES OF LASERS AND LIGHT

Light is electromagnetic energy in or close to the visible range of the spectrum. Light from all sources except lasers comprises a range of wavelengths. Light that appears white is made up of a combination of light wave frequencies across the entire visible range of the spectrum. Sunlight includes visible light, as well as shorter wavelengths of light in the UV part of the spectrum and longer wavelengths of light in the IR part of the spectrum. Light that appears to the human eye to be one color but that is not from a laser includes light waves with a narrow range of wavelengths, with most of the light energy around a given wavelength. Lasers produce coherent light of a single wavelength only. Light sources used for therapy generally produce light in narrow ranges of the visible or near visible part of the spectrum.

Light Sources

Light can be produced by emission from a gas-filled glass tube or a photodiode, with tubes being the older type of device. Spontaneously emitted mixed wavelength light, such as light from a household light bulb, is generated by applying energy in the form of electricity to molecules of a contained gas. The electricity moves electrons in these molecules to a higher energy level, and as the electrons spontaneously fall back down to their original level, they emit photons of light of various frequencies, depending on how far they fall (Fig. 12-7). The original clinical laser devices used vacuum tube technology similar to a tube fluorescent light bulb to produce monochromatic coherent laser light. With this type of laser, energy in the form of electricity is also applied to molecules of a contained gas. However, in this case, only certain gases can be used and the gas is contained in a tube with mirrored ends. One end of the tube is fully mirrored and the other end is semimirrored. When electricity is applied to the gas, it causes electrons to jump up to a higher energy level. When these electrons fall, they produce photons that are reflected by the mirrored ends of the tube. As the photons travel back and forth from one mirrored end of the tube to the other, each excited atom they encounter releases two identical photons. These two photons can then travel back and forth and encounter two more excited atoms, causing the release of a total of four identical photons. Eventually, many identical photons are traveling back and forth between the mirrored ends of the tube, stimulating the emission of yet more identical photons. When the number of identical photons is sufficient, this strong light, which is coherent and of a single frequency, escapes through the semimirrored end of the tube as monochromatic coherent directional laser light (Fig. 12-8).

Today, therapeutic light sources generally use photodiodes instead of glass tubes (Fig. 12-9). Photodiodes are made up of two layers of semiconductor, one layer with P-type material, with more positive charges, and the other layer with N-type material, with more negative charges. When electrons fall from the N type to the P type, photons

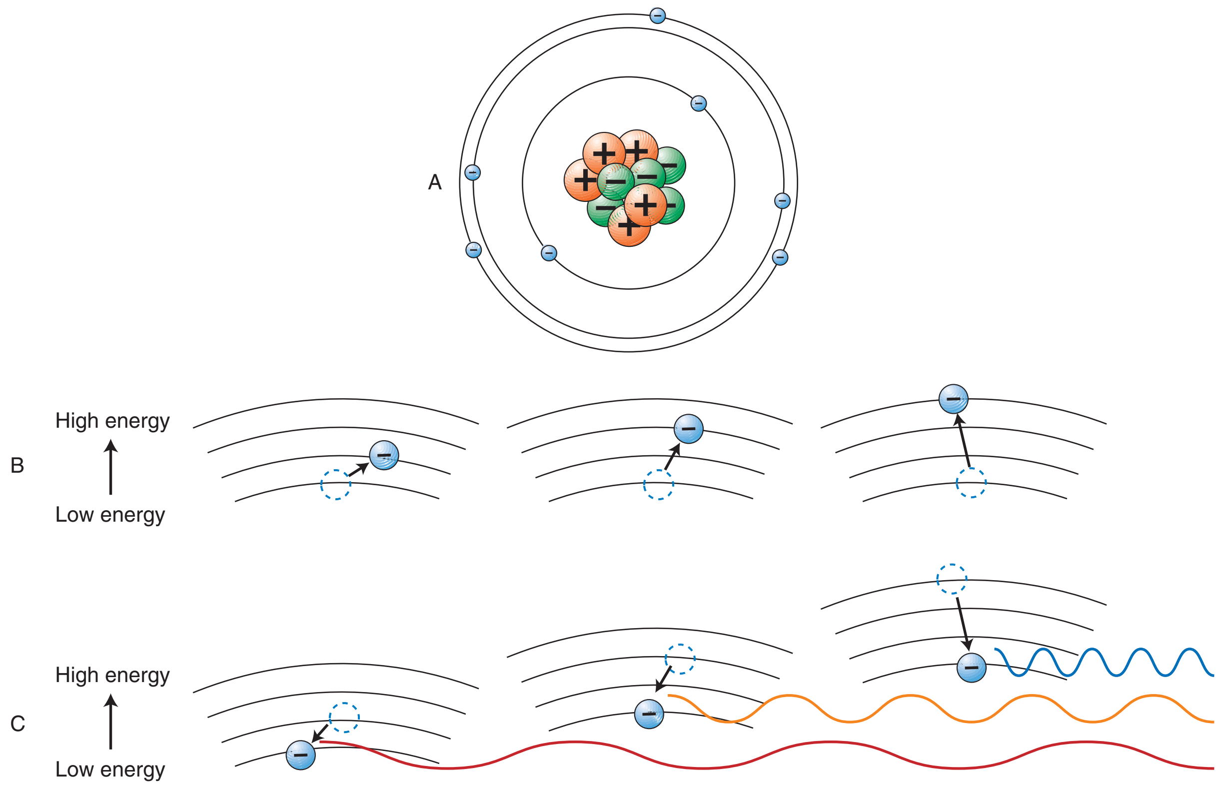

FIG 12-7 Spontaneous emission of light. **A,** Atom with shells of electrons; **B,** electricity applied and electrons move up to different shells; **C,** electrons fall down and photons of various wavelengths are emitted.

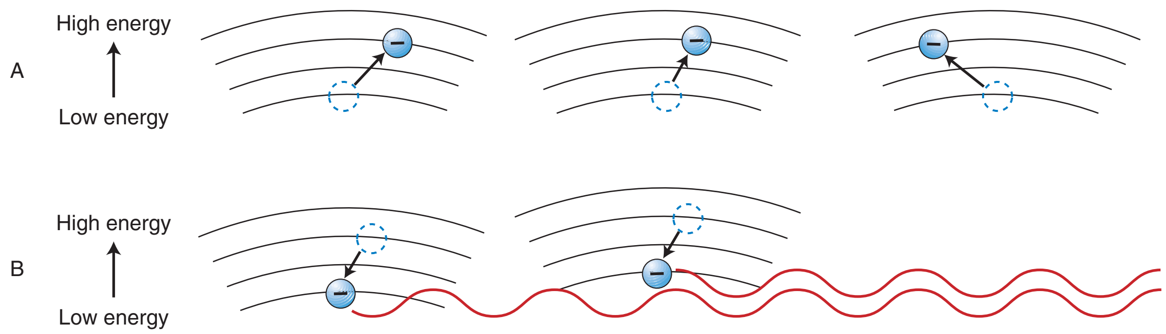

FIG 12-8 Stimulated emission of light. **A,** Electricity applied and electrons all move up to the same level; **B,** electrons fall down and photons all with the same wavelength are emitted.

FIG 12-9 Photodiodes. *Courtesy LaserMate Group, Pomona, CA.*

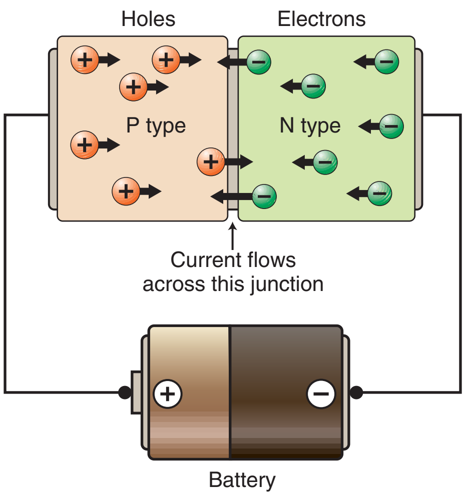

FIG 12-10 Light diode technology.

of various frequencies are emitted (Fig. 12-10). If the diode has mirrored ends, it can also be engineered to produce monochromatic laser light. Photodiodes offer the advantages of being small, hardy, and relatively inexpensive. Photodiodes may be laser diodes, LEDs, or SLDs.

Clinical Pearl

Photodiodes can be laser diodes, LEDs, or SLDs. All of these diodes are small, hardy, and relatively inexpensive.

Laser diodes produce light that is monochromatic, coherent, and directional, providing high-intensity light in one area. LEDs produce low-intensity light that may appear to be one color but that is not coherent or monochromatic. LED light is also not directional and spreads widely. LED therapeutic light applicators are generally arrays that include many (>30) LEDs, with each LED having a low-output power. The low power of LEDs increases the application time required when using these for treatment, but the large number of diodes and their divergence allows the light energy to be delivered to a wide area. SLDs produce high-intensity, almost monochromatic light that is not coherent and that spreads a little but less than the light produced by an LED (Fig. 12-11). Thus SLDs require shorter application times than LEDs and deliver energy to a wider area than do laser diodes. Many applicators include a few laser diodes, SLDs, and LEDs together in a cluster. Clusters usually include 10 to 20 diodes.

Wavelength

The wavelength of light most affects the depth to which the light penetrates and impacts the nature of the cellular effects of light.[4] Light with wavelengths between 600 and 1300 nm, which is red or IR, has the optimal depth of penetration in human tissue and is therefore most commonly used for patient treatment.[14,15] Light with a wavelength at the longer end and a frequency at the lower end of this range penetrates deeper, whereas light with a shorter wavelength and higher frequency penetrates less deeply.[16,17]

Clinical Pearl

Light with a longer wavelength penetrates more deeply than light with a shorter wavelength.

IR light penetrates 2 to 4 cm into soft tissue, whereas red light penetrates only a few millimeters, just through and below the skin. Light may also produce physiological

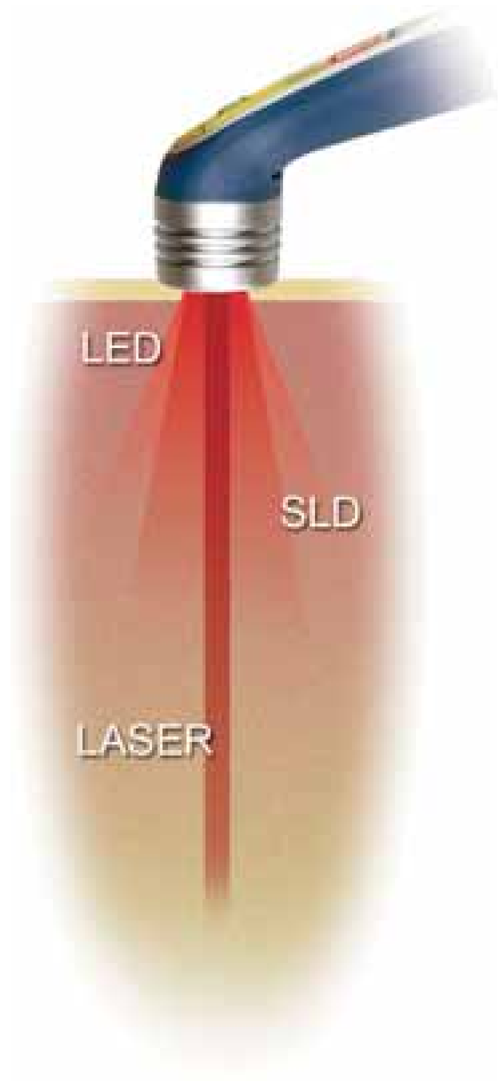

FIG 12-11 Comparison of the spread of laser, SLD, and LED light.
Courtesy Chattanooga Group, Hixson, TN.

effects beyond its depth of penetration because the energy may promote chemical reactions that mediate processes distant from the site of application.

Power and Power Density

Light intensity can be expressed in terms of power, measured in watts or milliwatts, or **power density**, measured in milliwatts per centimeter squared (mW/cm^2). Power is the rate of energy flow, and power density is the amount of power per unit area. Laser and other light therapy applicators generally have a fixed power, although in some cases this can be reduced by pulsing the output.

Because high-intensity lasers have the potential to cause harm, lasers have been divided into four classes, according to their power ranges (Table 12-1). The power of most laser diodes used for therapy is between 5 and 500 mW and are thus classified as class 3B.

TABLE 12-1 Laser Classifications

Class	Power	Effects
1	<0.5 mW	No hazard.
1M		No hazard because the beam has a large diameter or is divergent.
2	<1 mW	Safe for momentary viewing; will provoke a blink reflex.
3A	<5 mW	Commonly used for laser pointers. Poses an eye hazard with prolonged exposure.
3B	<500 mW	Used for therapy. Can cause permanent eye injury with brief exposure. Direct viewing of the beam should be avoided. Viewing of the diffuse beam reflected from the skin is safe. Can cause minor skin burns with prolonged exposure.
4	>500 mW	Surgical and industrial cutting lasers. Can cause permanent eye injury before you can react. Can cause serious skin burns. Can burn clothing. Use with extreme caution.

Clinical Pearl

Most laser diodes used for therapy have a power between 5 and 500 mW.

When a laser or light therapy applicator includes a number of diodes, the power of the applicator is equal to the sum of the power of all its diodes and the power density is equal to the total power divided by the total area.

High power-density light applicators have the advantage of taking less time to deliver a given amount of energy. It is not known if the clinical effects are the same with longer applications of low power light as with delivery of the same amount of energy in a shorter period of time using a high power light source. There is more research on the use of lower power lasers than the newer higher power lasers or SLDs because these were available first. However, some studies have found that the effects of the laser are more pronounced with short-duration, high-power doses than with long-duration, low-power doses delivering the same total amount of energy.[18]

Energy and Energy Density

Energy is the power multiplied by the time of application and is measured in Joules:

$$\text{Energy (J)} = \text{Power (W)} \times \text{Time (s)}$$

Energy density, also known as fluence, is the amount of power per unit area. Energy density is measured in Joules per centimeter squared (J/cm^2). Energy density is the treatment dose measure preferred by most authors and researchers in this field. This measure takes into account the power, the treatment duration and the area of application.

$$\text{Energy density } (\text{J/cm}^2) = \frac{\text{Energy (J)}}{\text{Area of irradiation (cm}^2)}$$

Most laser and light therapy devices allow for selection of energy or energy density. Because energy (Joules) includes time (watts × seconds), when using a laser light therapy device, the clinician generally does not need to select the treatment time (duration).

Clinical Pearl

Energy density is the measure of laser and light treatment dose used most often, and most therapy devices allow for selection of energy or energy density.

EFFECTS OF LASERS AND LIGHT

Low-intensity lasers and other forms of light have been studied and recommended for use in rehabilitation because there is evidence that this form of electromagnetic energy may be biomodulating and facilitate healing.[19,20] The clinical effects of light are thought to be related to the direct effect of light energy, photons, on intracellular chromophores in many different types of cells.[4,21,22] A chromophore is the light-absorbing part of a molecule that gives it color and that can be stimulated by light energy to undergo chemical reactions. To produce an effect, the photons of light must be absorbed by a target cell to promote a cascade of biochemical events that affects tissue function. There is evidence that light has a wide range of effects at cellular and subcellular levels, including stimulating ATP[23] and RNA production, altering the synthesis of cytokines involved in inflammation, and initiating reactions at the cell membrane by affecting calcium channels[24] and intercellular communication.[25,26]

Clinical Pearl

Light can stimulate ATP and RNA production within cells.

PROMOTE ADENOSINE TRIPHOSPHATE PRODUCTION

The primary function of mitochondria, the power house of the cell, is to generate ATP, which can then be used as the energy source for all other cellular reactions. ATP generation is a multistep process that occurs on the inner mitochondrial membrane. Red laser (632.8 nm)[27] and LED (670 nm)[28] light have been shown to improve mitochondrial function and increase their production of ATP by up to 70%. It appears that light promotes this increase in ATP production by increasing cytochrome oxidase production and enhancing electron transfer by cytochrome-C oxidase (Fig. 12-12).[27,29-31] This effect may also be partly mediated by cellular or mitochondrial calcium uptake.[24,32] The

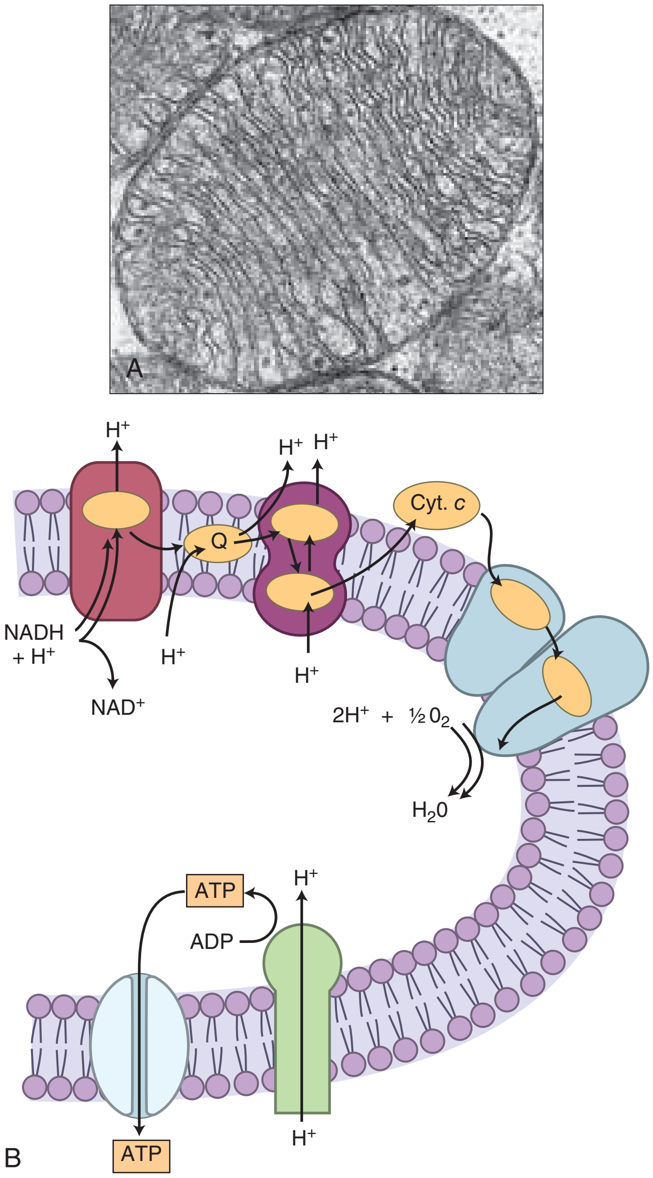

FIG 12-12 Mitochondrion. **A,** Electron micrograph of structure; **B,** electron transport chain and ATP production within a mitochondrion. *From Stevens & Lowe: Human Histology, ed 3. London, Mosby, 2005.*

increased ATP production promoted by laser and other forms of light is thought to be the primary contributor to many of the clinical benefits of laser and light therapy, particularly enhancement of tissue healing.[23] In addition, this effect may explain the reduction in fatigue from electrically stimulated muscle contraction produced by laser irradiation.[33]

PROMOTE COLLAGEN PRODUCTION

Laser and light therapy is also thought to enhance tissue healing by promoting collagen production, likely by stimulating production of mRNA that codes for procollagen. Red laser light has been shown to promote an increase in collagen synthesis[34-36] and mRNA production[37] and to induce a more than threefold increase in procollagen production.[36]

MODULATE INFLAMMATION

Laser irradiation can modulate inflammation and is associated with increased levels of prostaglandin-$F_{2\alpha}$ ($PGF_{2\alpha}$),[38,39] interleukin-1α (IL-1α), and interleukin-8 (IL-8)[40] and decreased levels of PGE_2[38,39] and tumor necrosis factor-alpha (TNF-α).[41] The changes in prostaglandin balance likely result in increased blood flow. The stimulation of IL-1α and IL-8 release has been shown to induce keratinocyte migration and proliferation.[40] There is also evidence that red (He-Ne) laser irradiation activates T and B lymphocytes,[42] enhancing their ability to bind bacteria,[43] and that laser light promotes degranulation of mast cells[44,45] and synthesis and release of chemical mediators of fibroblast proliferation by macrophages.[46,47] Laser and LED light in the red to IR wavelength range can also stimulate proliferation of various cells involved in tissue healing, including fibroblasts,[48-50] keratinocytes,[51] and endothelial cells.[52]

INHIBIT BACTERIAL GROWTH

Laser light can also inhibit bacterial growth. A study published in 1999 reported that red (632.8 or 670 nm) laser light had a dose-dependent bactericidal effect on photosensitized *Staphylococcus aureus* (*S. aureus*) and *Pseudomonas aeruginosa (P. aeruginosa)*.[53] A more recent study examining the effects of different wavelengths of laser light on bacterial growth found that 630 nm laser irradiation at 1 to 20 J/cm^2 was more effective than 660, 810, or 905 nm laser light at inhibiting the growth of *P. aeruginosa*, *S. aureus*, and *Escherichia coli*.[54] In addition, two more recent studies found that shorter wavelength blue (405 nm or 405 nm combined with 470 nm) light also had a dose-dependent bactericidal effect on *S. aureus* and *P. aeruginosa* when doses of 10 to 20 J/cm^2 were used, reducing bacterial colonies by approximately 62% to 95%.[55,56] However, one study found that certain doses and pulse frequencies of IR (810 nm) wavelength laser irradiation can enhance bacterial growth.[57]

Based on the overall results of the research on the effects of laser light on bacterial growth, it appears that light generally inhibits bacterial growth and that wavelengths of 670 to 405 nm (visible red to blue) are the most effective. It appears that only wavelengths that are longer but not shorter than this range have been studied for this effect.

PROMOTE VASODILATION

Some authors also report that laser light can induce vasodilation, particularly of the microcirculation.[20,58] This effect may be mediated by the release of preformed nitric oxide, which has been found to be enhanced by irradiation with red light.[59] Such vasodilation could accelerate tissue healing by increasing the availability of oxygen and other nutrients and by speeding the removal of waste products from the irradiated area.

ALTER NERVE CONDUCTION VELOCITY AND REGENERATION

Some studies have shown increased peripheral nerve conduction velocities, increased frequency of action potentials, decreased distal sensory latencies, accelerated nerve regeneration, and reduced nerve scarring in response to laser stimulation, all of which indicate increased activation of the nervous tissue by laser light.[37,60-67] This effect has appeared to be more pronounced with red laser light than with blue or IR.[37] These positive effects occur in response to laser irradiation over the site of nerve compression and are enhanced by irradiation of the corresponding spinal cord segments.[68,69] In addition, laser irradiation has been found to induce axonal sprouting and outgrowth in cultured nerves[70] and in in vitro brain cortex.[71]

As with other areas of laser and light research, there are conflicting findings in the literature. Some studies have found that laser light irradiation results in decreased nerve conduction velocities and increased distal conduction latencies,[72-74] indicating decreased activation of the nervous tissue, and other studies report no change in nerve conduction in response to laser light irradiation.[75-79] Given the currently available data, further research is necessary to clarify the effects of lasers and light on nerve conduction and to determine the specific parameters required to achieve these effects.

CLINICAL INDICATIONS FOR THE USE OF LASERS AND LIGHT

TISSUE HEALING: SOFT TISSUE AND BONE

A number of studies,[9-12,24,80-91] review articles,[92-95] and meta-analyses[96-99] have been published concerning the use of low-level laser and light therapy to promote the healing of chronic and acute wounds in humans and animals. This area of research was based on Mester's early findings that low-level laser irradiation appeared to accelerate wound healing.[10] Although many studies supported the effectiveness of this intervention,[9-12,24,81-88] a number of studies failed to show improved wound healing with laser light therapy.[80,82,89-91] Therefore various groups of authors have attempted to analyze the overall data through metaanalysis. Initial metaanalyses, published in 1999 and 2000, of the studies on the effects of **low-level laser therapy** (LLLT) on venous leg ulcer healing, reported no evidence of any benefit associated with this specific application of laser therapy, although they reported that one small study suggested that a combination of IR light and red He-Ne laser may have some benefit.[99,96] However, two more recent metaanalyses,[97,98] both published in 2004, including 34 and 24 studies, respectively, reported strong (Cohen's d = +1.81[97] and +2.22[98]) positive effects of laser therapy on tissue repair. Laser therapy was associated with increased collagen synthesis, rate of healing and wound closure, tensile strength, tensile stress, number of degranulated mast cells, and reduced wound healing time.

Based on these extensive and thorough reviews, it appears that laser therapy can promote tissue repair. However, most of the published studies are of poor quality, lack adequate controls, and vary in or poorly report treatment parameters. The limited data available from clinical trials in humans continue to limit the strength with which laser and light therapy is recommended and limits the ability to develop clear guidelines for the clinical application of lasers and light for the treatment of wounds in patients.

Although most of the publications on tissue healing have focused on the effects of laser and light therapy on general soft tissue healing, as occurs with pressure ulcers or surgical incisions, some studies have examined the effects of laser or light therapy on the healing of specific types of tissue such as tendon,[100-102] ligament,[103] or bone.[104-109] The few studies on tendon and ligament healing have consistently shown positive outcomes. However, the studies on fracture healing have produced conflicting results with some showing acceleration of fracture healing or physiologic processes associated with fracture healing,[104-106] whereas others have found no effect or even signs of delayed ossification after laser irradiation.[107,108] The one study comparing the effects of laser therapy with those of low-level ultrasound in promoting fracture healing found both to be equally effective and for the combination of both to be no more effective than either intervention alone.[109] It is thought that low-level laser accelerates bone healing by increasing the rate of hematoma absorption, bone remodeling, blood vessel formation, and calcium deposition, as well as by stimulating macrophage, fibroblast, and chondrocyte activity[89] and increasing osteoblast number and osteoid volume[109] and the amount of intracellular calcium in osteoblastic cells.[110]

Although the ideal treatment parameters for promoting tissue healing are uncertain, the evidence at this time indicates that red or IR light with an energy density between 5 and 24 J/cm^2 is most effective.[98,111] There is some evidence that a dose too high or too low may be ineffective and a dose above 16-20 J/cm^2 may even inhibit wound healing.[112-114] Therefore current recommendations are to use 4-16 J/cm^2 for most wound healing applications, starting at the lower end of this range and progressing up as tolerated. The addition of shorter wavelength light, in the blue to red range, may provide additional benefit in open areas infected or colonized by aerobic bacteria.

ARTHRITIS

A number of studies regarding the application of laser and light therapy for the management of pain and dysfunction associated with arthritis have been published. Some of these studies have found that laser therapy can benefit patients with arthritis, resulting in increased hand grip strength and flexibility and decreased pain and swelling in patients with rheumatoid arthritis, decreased pain and increased grip strength in patients with osteoarthritis (OA) affecting the hands, and decreased pain and improved function in patients with cervical OA.[92,115-119] However, some blinded, controlled studies using lasers for the treatment for osteoarthritis reported that this intervention did not relieve pain in the subjects studied.[120,121]

Metaanalyses and reviews of the studies concerning the effects of laser therapy on pain, strength, stiffness and function in patients with rheumatoid arthritis (RA) and OA concluded that there is sufficient evidence to recommend consideration of LLLT for short-term (up to 4 weeks) relief of pain and morning stiffness in RA, but that for OA the results are conflicting, with only 5 out of 8 included studies finding benefit.[122-125] Different outcomes may be a result of different laser doses, different methods of application, or differences in the pathology of RA and OA. Improvements in arthritic conditions may be the result of reduced inflammation caused by changes in the activity of inflammatory mediators[41,126] or reduced pain caused by changes in nerve conduction or activation. Given the variability in treatment parameters used in different studies, ideal treatment parameters are not clear. In general, shorter wavelengths, application to the nerve as well as the joint, and longer durations of application may be more effective.

LYMPHEDEMA

Two recent studies have examined the effects of LLLT on postmastectomy lymphedema.[127,128] Based on the findings of the first of these studies,[127] the FDA authorized the use of one laser device (the LTU-904, RianCorp, Richmond, South Australia) for use as part of a therapy regimen to treat postmastectomy lymphedema. This device has a 904 nm wavelength (i.e., in the IR range), a peak pulse power of 5 W, and a fixed average power of 5 mW. In this study, laser treatment was applied at 1.5 J/cm^2 (300 mJ per 0.2 cm^2 spot, to 17 spots for a total of 5.1 J) to the area of the axilla 3 times per week for 1 or 2 cycles of 3 weeks each. Although there was no significant improvement immediately after any of the treatments, the mean affected limb volume was significantly reduced 1 and 3 months after completion of 2 (although not 1) treatment cycles. Approximately one third of the 37 actively treated subjects had a clinically significant (>200 ml) reduction in limb volume 2 to 3 months after treatment with the laser.

The latter study[128] was much smaller, with a total of 8 subjects who completed the 22 week intervention. After applying an 890 nm IR laser at 1.5 J/cm^2 to the arm and axilla for 22 weeks, actively treated patients had a greater reduction in limb circumference and generally less pain than placebo-treated patients.

Although these studies provide only limited data, they suggest that IR laser therapy may help to reduce postmastectomy lymphedema. It is interesting to note that the effects of laser treatment were delayed by 1 to 3 months after completion of the treatment sessions, suggesting that laser affects the development of lymphatic drainage pathways rather than directly facilitating lymphatic circulation at the time of application. Based on these studies, it is recommended that laser treatment for lymphedema be at an energy density of around 1.5 J/cm^2 to a total area of 3 cm^2 3 times per week for a total of 3 weeks for 1 to 2 cycles.

NEUROLOGICAL CONDITIONS

Several studies have attempted to determine the impact of laser light irradiation on nerve conduction, regeneration, and function. The first FDA clearance for laser therapy was based on a 1995 study of IR laser (830 nm) therapy for approximately 100 General Motors' employees with carpal tunnel syndrome.[65] This randomized double-blind controlled study compared the effect of physical therapy combined with laser to physical therapy alone for the treatment of carpal tunnel syndrome. Grip and pinch strength, radial deviation range of motion (ROM), median nerve motor conduction velocity across the wrist, and incidence of return to work were all significantly higher in the laser-treated group than in the control group. The treatment protocol was to apply 3 J (90 mW for 33 seconds) during therapy for 5 weeks. A recent review of seven studies of laser or light therapy for the treatment of carpal tunnel syndrome found that two controlled studies and three open-protocol studies found laser to be more effective than placebo, whereas two studies did not find such a benefit. The studies finding benefit applied higher-dose laser (≥9 J) than those not finding benefit (≤6 J/cm^2). Laser light treatment was applied to the area of the carpal tunnel or proximally up to the area of the nerve cell body at the neck.

Laser therapy has also been investigated for the treatment of a number of other neurological conditions. A number of studies have investigated the effect of laser and light therapy on diabetic peripheral neuropathy, and these trials are ongoing.[129,130] Overall, these trials have found that IR light may help reduce the pain associated with this condition. IR[131] and red[132] laser irradiation have also been found to be more effective than placebo at reducing the pain associated with postherpetic neuralgia, and preliminary studies have found improved functional outcome after stroke with application of IR laser therapy to the head within 24 hours of stroke onset.[133] Studies in all of these areas are ongoing.

PAIN MANAGEMENT

Many studies have found that laser and light therapy may reduce the pain and disability associated with a wide variety of neuromusculoskeletal conditions other than arthritis and neuropathy,[134] including lateral epicondylitis,[135-137] chronic low-back and neck pain,[138-140] trigger points,[141,142] and delayed-onset muscle soreness.[143]

Laser light's effects on pain may be mediated by its effects on inflammation,[126] tissue healing, nerve conduction, or endorphin release or metabolism.[144] Analgesic effects are generally most pronounced when laser or light is applied to the skin overlying the involved nerves or nerves innervating the area of the involved dermatome.[136] Although some studies have not found a significant difference in subjective or objective treatment outcomes when comparing treatment with low-level laser to alternative sham treatments,[145-147] a recent metaanalysis of studies on the effects of laser therapy on pain found an overall positive treatment effect (d = +1.11) of laser light therapy on pain in humans.[97]

CONTRAINDICATIONS AND PRECAUTIONS FOR LASERS AND LIGHT

Various authors and manufacturers list different contraindications and precautions for the application of laser and light therapy. The following general recommendations are a summary. However, the clinician should adhere to the recommendations provided with the specific unit(s) being used.

CONTRAINDICATIONS FOR THE USE OF LASERS AND LIGHT

CONTRAINDICATIONS
for the Use of Lasers and Light

- Direct irradiation of the eyes
- Malignancy
- Within 4 to 6 months after radiotherapy
- Over hemorrhaging regions
- Over the thyroid or other endocrine glands

Direct Irradiation of the Eyes

Because lasers can damage the eyes, all patients treated with lasers should wear goggles opaque to the wavelength of the light emitted from the laser being used throughout treatment.[16] The clinician applying the laser should also wear goggles that reduce the intensity of light of the wavelength produced by the specific device to a nonhazardous level. Goggles should be marked with the wavelength range they attenuate and their optical density within that **band**.

Clinical Pearl

Both the clinician and patient should wear goggles during laser treatment, and the goggles should be marked with the range of wavelengths they block.

Clinicians should remember that the higher the optical density, the greater the attenuation of the light. Also, safety goggles suitable for one wavelength should not be assumed to be safe at any other wavelength. Particular care should be taken with IR lasers because the radiation they produce is not visible but it can easily damage the retina. The laser beam should never be directed at the eyes, and one should never look directly along the axis of the laser light beam.

This contraindication does not apply to nonlaser light sources, including SLDs and LEDs. Lasers can damage the eye, particularly the retina, because the light is directional and thus very concentrated in one area. In contrast, other light sources are **divergent** and thus diffuse the light energy so that concentrated light energy would not reach the eye.

Malignancy

Laser and light therapy have been shown to have a range of physiological and cellular effects, including increasing blood flow and cellular energy production. These effects may increase the growth rate or rate of metastasis of malignant tissue.

Because a patient may not know that he or she has cancer or may be uncomfortable discussing this diagnosis directly, the therapist should first check the chart for a diagnosis of cancer.

Ask the Patient

- Are you under the care of a physician for any major medical problem? If so, what is the problem?
- Have you experienced any recent unexplained weight loss or weight gain?
- Do you have constant pain that does not change?
- If the patient has experienced recent unexplained changes in body weight or has constant pain that does not change, laser or light therapy should be deferred until a physician has performed a follow-up evaluation to rule out malignancy. If the patient is known to have cancer, the following questions should be asked.

Ask the Patient

- Do you know if you have a tumor in this area?

Laser or light therapy should not be applied in the area of a known or possible malignancy.

Within 4 to 6 Months After Radiotherapy

It is recommended that lasers and light not be applied to areas that have recently been exposed to radiotherapy because radiotherapy increases tissue susceptibility to malignancy and burns.

Ask the Patient

- Have you recently had radiation applied in this area (the area being considered for treatment application)?

If the patient has recently had radiation therapy applied to the area, laser or light therapy should not be applied in that area.

Over Hemorrhaging Regions

Laser and light therapy are contraindicated in hemorrhaging regions because this intervention may cause vasodilation and thus increase bleeding.

Assess

- Check for signs of bleeding, including blood in a wound or worsening or recent bruising.

Laser or light therapy should not be applied in the area of bleeding.

Over the Thyroid or Other Endocrine Glands

Studies have found that the application of LLLT to the area of the thyroid gland can alter thyroid hormone levels in animals.[148] Therefore irradiation of the area near the thyroid gland (the midanterior neck) should be avoided. LLLT may also result in changes in serum concentrations of luteinizing hormone (LH), follicle-stimulating hormone (FSH), adrenocorticotropic hormone (ACTH), prolactin, testosterone, cortisol, and aldosterone.

PRECAUTIONS FOR THE USE OF LASERS AND LIGHT

PRECAUTIONS

for the Use of Lasers and Light[149,150]

- Low back or abdomen during pregnancy
- Epiphyseal plates in children
- Impaired sensation
- Impaired mentation
- Photophobia, or abnormally high sensitivity to light
- Pretreatment with one or more photosensitizers

Low Back or Abdomen During Pregnancy

Because the effects of LLLT on fetal development and fertility are not known, it is recommended that this type of treatment not be applied to the abdomen or low back during pregnancy.

Ask the Patient

- Are you pregnant?
- Do you think you may be pregnant?
- Are you trying to get pregnant?

If the patient is or may be pregnant, laser light therapy should not be applied to the abdomen or low back.

Epiphyseal Plates in Children

The effect of laser light therapy on epiphyseal plate growth or closure is not known. However, because laser light therapy can affect cell growth, application over the epiphyseal plates before their closure is not recommended.

Impaired Sensation or Mentation

Caution is recommended when treating patients with impaired sensation or mentation because these patients may not be able to report discomfort during the treatment. Although discomfort is rare during the application of laser light therapy, the area of the applicator in contact with the patient's skin can become warm and may burn the skin if applied for prolonged periods or if malfunctioning.

Ask the Patient

- Do you have normal feeling in this area?

Assess

- Check sensation in the application area. Use test tubes containing hot and cold water or metal spoons put in hot and cold water to test thermal sensation.
- Check alertness and orientation.

Laser light therapy should not be applied to any area where thermal sensation is impaired. Laser light therapy should not be applied if the patient is unresponsive or confused.

Photophobia or Pretreatment with Photosensitizers

Certain authors recommend that laser and light therapy should not be applied to any patient who has abnormally high sensitivity to light, either intrinsically or as the result of treatment with a photosensitizing medication. However, because increased skin sensitivity to light is generally limited to the UV range of the electromagnetic spectrum, only UV irradiation must be avoided in such patients. When wavelengths of light outside the UV range are being used in patients with photosensitivity, the clinician should check closely for any adverse effects and stop treatment if they occur.

Ask the Patient

- Are you taking any medication that increases your sensitivity to light or your risk of sunburn?
- Do you sunburn easily?

Assess

- Observe the skin for any signs of burning including erythema or blistering.

Treatment with laser or light therapy should be stopped if the patient show any signs of burning.

ADVERSE EFFECTS OF LASERS AND LIGHT

Although most reports concerning the use of low-level laser or other light devices note no adverse effects in the treatment area from the application of this physical agent,[123,151] there have been reports of transient tingling, mild erythema, skin rash, or a burning sensation, and increased pain or numbness in response to the application of low-level lasers and light therapy.[105,118,152-156]

The primary hazards of laser irradiation are the adverse effects that can occur with irradiation of the eyes. Laser devices are classified on a scale from 1 to 4 according to their power and associated risk of adverse effects to unprotected skin and eyes (see Table 12-1). The low-level lasers used in clinical applications are generally class 3B, which means that although they are harmless to unprotected skin, they do pose a potential hazard to the eyes if viewed along the beam. Exposure of the eyes to laser light of this class can cause retinal damage as a result of the concentrated intensity of the light and the limited attenuation of the beam intensity by the outer structures of the eye. As noted previously, this hazard does not apply to nonlaser light sources (LED and SLD) where the light is divergent and therefore not concentrated in one particular area.

FIG 12-13 LED-array light applicators. **A,** Anodyne; **B,** MedX in Canada. *Courtesy Anodyne Therapy, Tampa, FL.*

The other potential hazard of laser or light therapy is burns. Although the mechanism of therapeutic action of laser and light therapy is not thermal, the diodes used to apply laser or other light therapy will get warm if they are on for a prolonged period. This is more likely to occur with lower-power LEDs that take a long time to deliver a therapeutic dose of energy and where many diodes may be used together in an array (Fig. 12-13). For this reason, particular caution should be taken when applying laser or any other form of light therapy to patients with impaired sensation or mentation and to areas of fragile tissue such as open wounds.

APPLICATION TECHNIQUE FOR LASERS AND LIGHT

APPLICATION TECHNIQUE 12-1 LASERS AND LIGHT

Procedure

1. Evaluate the patient's clinical findings and set the goals of treatment.
2. Determine if laser or light therapy is the most appropriate treatment.
3. Determine that laser or light therapy is not contraindicated for the patient or the condition. Check with the patient and check the patient's chart for contraindications regarding the application of laser or light therapy.
4. Select an applicator with the appropriate diode(s) including type(s) (LED, SLD, or laser diode), wavelength(s), and power. See discussion of parameters in next section.
5. Select the appropriate energy density (fluence) (J/cm^2). Recommendations for different clinical applications are summarized in Table 12-2 and the parameter discussion in the next section.
6. Before treating any area with a risk of cross-infection, swab the face of the applicator with 0.5% alcoholic chlorhexidine or the antimicrobial approved for this use in the facility.

Continued

APPLICATION TECHNIQUE 12-1 LASERS OR LIGHT—*cont'd*

7. If using an applicator that includes laser diodes, the patient and the therapist should wear protective goggles (Fig. 12-14). These goggles should shield the eyes from light of the wavelength of the laser. DO NOT substitute sunglasses for the goggles provided with or intended for your laser device. Sunglasses do not adequately filter IR light. Never look into the beam or the laser aperture. Remember, a laser beam can damage the eyes even if the beam cannot be seen.
8. Expose the area to be treated. Remove overlying clothing, opaque dressings, and any shiny jewelry from the area. Nonopaque dressings, such as thin films, do not need to be removed because it has been shown that most of the laser light can penetrate through these wound dressings.[157]
9. Apply the applicator to the skin with firm pressure, keeping the light beam(s) perpendicular to the skin (see Fig. 12-14). If the treatment area does not have intact skin, is painful to touch, or does not tolerate contact for any other reason, treatment may be applied with the applicator slightly above the tissue, without touching the skin but with the light beam(s) still kept perpendicular to the tissue surface (Fig. 12-15).
10. Start the light output and keep the applicator in place throughout the application of each dose. If the treatment area is larger than the applicator, repeat the dose to areas approximately 1 inch apart throughout the treatment area. The device will automatically stop after delivery of the set dose (J/cm^2).

FIG 12-14 Patient wearing goggles during laser therapy. *Courtesy Chattanooga Group, Hixson, TN.*

FIG 12-15 Noncontact laser light therapy application.

PARAMETERS FOR THE USE OF LASERS AND LIGHT

Note that because laser and light therapy is an active area of research in which new information about the effects of different treatment parameters becomes available almost every day, recommendations for ideal parameters are evolving and change over time. The recommendations given here are based on this author's interpretation of the current literature, which is likely to change as new discoveries are made about the effects of specific parameters of laser and light therapy.

Type of Diode

There is much controversy in the literature and among experts concerning the importance of selecting a specific type of diode for clinical application. Although it is clear that the different diodes produce light of different degrees of wavelength range, coherence, and collimation, it is not clear if these differences have a clinical impact, and there are very few studies directly comparing the effects of coherent (laser) and noncoherent (LED and SLD) light.[154,155] There are more studies on the effects of laser light than on the effects of light emitted by LEDs and SLDs, largely because laser applicators were available many years earlier, but there are studies showing beneficial effects of all three. What remains uncertain and controversial is whether the effects of coherent laser light can be assumed to also occur in response to noncoherent LED and SLD light, and whether one type of light is superior to another.[48,158-160]

LEDs provide the most diffuse light with the widest frequency range and are low power individually. Because they output diffuse light, LEDs are most suitable for treating larger more superficial areas. Applicators that use LEDs as the treatment light source generally contain many LEDs in an array (see Fig. 12-15) or cluster to provide more power for the entire applicator and to treat a larger area. The power of the applicator equals the sum of the power of all of its diodes. Some cluster applicators may include a small number of low-power LEDs in the visible wavelength range to serve as indicators for when the device is emitting, particularly when the other higher-power

FIG 12-16 A cluster light applicator that includes LEDs that emit low-power red light and SLDs that emit higher power infrared light. *Courtesy Dynatronics, Salt Lake City, UT.*

FIG 12-17 A laser diode applicator. This applicator includes one infrared laser diode and three blue LEDs that serve as indicators to show when the applicator is on. *Courtesy Mettler Electronics, Anaheim, CA.*

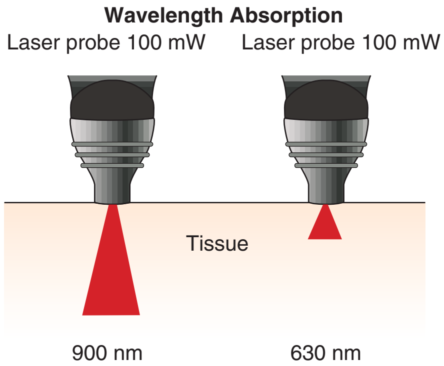

FIG 12-18 Depth of penetration according to wavelength.

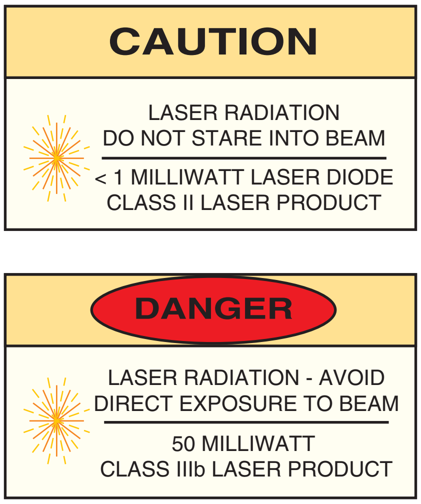

FIG 12-19 Labels denoting laser class.

SLDs or laser diodes emit only in the invisible IR range (Fig. 12-16).

SLDs provide light that is less diffuse and of a narrower wavelength range than LEDs and they are also higher power than LEDs (see Fig. 12-16). SLDs are suitable for treating superficial or moderately deep areas, depending on their wavelength.

Laser diodes provide light of a single wavelength that is very concentrated (Fig. 12-17). Laser diodes are suitable for treating small areas and, for the same wavelength and power, will deliver the most light deepest to a focused area of tissue. Protective goggles should be worn by both the patient and the clinician when using any applicator that includes one or more laser diodes because this concentrated light can damage the eyes.

Wavelength

Laser light applicators output light in the visible or near-visible wavelength range of the electromagnetic spectrum, between 500 and 1,100 nm. Most applicators include near IR (≈700 to 1,100 nm) or red (≈600 to 700 nm) light. IR, with its longer wavelength, penetrates deeper than red light (Fig. 12-18) and is therefore most suitable for treating deeper tissues up to 30 to 40 mm deep. Red light is most suitable for treating more superficial tissues, at a depth of 5 to 10 mm, such as the skin and subcutaneous tissue. Applicators that output blue light have recently also become available. These are most suitable for treating surface tissue such as skin or exposed soft tissue.

Power

Laser light applicator power is measured in milliwatts (1 mW = 1/1000th of a watt). Lasers are classified by international agreement as class 1 to class 4, according to their power and resulting effects (see Table 12-1). All lasers carry a label denoting their class (Fig. 12-19).

Lasers used for therapy are generally power class 3B, with the power of any individual diode being more than 5 mW and less than 500 mW. A number of laser diodes may be combined in a single applicator to provide a total power of more than 500 mW.

The laser classification system does not apply to LEDs and SLDs because these diodes do not produce light that is concentrated in a small area and that can therefore be damaging to the eye. The power of a single LED is generally in the range of 1 to 5 mW but can be as high as 30 to 40 mW. A number of LEDs, often around 20 to 60, but up to 200 or more, are generally placed in a pad or array applicator to provide an applicator with more total power. The power of SLDs is generally in the range of 5 to 35 mW

TABLE 12-2 Energy Density Suggestions Based on Condition

Type of Condition	Suggested Treatment Dose Range (J/cm^2)
Soft tissue healing	5-16
Fracture healing	5-16
Arthritis: acute	2-4
Arthritis: chronic	4-8
Lymphedema	1.5
Neuropathy	10-12
Acute soft tissue inflammation	2-8
Chronic soft tissue inflammation	10-20

each, but may be as high as 90 mW or more each. A number of SLDs, generally about 3 to 10, are usually placed together in a cluster applicator to provide more total power.

As discussed earlier in this chapter, lower-power light applicators require longer application times to deliver the same amount of energy as higher-power light applicators. Thus the applicator power should be selected to optimize the practicality of the treatment time.

Energy Density

In general, low energy densities are thought to be stimulatory, whereas too high an energy density can be suppressive or damaging. Most recommend using lower doses for acute and superficial conditions and higher doses for chronic and deeper conditions and that treatment be initiated at the lower end of the recommended range and increased in subsequent treatments if the prior treatment was well tolerated (Table 12-2).

DOCUMENTATION

When using laser, LED, or SLD light therapy, document the following:

- Type of diode (laser, LED, SLD)
- Wavelength (nm)
- Power (mW)
- Area of body treated
- Energy density (J/cm^2)

Note that duration of treatment is not listed because this is included in the energy density parameter, and the unit will stop automatically when the total dose (energy density) has been delivered.

EXAMPLES

When applying laser to a pressure ulcer over the left greater trochanter in a patient with T10 level paraplegia, in the second week of treatment document the following:

S: Pt reports his wound over the left thigh was stable for the 2 months before initiating laser therapy but is now closing up.
O: Stage IV pressure ulcer over left greater trochanter, 3 cm × 4 cm, 2 cm deep.
Treatment: IR laser 904 nm, 200 mW, to area of wound, 9 J/cm^2 to 4 areas over the wound.
A: Wound size decreased from 4 cm × 5 cm × 2.5 cm deep at initiation of laser therapy.
P: Continue current laser therapy and pressure management.

When applying light therapy to a patient with lateral epicondylitis, document the following:

S: Pt reports 5/10 pain over the right lateral elbow and increased pain with gripping.
O: Tender to deep palpation over extensor carpi radialis brevis tendon.
Treatment: Red SLD, 630 nm, 500 mW cluster, 3 J/cm^2.
Posttreatment: Minimal tenderness, pain decreased to 2/10.
A: Reduced pain and tenderness after light therapy.
P: Continue light therapy. Modify work activities to reduce strain on wrist extensors.

CLINICAL CASE STUDIES

The following case studies summarize the concepts of laser and light therapy discussed in this chapter. Based on the scenarios presented, an evaluation of the clinical findings and goals of treatment are proposed. These are followed by a discussion of the factors to be considered in the selection of laser or light therapy as an indicated intervention and in the selection of the ideal laser or light therapy parameters to promote progress toward the set goals.

CASE STUDY 12-1

Open Wound

Examination

History

JM is a 78-year-old man with an open wound on his right foot. JM states that the wound has been present for 6 months and has not improved with compression bandaging and regular dressing changes. His doctor has diagnosed chronic venous insufficiency and diabetes, and JM has had similar ulcers in the past that have healed slowly. JM relies on his wife to help him with daily dressing changes, and his wife notes that there is yellow-colored drainage on the dressings when they are changed. Although the wound does not cause much pain, JM has been walking less to avoid aggravating the wound. As a result, he has not been as active in many of his usual activities, including gardening and Sunday night bingo.

Tests and Measures

The patient is an alert man with mild bilateral lower extremity edema. He has an ulcerated area approximately 4 × 5 cm on the plantar aspect of his right foot with purulent drainage and no evidence of granulation tissue or bleeding. His left foot and lower extremity are free of

CLINICAL CASE STUDIES—*cont'd*

wounds. Sensation in both feet and around the wound is moderately impaired.

Why might the clinician need to use caution when applying laser or light to this patient? Should the patient continue compression? How will you know if this patient is or is not improving?

Evaluation, Diagnosis, Prognosis, and Goals

Evaluation and Goals

ICF Level	Current Status	Goals
Body structure and function	Chronic right foot ulcer Decreased bilateral lower extremity sensation	Closed right foot ulcer
Activity	Decreased ambulation	Increase ambulation to pre-wound distances
Participation	Decreased participation in hobbies such as gardening and bingo	Return to gardening and bingo

Diagnosis

Preferred Practice Pattern 7D: Impaired integumentary integrity associated with full-thickness skin involvement and scar formation.

Prognosis/Plan of Care

This patient presents with a chronic ulcer of the foot that is likely a result of his diabetes and chronic venous insufficiency. Compression bandages and daily dressing changes over several months have not resulted in wound healing. At this point, it is appropriate to add a new modality. Laser or light, electrical stimulation, and ultrasound might be options for this patient, but laser or light has the advantage of short treatment time and the ability to be applied without touching the wound, thus minimizing cross-infection risk. With this intervention and ongoing management of his impaired venous return, the wound can be expected to close completely over a period of weeks.

Intervention

Laser and light therapy was selected as an adjunctive treatment modality to promote tissue healing. Laser and light therapy have been shown in a number of studies and a recent metaanalysis to accelerate wound healing. This effect is likely in part a result of increased ATP and collagen production.

A cluster probe that included laser diodes and SLDs was selected because this provides both focal and broad coverage with light.

Red light with around 600 nm wavelength was selected because it has shallow penetration, consistent with the depth of tissue involved with this wound. In addition, some studies have found that light in this wavelength range can reduce bacterial viability.

A cluster probe with a total power of 500 mW was selected so that treatment time could be fairly short.

The dose for the first treatment was 4 J/cm^2, which was increased by 2 J/cm^2 at each subsequent treatment up to 16 J/cm^2.

Treatment was provided twice a week for 8 weeks.

Documentation

S: Pt reports a right foot ulcer present for 6 months.

O: **Pretreatment:** 4 × 5 cm ulcer on plantar surface of right foot.

Intervention: Laser SLD cluster, 630-650 nm, 500 mW, 4 J/cm^2, applied to right foot ulcer without contact.

A: Pt tolerated intervention with no signs of discomfort.

P: Continue laser and light treatment 2 × /week, increasing by 2 J/cm^2 at each subsequent treatment up to 16 J/cm^2, until wound has healed. Educate pt to keep his lower extremities elevated and in the proper use of compression bandages or stockings.

CASE STUDY 12-2

Rheumatoid Arthritis

Examination

History

RM is a 42-year-old electrical engineer with RA. She has been referred to therapy for stiffness and pain, particularly in the joints of her hands. In the past when RM received therapy, she was taught ROM exercises that she now performs three times weekly. The patient's work involves using her hands on the computer and when troubleshooting projects involving fine wires. She finds she has become slower at these fine motor tasks and is unable to do some of the finest work. She is worried that this will affect her ability to continue her current job or to maintain other types of employment.

RM's medications include methotrexate and ibuprofen, which provide some relief of hand pain and stiffness.

Tests and Measures

The patient appears to be generally healthy, although she walks somewhat stiffly. She reports hand pain that varies from 4/10 at rest to 7/10 with motion. She reports that her hands are particularly stiff for the first 1 to 1½ hours each morning. ROM appears to be generally decreased in all joints of both hands, and there is mild ulnar drift at the metacarpophalangeal joints. Passive ROM was measured in a number of joints and was as follows:

Joint	Right	Left
Thumb interphalangeal (IP) flexion	80°	80°
Thumb IP extension	–20°	–20°
Index finger proximal IP (PIP) joint flexion	90°	90°
Index finger PIP joint extension	–20°	–25°
Middle finger PIP flexion	100°	90°
Middle finger PIP extension	–20°	–30°

Continued

CLINICAL CASE STUDIES—cont'd

Grip strength is 4/5 bilaterally and is limited by pain and stiffness.

What would be reasonable goals for therapy with laser or light therapy? What other interventions would you consider in addition to laser or light therapy? What are advantages and disadvantages for this patient of laser or light therapy compared with other interventions?

Evaluation, Diagnosis, Prognosis, and Goals

Evaluation and Goals

ICF Level	Current Status	Goals
Body structure and function	Bilateral hand joint pain, stiffness, and decreased ROM	Decrease pain by 50%, shorten duration of morning stiffness to 30 minutes, and increase ROM by ≥5 degrees in measured joints in both hands
Activity	Decreased fine motor skill and speed	Improve fine motor skill and speed Be aware of adaptive tools and other methods to perform certain fine motor skills
Participation	Slowed and limited work performance	Continue working at current job at an acceptable level

Diagnosis

Preferred Practice Pattern 4E: Impaired joint mobility, motor function, muscle performance, and ROM associated with localized inflammation.

Prognosis/Plan of Care

This patient presents with reduced functional abilities and participation as a result of reduced ROM, pain, and stiffness in her fingers from RA. Laser light therapy has been found in individual studies and in a metaanalysis of current studies to reduce pain and morning stiffness in patients with RA. This form of therapy would be a good choice for RM because laser light could be delivered quickly and easily to many of her joints with the appropriate applicator. Given the chronic progressive nature of RA, treatment should be provided in conjunction with body mechanics and adaptive equipment evaluation and intervention to optimize function and participation over the long term.

Intervention

Laser light therapy was selected as an adjunctive treatment modality to modify inflammation.

A cluster probe that included laser diodes and SLDs was selected because this provides both focal and broad coverage with light and could be used to treat a number of involved joints at once. Alternatively, a single diode could be used and applied to individual joints separately or an array of LEDs could be applied to most or all of each hand, although this would likely require a longer application time because these arrays output light with a low energy density.

IR light with around 800-900 nm wavelength was selected because it has deep penetration and may penetrate to the involved joint structures.

A cluster probe with a total power of 200-500 mW was selected so that treatment time could be fairly short.

The dose for the first treatment was 2 J/cm^2. This low dose was used at first as higher doses have been found by some clinicians to exacerbate inflammation. If this dose is well tolerated, the dose may be increased to 4 or possibly 8 J/cm^2.

Treatment was provided twice per week for 4 weeks.

Documentation

S: Pt reports stiffness of her hands that is worst for the first 60-90 minutes each morning and that interferes with fine motor tasks at work.

O: Pretreatment PROM:

Joint	Right	Left
Thumb IP flexion	80°	80°
Thumb IP extension	–20°	–20°
Index finger PIP joint flexion	90°	90°
Index finger PIP joint extension	–20°	–25°
Middle finger PIP flexion	100°	90°
Middle finger PIP extension	–20°	–30°

Intervention: Laser SLD cluster, 800-900 nm, 500 mW, 2 J/cm^2 applied to both hands, 2 different areas to focus on IP joints.

A: Pt tolerated laser with no signs of discomfort.

P: Continue laser treatment 2 × week. Recheck ROM in 1 week and if improved and pt tolerating treatment well, increase dose to 4-8 J/cm^2. Educate patient in joint protection techniques.

CHAPTER REVIEW

1. Electromagnetic radiation is composed of electric and magnetic fields that vary over time and are oriented perpendicular to each other.
2. Different frequencies of electromagnetic radiation have different names, different properties and different applications. Shortwave, microwave, infrared, visible light, and UV radiation all have clinical therapeutic applications.
3. Laser light has the unique features of being monochromatic (one frequency), coherent and directional while light produced by LEDs and SLDs has a range of frequencies, is noncoherent and spreads. Low-intensity laser or noncoherent light may be used as physical agents in rehabilitation.

4. Lasers and light affect cells via their interaction with intracellular chromophores. This interaction leads to a range of cellular effects, including increased ATP and RNA synthesis. These effects can promote tissue healing, reduce pain and improve function in patients with a range of conditions, including arthritis, neuropathy, and lymphedema.
5. Contraindications to the use of lasers include direct irradiation of the eyes, malignancy, within 4 to 6 months after radiotherapy, hemorrhaging regions, and application to the endocrine glands. Precautions include application to the low back or abdomen during pregnancy, epiphyseal plates in children, impaired sensation and mentation, photophobia or abnormally high sensitivity to light, and pretreatment with one or more photosensitizers. Clinicians should always read and follow the contraindications and precautions listed for a particular unit.
6. When selecting a device, the clinician should first consider whether light therapy will be effective for the patient's condition. After deciding on the type of diode (laser, LED, or SLD), the clinician should set the appropriate parameters, including wavelength, power, and energy density.
7. The reader is referred to the Evolve web site for further exercises and links to resources and references.

ADDITIONAL RESOURCES evolve

Web Sites

Laser World (Swedish Laser Medical Society): www.laser.nu

Excellent bibliography of laser papers with abstracts produced by the Société Francophone des Lasers Médicaux: www.sflm.org/s3/dl/applisusr/angio/BiblioBiostimulation.pdf

Books

Baxter DG: *Therapeutic lasers: theory and practice,* London, 1994, Churchill Livingstone.

Tuner J, Hode L: *Laser therapy clinical practice and scientific background,* Grangesburg, Sweden, 2002, Prima Books.

Tuner J, Hode L: *The laser therapy handbook,* Grangesburg, Sweden, 2004, Prima Books.

Manufacturers

Chattanooga Group: www.chattgroup.com
Dynatronics: www.dynatronics.com
Mettler Electronics: www.mettlerelectronics.com
MedX: www.medxonline.com
Thor: www.thorlaser.com
Microlight Corporation: www.microlightcorp.com
Photothera: www.photothera.com

GLOSSARY evolve

Band (frequency band): A range within the electromagnetic spectrum defined by wavelength (e.g., the band for UVA radiation is 320-400 nm).

Chromophores: Light-absorbing parts of a molecule that give it its color.

Cluster probe: Light therapy applicator with multiple diodes that may be any combination of laser diodes, LEDs, or SLDs. The use of multiple diodes allows coverage of a larger treatment area, takes advantage of the properties of the different types of diodes, and may reduce treatment time.

Coherent: Light in which all the waves are in phase with each other; lasers produce coherent light.

Diathermy: The application of shortwave or microwave electromagnetic energy to produce heat within tissues, particularly deep tissues.

Directional (collimated): Light with parallel waves.

Divergent: Light that spreads; the opposite of collimated.

Electromagnetic radiation: Radiation composed of electric and magnetic fields that vary over time and are oriented perpendicular to each other. This type of radiation does not need a medium to propagate.

Energy: The total amount of electromagnetic energy delivered over the entire treatment time. Energy is usually measured in Joules (J). Energy is equal to power multiplied by time.

$$1\ J = 1\ W \times 1\ sec$$

Energy density: The total amount of electromagnetic energy delivered per unit area over the entire treatment time. Energy density isgenerally measured in Joules per centimeter squared (J/cm^2). Most authors agree that this should be the standard dosage measure for laser light therapy.

Frequency: Number of waves per unit time, generally measured in hertz (Hz), which is waves per second.

Hot laser: Heats and destroys tissue directly in beam and is used for surgery. Also called high-intensity laser.

Ionizing radiation: Electromagnetic radiation that can penetrate cells and displace electrons from atoms or molecules to create ions. Ionizing radiation includes x-rays and gamma rays. Ionizing radiation can damage the internal structures of living cells.

Laser: Acronym for light amplification by stimulated emission of radiation. Laser light has the unique properties of being monochromatic, coherent, and directional.

Laser diodes: Light source that uses semiconductor diode technology and optics to produce laser light.

Light-emitting diode (LED): Semiconductor diode light source that produces relatively low-power light in a range of frequencies. LED light may appear to be one color (e.g., red) but will always have a range of wavelengths and not be coherent or directional.

Low-level laser therapy (LLLT): Application of laser light for therapeutic purposes. LLLT is also known as cold laser, low-intensity, low-power, or soft laser. LLLT generally uses laser light diodes that have less than 500 mW power per diode. LLLT cluster probes may contain a number of diodes with a total combined power above 500 mW.

Maser: Acronym for microwave amplification by stimulated emission of radiation.

Monochromatic: Light of single frequency, wavelength, and color. Laser light is monochromatic. Other light sources produce light with a range of wavelengths.

Photobiomodulation: Stimulatory or inhibitory effects on the body caused by light phototherapy; the therapeutic use of light.

Power: Rate of energy production, generally measured in milliwatts (mW) for laser light.

Power density (irradiance): The concentration of power per unit area, measured in watts per centimeter squared (W/cm^2).

Speckling: Variability of light intensity that occurs when a coherent light illuminates a rough object.

Stimulated emission: Occurs when a photon hits an atom that is already excited (i.e., electrons are at a higher energy level than usual). The atom being hit releases a new photon that is identical to the incoming photon—the same color, going in the same direction.

Supraluminous diode (SLD): Light source that uses semiconductor diode technology to produce high-power light in a narrow frequency range.

Ultraviolet (UV) radiation: Electromagnetic radiation with wavelength from < 290 nm to 400 nm, which lies between x-ray and visible light.

Wavelength: The length of a wave of light from peak to peak determines frequency and color. Longer wavelengths are associated with deeper penetration.

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