Chapter 11

Low-Level Laser Therapy

Chapter Outline

Learning Objectives

Remembering: State and describe the fundamental properties of a laser light and the key physical components of a laser device.

Understanding: Distinguish between the process of spontaneous and stimulated emission of photons.

Applying: Demonstrate contact versus noncontact methods as well as gridding, scanning, and stationary application techniques.

Analyzing: Explain how laser energy induces photobiomodulation effects in soft tissues.

Evaluating: Explain the difference between laser and nonlaser light as well as the difference between visible red and infrared laser therapy.

Creating: Formulate the strength of evidence behind the use of low-level laser therapy, and write a recommendation on its overall effectiveness.

I. FOUNDATION

A. DEFINITION

Laser is the acronym for *light amplification by stimulated emission of radiation*. *Light* is defined as the emission of electromagnetic waves, made of photons, traveling in space. A laser light, in comparison with all other forms of light, such as incandescent (light bulb) and luminescent (fluorescent tube), is monochromatic, collimated, and coherent in nature. The use of lights, or photons, for therapeutic purposes, is known as phototherapy. *Low-level laser therapy,* known under the acronym *LLLT,* is the application of low-power light energy, in the visible red and near-infrared band of the electromagnetic spectrum, for the purpose of photoactivating cellular mechanisms leading to enhanced soft-tissue repair and pain modulation.

Historical Overview

In 1917, Albert Einstein proposed the theoretical biophysical concept of stimulated (*S*) emission (*E*) of radiation (*R*), which became the central process underlying the production of a la*SER* light. Einstein is thus considered to be the *biophysical father* of all lasers. In 1960, American physicist Theodore Maiman developed and manufactured the first laser, using a solid ruby crystal as the lasing medium (Calderhead, 1988; Baxter, 1994). A year later, another American physicist, Ali Javan, constructed the first HeNe gas laser. The invention of diodes, or semiconductors, in the 1970s led to the development of lower-cost, more powerful lasers than the first HeNe gaseous lasers. Today, the very large majority of lasers used to deliver low-level laser therapy (LLLT) are diode-type lasers made of gallium arsenide (GaAs), and gallium-aluminum-arsenide (GaAlAs) lasing substrates. A few years after the first laser was invented, Hungarian Endre Mester wanted to test whether laser radiation might cause cancer in animals (Mester et al., 1968). He shaved the dorsal hair of mice, divided them in two groups, and exposed one group to a low-power ruby laser. The results were spectacular. Mester showed not only that ruby laser radiation caused no cancer in the skin of the irradiated mice but also that the hair of the treated group of mice grew more quickly than the hair of the untreated group. This was the first demonstration that laser energy can induce photobiostimulation effects on in vivo mammalian soft tissues (Hamlin et al., 2006). Mester is credited with the first human applications of LLLT conducted in patients with various chronic and recalcitrant wounds and ulcers (Mester et al., 1971, 1985, 1989).

B. LASER CLASSIFICATION

Lasers are classified into four major hazard classes (I, II, IIIa/IIIb, and IV) based on the power outputs and exposure time of the devices (Occupational Safety and Health Administration, 2007). Hazard refers to the potential risk of laser to cause biologic damage to the skin and eyes. Class I, II, and IIIa lasers have single-diode power outputs of less than 5 megawatt (mW) and are not used for therapeutic purposes. Class IIIb lasers have power outputs ranging between 5 and 500 mW and are used for therapeutic purposes. These lasers pose eye hazards, such as damage to the retina, if their beams of energy are focused on the human eye. They pose no hazard to the skin. Finally, class IV lasers, which have single-diode power outputs greater than 500 mW, are not used therapeutically, because they pose eye (damage to retina) and skin (cell destruction) hazards if their beams of energy are focused on these biologic tissues.

C. THERAPEUTIC LASERS

Lasers with power outputs less than or equal to 500 mW are labeled as *low-level laser* (LLL) and are used for *therapy* (T), thus the acronym *LLLT.* Lasers with power outputs greater than 500 mW, on the other hand, are labeled as *high-level laser* (HLL) and are used for *surgery* (S). Table 11-1 shows a comparison between class IIIb and

TABLE 11-1 COMPARISON OF LASER TYPES USED IN HEALTH CARE

	LLLT	HLLS
OSHA classification	IIIb	IV
Single diode power	≤500 mW	>500 mW
Use	Therapy	Surgical therapy
Physiologic effect	Photobiomodulation	Photothermal
Therapeutic effect	Enhance cellular function	Cellular destruction

LLLT, low-level laser therapy; HLLS, high-level laser surgery; OSHA, Occupational Safety and Health Administration.

IV lasers used in health care (see Baxter, 1994; Kamami, 1987; Karu, 1998; Schindl et al., 2000; Tuner et al., 2002). The word *therapy* is used in reference to the improved cell function achieved through laser-induced photobiomodulation effects. Class IV lasers, because of their high power level, are used in surgery; this application is known under the acronym *HLLS*. The term *surgery* is used in reference to the cell destruction due to laser-induced photothermal effects. This chapter focuses on the use of low-level laser devices to treat soft-tissue pathologies in the field of physical rehabilitation.

D. LOW-LEVEL LASER DEVICES AND ACCESSORIES

Figure 11-1 illustrates a typical line-powered cabinet-type diode laser used to deliver LLLT. A complete laser device consists of a console (power supply) attached via a cable to the applicator, which contains the diodes. Figure 11-2 shows two common types of applicators or probes used to deliver LLLT. The key difference between the wand (see Fig. 11-2A) and cluster (see Fig. 11-2B) probe is that the former contains only one laser diode (LD), whereas the latter contains a group, or a cluster, of LDs. An array pad applicator, with its diodes positioned in an array as opposed to a cluster fashion, is also used. Practically speaking, wand probes are used to treat smaller areas, whereas cluster probes and array pads are used to treat medium to large treatment surfaces. The use of class IIIb lasers requires *both* the patient and the operator to wear eye protection goggles during therapy (www.osha.gov). Figure 11-2C also shows a typical pair of laser safety goggles. These goggles filter out the wavelength(s) generated by the LLLT device while allowing maximum visible light transmission to the clinician's eye during therapy. For a pair of goggles to be effective, its filter *must* match the photonic wavelength range generated by the laser device being used.

FIGURE 11-1 Typical cabinet diode-type low-level laser therapy device. (Courtesy of THOR Laser, Inc.)

E. RATIONALE FOR USE

The use of LLLT arose from pioneering studies on animals and humans performed in the 1960s and 1970s by the Hungarian Endre Mester, who is regarded by many in the field as the *therapeutic father* of LLLT (Calderhead, 1988; Baxter, 1994, Tuner et al., 2002). More specifically, Mester et al. (1970, 1971, 1985, 1989) claimed that by using a ruby-type laser of low-level power, a therapeutic response rate of approximately 90% was obtained after treating more than 1,000 patients with various chronic and recalcitrant wounds and ulcers. Global recognition of these findings spurred researchers and clinicians to further explore the photobiologic effects induced by LLLT

FIGURE 11-2 Typical wand **(A)** and cluster **(B)** applicators used to deliver low-level laser therapy. Each applicator may contain a mix of laser diodes, superluminous diodes, and light-emitting diodes. **C:** Typical laser protective goggles worn by both patient and operator during treatment. (A–C: Courtesy of THOR Laser, Inc.)

in humans. There is clear evidence, based on the body of research, that the use of the gaseous helium–neon (HeNe) laser is now obsolete, with the focus now being on the use of diode-type lasers. This chapter, therefore, focuses on the use of diode-type lasers, emitting within red and infrared lights, for treating soft-tissue pathology. In summary, the rationale for inducing photobiomodulation using LLLT is based on its ability to affect cellular function using a nonthermal, nondestructive source of light energy with no known side effects.

II. BIOPHYSICAL CHARACTERISTICS

A. FUNDAMENTAL ELEMENTS

The biophysics of lasers is a very complex subject (Nolan, 1987; Karu, 1989, 1998; Baxter, 1994; Kamami, 1997; Knappe et al., 2004), and addressing its full complexity is beyond the scope of this chapter. Nonetheless, to understand the basis of laser therapy, one must consider the following three fundamental elements: the properties of light, the physical components of a laser, and the process of laser light emission.

1. Properties of Light

Laser light, as shown in Table 11-2, differs from all other lights based on the following three properties of light: monochromacity, coherence, and collimation (Baxter, 1994; Knappe et al., 2004). *Monochromacity* implies that all photons accounting for the laser light have a single wavelength, and thus a single color. The therapeutic advantage of monochromatic light is that its absorption can be targeted at specific, wavelength-dependent photoacceptor molecules, called *chromophores,* buried within soft tissues. *Coherence* refers to the fact that the photons that make up a laser light travel in phase, in both time (temporal) and space (spatial), with each other. In other words, it means that all photons travel in the same direction at the same time. *Collimation* refers to the ability of a beam of laser light not to diverge, or spread, significantly with distance. The advantage of a collimated beam of light is its ability to be focused precisely on a very small target area. Table 11-2 thus indicates that laser light, generated by an LD, is monochromatic, coherent, and collimated in nature. It also shows that all regular lights (incandescent and fluorescent) are polychrome, incoherent, and noncollimated, with the exception of lights generated by light-emitting diodes (LEDs), and superluminous diodes (SLDs), which are monochomatic and collimated but noncoherent. Lights originating from LEDs and SLDs, therefore, are nonlaser lights (see later discussion).

2. Laser Physical Components

The second element to consider is the three basic physical components of a laser device: active medium, resonance chamber, and power source (Knappe et al., 2004). As shown in Table 11-3 and illustrated in Figure 11-3, LLLT is clinically delivered using gaseous- and diode-type lasers. The first component, the *active medium,* also known as the lasing medium, corresponds to the material used to emit a laser light, for which the laser is named. For example, a laser made of a mixture of two inert gases, such as helium (He) and neon (Ne), is labeled as a HeNe laser (see Fig. 11-3A). Diode lasers, as their name implies, are made of diodes—that is, semiconductors (two slabs of material separated by a junction) made of different chemical lasing elements (see Fig. 11-3B). The three main active media, or organic material, used to construct a diode laser for LLLT are gallium (Ga), aluminum (Al), and arsenide (As). These lasers are thus named *GaAs lasers* and *GaAlAs lasers* (see Table 11-3). The second component of a laser, the *resonance chamber,* is the cavity within the laser device that contains the active medium. In this chamber, the active medium is activated or lased, leading to the production of a beam of laser light. The resonance chamber of a HeNe laser is made of a *sealed glass tube,* housing the active medium (see Fig. 11-3A). This tube is mounted with a fully reflective mirror at one end and a semi-reflective mirror at the other. The beam of laser light is emitted through the semi-reflective mirror. The resonance chamber of a diode laser, on the other hand, corresponds to the *p–n junction gap* between two slabs of semiconductor material sandwiched together (see Table 11-3). This p–n junction gap is commonly referred to as a diode (see Fig. 11-3B). The p–n junction is created by placing a p-type semiconductor material (*p* for positively charged, because it has a deficit of free electrons

TABLE 11-2 PROPERTIES OF LIGHT

Light	Monochromacity	Coherence	Collimation
Laser diode	Monochromatic	Coherent	Collimated
Light-emitting diode Superluminous diode	Monochromatic	Noncoherent	Collimated
Regular	Polychromatic	Noncoherent	Noncollimated

TABLE 11-3 PHYSICAL COMPONENTS OF LOW-LEVEL LASER

Component	Gaseous	Diode
Active medium	Helium–Neon (HeNe)	Gallium arsenide (GaAs) Gallium-aluminum-arsenide (GaAlAs)
Resonance chamber	Sealed glass cylinder	Diode p–n junction gap
Power source	Electrical	Electrical

and therefore contains holes that accept free electrons) in contact with an n-type semiconductor material (*n* for negatively charged, because it has a surplus of electrons). The chamber's parallel reflecting mirrors are obtained by cleaving along the natural planes of the semiconductor materials used to make the diode. The third physical component, the *power source*, is electrical in nature and is common to both gaseous- and diode-type lasers. An electrical current, passing through the resonance chamber, powers the laser, thus stimulating (or lasing) its active medium, which results in the emission of a beam of laser light (see arrows in Fig. 11-3).

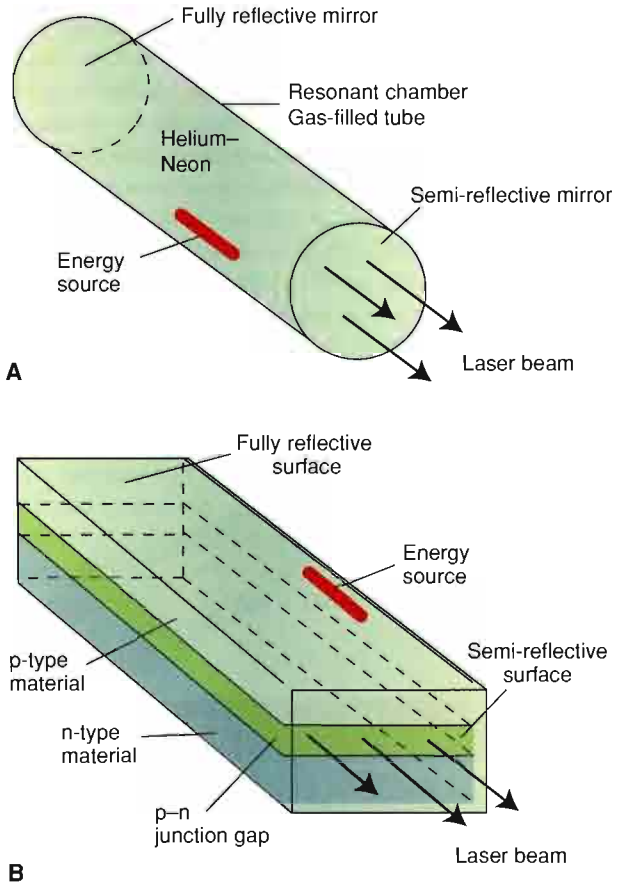

FIGURE 11-3 Schematic physical representation of a helium–neon (**A**) and diode-type (**B**) laser device. The active medium, resonance chamber, and power source are shown for each laser type. The laser beam (shown by *arrows*) for both lasers escapes through the semi-reflective mirror of the resonance chamber.

3. Process of Laser Light Emission

The third and final element that one needs to know in order to understand the nature of laser is the all important *process of light emission*, which results from activation of the active medium, housed in the resonance chamber. The sequential biophysical steps leading to emission of a laser light are described next. These biophysical steps are the same regardless of the laser type. Figure 11-4 illustrates a simple atomic model to help visualize the complex

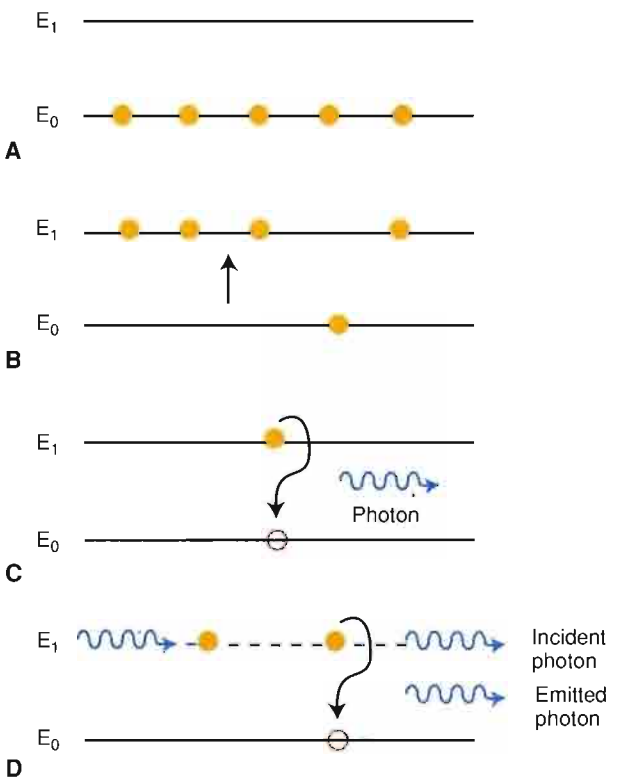

FIGURE 11-4 Schematic sequences of key atomic states and processes leading to emission of a laser beam of light. For simplicity, an active medium population of only five atoms is presented in a system with two energy levels. **A:** Active medium in its resting or ground state. **B:** Pumping of active medium causes the majority of atoms to jump to their metastable energy level, thus causing a population inversion. **C:** Spontaneous emission of a photon traveling parallel to the lateral wall of the resonance chamber. **D:** An incident photon striking an electron in its metastable energy level, thus causing the process of stimulated emission, which corresponds to the release of a newly emitted photon perfectly identical to the incident photon. E_1, metastable energy state; E_0, ground energy state.

fundamental steps needed to create a laser light. This model presupposes the use of an active medium with a population of five atoms, all shown resting (i.e., power Off) at their ground level (see Fig. 11-4A). In reality, any given active medium has a population of millions of molecules and billions of atoms.

a. First Step: Pumping of Active Medium

This step involves the activation, or pumping, of the active medium caused by an electrical current (i.e., power On) passing into the resonance chamber. To pump the active medium is to energize it. It is the process of moving atoms, and therefore their electrons, from their resting ground state (E_0) to their excited state (E_1). This means that in the resonance chamber, there are now a growing number of atoms whose electrons have been excited.

b. Second Step: Population Inversion

This step is achieved when a majority of atoms are in their excited state. Figure 11-4B illustrates this population inversion by showing electrons of four of the five atoms (80%) in their excited state.

c. Third Step: Spontaneous Emission

This step corresponds to the emission of a photon caused by the spontaneous drop of an electron from its excited state to its ground state, as illustrated in Figure 11-4C. As more and more electrons spontaneously drop from their higher energy level, more and more spontaneous photons are emitted in the resonance chamber. All photons not traveling parallel to the wall of the resonance chamber are absorbed by the lining of the wall and cease to exist. These three first steps are common to the production of all light sources.

d. Fourth Step: Stimulated Emission

This fourth step is critical to the creation of a laser light. Remember that the term *laser* stands for *light amplification by stimulated emission of radiation*. This process corresponds to the emission of a photon caused by an incident photon striking an atom's electron into its metastable energy state, which is defined as an excited state that has a long lifetime (i.e., a state that lasts long enough for the incident photon to strike the excited atom before it spontaneously de-excites itself by dropping to its ground state). This striking action, illustrated in Figure 11-4D, causes the electron to drop from its metastable energy level to its resting energy level, releasing a new photon that is identical to the incident photon. Physics has shown that only one spontaneously emitted photon, traveling parallel to the lateral wall of the resonance chamber, is needed to trigger the process of stimulated emission. Both the incident and the newly emitted photons now travel together and in phase with each other in the resonance chamber (see Fig. 11-4D). This process of stimulated emission is self-perpetuating in that these 2 traveling photons will later strike 2 other excited electrons, leading to the emission of 4 photons, and later to 8, 16, 32, 64 photons, and so on.

e. Fifth and Final Step: Amplification

The final step—amplification—is achieved through the back-and-forth movements of incident and newly emitted photons traveling parallel to the lateral wall of the resonance chamber as they are reflected between the parallel reflective and semi-reflective mirrors forming the end walls of the chamber. Physics has shown that the back-and-forth passing of these photons through the active medium dramatically amplifies the process of stimulated emission, triggering a chain reaction as more and more perfectly identical photons fill the resonance chamber (see earlier discussion). The ultimate emission of a beam of laser light through the laser's probe occurs when the amplification process is maximal—that is, when the resonance chamber has reached its maximum capacity to store photons. At this point, and as long as pumping continues (i.e., the laser device is turned On), a percentage of photons escapes the chamber through the semi-reflective mirror to form an almost perfect monochromatic, collimated, and coherent beam of light at the tip of the probe. This beam of laser light is then delivered to soft tissues during LLLT.

B. LOW-LEVEL LASER THERAPY RADIATION SPECTRUM

Photons emitted by LLLT lasers have different wavelengths that are determined by the nature and specific composition of their active medium. Figure 11-5 illustrates the electromagnetic radiation spectrum occupied by LLLT, which spans between the visible red and the infrared band of the electromagnetic spectrum. The *visible band* of the electromagnetic spectrum is between 750 and 400 nm. Visible light is made of six different

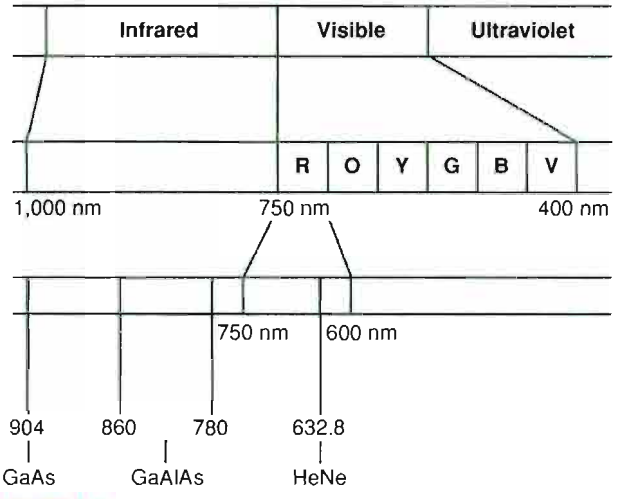

FIGURE 11-5 Low-level laser therapy radiation spectrum. GaAs, gallium arsenide; GaAlAs, gallium-aluminum-arsenide; HeNe, helium–neon. (R, red; O, orange; Y, yellow; G, green; B, blue; V, violet)

lights ranging from violet to red. The *infrared band* is adjacent to the visible band, with wavelengths ranging between 1,000 and 750 nanometers (nm). Infrared light is invisible to the human eye. Low-level laser light is nonionizing in nature because its energy per photon is well below the 10 electron volt (eV) ionizing energy per photon threshold value (see Chapter 10).

C. RED AND INFRARED LASERS

Lasers used to deliver LLLT are commonly referred to as red and infrared lasers. The gaseous HeNe laser emits a light having a specific wavelength of 632.8 nm (10^{-9} m). Its laser light is red and visible to human eyes because it falls within the red band of the visible spectrum (see Fig. 11-5). Within the red band of visible light can be found Mester's original ruby laser, which emitted photons with a wavelength of 694 nm. Diode-type lasers, on the hand, emit lights within the infrared band. Located in Figure 11-5 are the GaAlAs laser, emitting photons within 860 to 780 nm, and the GaAs laser, emitting photons at 904 nm. Infrared light is invisible. Why then do practitioners see a red beam of light at the tip of an infrared laser applicator? What is the purpose of this red light? The red light comes from one or many LEDs embedded in the applicator, which contains one or many LDs. This red visible light has two purposes. First, it serves as a *safety measure* to remind both patient and operator that an invisible therapeutic laser beam is being emitted from the applicator. Second, it serves as a *visual guiding aid* to help in guiding this therapeutic beam of invisible light over the area being treated.

D. DIODE TYPES AND LOW-LEVEL LASER THERAPY LIGHTS

Three types of diodes are found in today's low-level lasers: LDs, SLDs, and LEDs (Fig. 11-6). LDs are the only diodes emitting a *laser light*—that is, a light that is monochromatic, coherent, and collimated. As discussed earlier, SLDs and LEDs emit nonlaser light—that is, a light that is monochromatic and collimated but noncoherent. Depending of the types and proportion of diodes contained in the applicators, modern lasers used to deliver LLLT may deliver laser-only light, or both laser and nonlaser lights to the tissues. Why does the field of laser therapy include nonlaser light? There is evidence to support the view that as soon as the laser light passes through the first millimeters of skin (see Fig. 11-5), its qualities of coherence and collimation are both *lost*. This means that the lights emitted by all three types of diodes should have the same phototherapeutic effects because their lights now share the same property—that of being monochromatic. To make use of nonlaser light in the field of LLLT, one has to postulate that it is the light's wavelength, or monochromacity, that is therapeutically *important*, not its coherence and collimation properties.

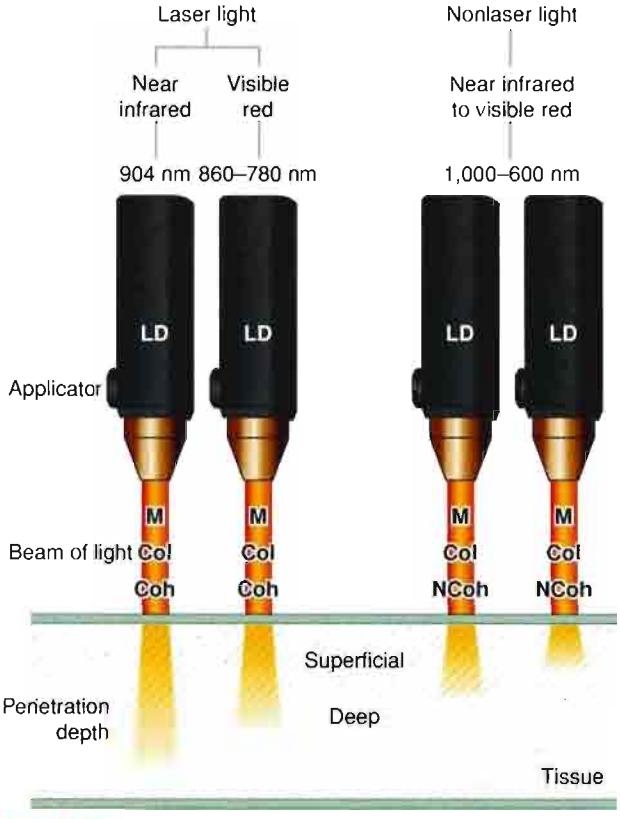

FIGURE 11-6 Laser and nonlaser light properties. LD, laser diode. M, monochromacity; Col, collimation; Coh, coherence.

E. PENETRATION DEPTH

Laser light emitted in the near-infrared band penetrates soft tissue deeper than light emitted in the visible red band (see Fig. 11-6). Why is it so? As shown in Table 11-4, the depth to which a laser beam of light can penetrate soft tissues depends on two factors: absorption and scattering. First, the greater the absorption of photons by superficial tissues, the fewer the number of photons the deeper tissues can absorb. In other words, penetration depth (P) is inversely related to absorption (A), meaning that the greater the absorption superficially, the lesser the penetration depth ($P = 1/A$). Biophysics indicates that visible red laser light is absorbed much more by superficial tissues (skin and blood) than is infrared invisible light (Nussbaum et al., 2003). Second, for any laser light to physiologically and therapeutically affect tissues, it must first be able to penetrate the skin and underlying targeted soft tissue before being absorbed by the wavelength-specific chromophores buried in the layers of this tissue. When a laser beam of light hits soft tissues, a significant portion of its photons is scattered, or deflected, in various directions away from the original direct path to the targeted area. The biophysics of laser indicates that scattering is inversely related to wavelength ($S = 1/\lambda$). It is greatest at short wavelengths and gradually decreases at longer wavelengths (Houza et al., 1993; Nussbaum et al., 2003). This means that photons of red lasers will experience

TABLE 11-4 LOW-LEVEL LASER PENETRATION DEPTH

Parameter	Formula	GaAlAs and GaAs	
Light		Red	Infrared
Wavelength (λ)		600–780 nm	780–904 nm
Absorption (A)		++	+
Scattering (S)	$S = 1/\lambda$	++	+
Penetration (P)	$P = 1/A$	+	++
Penetration (P)	$P = 1/S$	+	++
Penetration depth		~1.0 cm	~5.0 cm

GaAlAs, gallium-aluminum-arsenide; GaAs, gallium arsenide; +, less; ++, more.

more scattering than those of infrared lasers when penetrating soft tissues. Biophysics has also established that penetration depth (P) is inversely related to scattering (S), meaning that penetration depth decreases as scattering increases ($P = 1/S$). As stated earlier, scattering is more pronounced with shorter-wavelength lasers (red) than with longer-wavelength lasers (infrared). Compared to red light lasers, infrared light thus penetrates deeper into soft tissues because it presents less superficial absorption and scattering (see Table 11-4 and Fig. 11-6). Penetration depth value is defined (Low et al., 1990; Baxter, 1994) as the tissue depth, measured in centimeters, at which the laser beam energy is reduced to 37% of its original value (100%). This value is derived from the following formula: *Penetration depth value* = $1/e$, where e is a constant value of 2.718. Penetration depth values for human tissues are approximately less than 1 cm for red light lasers and less than 5 cm for infrared light lasers.

F. APPLICATOR DIODE ARRANGEMENT

The proportion of one type of diode, with each diode having different wavelengths and power, contained in a given applicator, varies from one manufacturer to the next. The wand probe, or single probe, contains one and only one LD. It may also contain one or two SLDs or LDs, if the light emitted by the LD is within the infrared or invisible spectrum. In such a case, the red light emitted by the SLD serves to guide the laser beam and ensure application safety. Cluster probes may contain up to 100 diodes and array pads up to 200 diodes, with both applicators also having different proportions of LDs, SLDs, and LEDs. It is important to keep in mind that the useful life of a laser is predetermined and specified by the manufacturer. This is because the laser's active medium has a finite number of hours, which may vary between 5,000 and 20,000 hours, during which it can be optimally stimulated or lased.

G. LAWS GOVERNING APPLICATION

As is the case with the application of electromagnetic energy using shortwave diathermy therapy (Chapter 10), the application of LLLT is also governed by the same four laws—that is, Arndt-Shultz (dosage), Grotthuss-Draper (absorption), inverse square (divergence), and Lambert's cosine (reflection). These laws are fully described and illustrated in Chapter 10. Note that the inverse square law does not apply to laser light (LD) application because its beam is collimated, thus showing no divergence with distance from the skin.

III. THERAPEUTIC EFFECTS AND INDICATIONS

A. PHOTOBIOMODULATION

The exact physiologic and therapeutic effects of LLLT on human soft tissues are, unfortunately, far from well established or understood. There is a strong consensus in the scientific literature, however, that LLLT induces **photobiomodulation** effects through photochemical interactions between photons and healthy cells within and surrounding the soft-tissue pathology (see Knappe et al., 1994; Reddy, 2004; Hamblin et al., 2006; Lopes-Martin et al., 2007; Bjordal et al., 2010; Chung et al., 2012; Farraresi et al., 2012; Prindeze et al., 2012).

B. PROPOSED THERAPEUTIC EFFECTS

Figure 11-7 illustrates the proposed physiologic and therapeutic effects of LLLT. It shows that the delivery of low-level laser electromagnetic energy within the visible red and near-infrared bands causes chromophore activation, which then triggers *photobiostimulation* effects

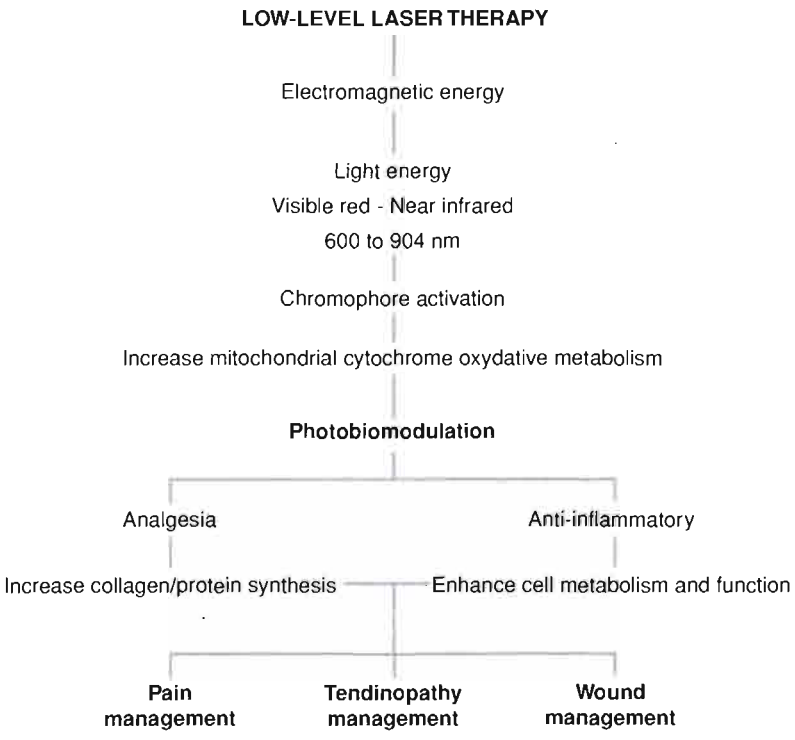

FIGURE 11-7 Proposed physiologic and therapeutic effects of low-level laser therapy.

in soft tissues. A *chromophore,* meaning "color lover" (*chromo* = color; *phore* = lover) is a light-absorbing part of a molecule that gives its color. Melanin (skin darkening), hemoglobin (red blood), and retinal rhodopsin (color vision) are among the best-known chromophores, or pigments, found in human tissues. The photobiologic effects of LLLT at the cellular level are based on the absorption of monochromatic visible (greater than 600 nm) and near-infrared (less than 1 mm) radiation or light by those photoacceptor molecules found in biologic tissues. There is evidence to suggest that LLLT photobiomodulates soft tissues by increasing the oxidative metabolism in mitochondria, which is caused by electronic excitation of components of the respiratory chain (see Smith, 1991 ; Knappe et al., 1994; Chung et al., 2012). The absorption of light energy by those chromophores (i.e., mitochondrial cytochromes) is presumed to trigger the process of photobiomodulation. As shown in Figure 11-7, effects such as analgesia, anti-inflammation, and increased protein and collagen synthesis have been postulated, leading to enhanced cellular metabolism and function promoting soft-tissue healing. The body of research shows that LLLT has been primarily used for the management of wounds, tendinopathies, and pain.

C. RESEARCH-BASED INDICATIONS

The search for evidence behind the use of LLLT, displayed in the *Research-Based Indications* box led to an impressive collection of 157 English peer-reviewed human clinical studies. The methodology, as well as the criteria, used to assess the strength of evidence and therapeutic effectiveness are described in Chapter 2. As indicated, the strength of evidence is ranked as *strong* for all the following conditions: dermal wounds, tendinopathies, myofascial/trigger point pain, rheumatoid arthritis, mixed painful musculoskeletal conditions, osteoarthritis, herpes/postherpetic pain, neck/low back pain, temporomandibular disorders, and carpal tunnel syndrome. Therapeutic effectiveness is *substantiated* for those conditions with the exception of tendinopathies and mixed painful musculoskeletal conditions, where the evidence is found to be *conflicting*. Analysis is *pending* for all other health conditions because fewer than five studies could be collected. Over all conditions, the strength of evidence behind the use of LLLT is found to be *strong* and its therapeutic effectiveness *substantiated*.

IV. DOSIMETRY

A. LASER AND NONLASER LIGHTS

As discussed earlier, there is evidence to show that the monochromacity of both laser (LD) and nonlaser (LED, SLD) lights may be the key property behind the photobiomodulation process attributed to LLLT. This is because both coherence and collimation properties are lost (see Fig. 11-6) as soon as their photons are absorbed by the exposed tissues (Enwemeka, 2006; Jenkins et al., 2011). This explains why today's LLLT lasers may emit laser light only, or a mixture of laser and nonlaser lights, for therapeutic purposes.

Research-Based Indications

LOW-LEVEL LASER THERAPY

	Benefit—Yes		Benefit—No	
Health Condition	**Rating**	**Reference**	**Rating**	**Reference**
Dermal wound	I	Schindl et al., 1998	I	Kopera et al., 2005
	I	Hopkins et al., 2004	I	Malm et al., 1991
	I	Kymplova et al., 2003	I	Santoianni et al., 1984
	I	Schindl et al., 2002	I	Lundeberg et al., 1991
	I	Gupta et al., 1998	I	Kokol et al., 2005
	I	Iusim et al., 1992	I	Lagan et al., 2002
	II	Robinson et al., 1991	II	Lucas et al., 2000
	II	Bihari et al., 1989	II	Freanek et al., 2002
	II	Sugrue et al., 1990	II	Lucas et al., 2003
	II	Crous et al., 1988	II	Nussbaum et al., 1994
	II	Mester et al., 1971	II	Lagan et al., 2001
	II	Mester et al., 1985		
	II	Schindl, et al., 1999b		
	II	Morita et al., 1993		
	III	Gogia et al., 1988		
	III	Ashford et al., 1999		
	III	Khan, 1984		
	III	Lagan et al., 2000		
	III	Herascu et al., 2005		
	III	Ohshiro et al., 1992		
	III	Schindl et al., 2000		
	III	Schindl et al., 1997		
	III	Schindl et al., 1999		
Strength of evidence: Strong **Therapeutic effectiveness:** Substantiated				
Tendinopathy	I	Vasseljen et al., 1992	I	Lundeberg et al., 1987
	I	Lam et al., 2007	I	Krashen-innikoff et al., 1994
	I	Simunovic et al., 1998	I	Haker et al., 1990
	I	Lam et al., 2007	I	Papadopoulos et al., 1996
	I	England et al., 1989	I	Haker et al., 1991a
	I	Saunders, 1995	I	Haker et al., 1991b
	I	Bjordal et al., 2006a	I	Basford et al., 2000
	I	Stergioulas et al., 2008	I	Vecchio et al., 1993
	I	Sharma et al., 2002	I	Darre et al., 1994
	II	Terashima et al., 1990	I	Tumilty et al., 2008
	II	Stergioulas, 2007	I	Siebert et al., 1987
	II	Oken et al., 2008	II	Konstantinovic et al., 1997
	II	Palmieri, 1984	II	Oken et al., 2008
	II	Saunders, 2003	II	Vasseljen et al., 1992
Strength of evidence: Strong **Therapeutic effectiveness:** Conflicting				
Myofascial/trigger point pain	I	Ceccherelli et al., 1989	I	Altan et al., 2005
	I	Ilbuldu et al., 2004	I	Thorsen et al., 1992
	I	Gur et al., 2004	I	Waylonis et al., 1988
	I	Snyder-Mackler et al., 1989	I	Dundar et al., 2007
	I	Olavi et al., 1989	I	Laakso et al., 1997
	I	Simunovic, 1996		
	I	Logdberg-Andersson et al., 1997		
	I	Ceylán et al., 2004		
	II	Hakguder et al., 2003		
Strength of evidence: Strong **Therapeutic effectiveness:** Substantiated				
Rheumatoid arthritits	I	Palmgren et al., 1989	I	Heussler et al., 1993
	I	Goldman et al., 1980	I	Johannsen et al., 1994
	I	Walker, et al., 1987b	I	Hall et al., 1994
	I	Goats et al., 1996	II	Bliddal et al., 1987
	II	Fulga, 1998		
	II	Fulga et al., 1994		
	II	Longo et al., 1997		
	II	Asada et al., 1989		
	II	Obara et al., 1987		
Strength of evidence: Strong **Therapeutic effectiveness:** Substantiated				

Health Condition	Benefit—Yes Rating	Benefit—Yes Reference	Benefit—No Rating	Benefit—No Reference
Mixed painful musculoskeletal conditions	I	Walker, 1983	I	De Bie et al., 1998
	I	Atsumi et al., 1987	I	Mulcahy et al., 1995
	I	Emmanoulidis et al., 1986	I	Basford et al., 1998
	II	Shiroto et al., 1989	I	Bingol et al., 2005
	II	Stergioulas, 2004	I	Rogvi-Hansen et al., 1991
	II	Li, 1990		
	II	Gartner et al., 1987		
	II	Tam, 1999		
Strength of evidence: Strong **Therapeutic effectiveness:** Conflicting				
Osteoarthritis	I	Lonauer, 1986	I	Bülow et al., 1994
	I	Willner et al., 1985	I	Basford et al., 1987
	I	Jensen et al., 1987	I	Brosseau et al., 2005
	I	Walker, 1983		
	I	Stelian et al., 1992		
	I	Gur et al., 2003a		
	I	Ozdemir et al., 2001		
	I	Lewith et al., 1981		
	II	Trelles et al., 1991		
Strength of evidence: Strong **Therapeutic effectiveness:** Substantiated				
Herpes/ Postherpetic pain	I	Schindl et al., 1999a		
	I	Moore et al., 1988		
	I	Ohtsuka et al., 1992		
	II	McKibben et al., 1990		
	II	Kemmotsu et al., 1991		
	II	Yaksish, 1993		
	III	Matsumura et al., 1993		
Strength of evidence: Strong **Therapeutic effectiveness:** Substantiated				
Neck/low back pain	I	Basford et al., 1999	II	Klein et al., 1990
	I	Soriano et al., 1998		
	I	Toya et al., 1994		
	I	Chow et al., 2006		
	II	Djavid et al., 2007		
	II	Gur et al., 2003b		
Strength of evidence: Strong **Therapeutic effectiveness:** Substantiated				
Temporomandibular disorders	I	Mazzetto et al., 2007	I	Conti, 1997
	I	Kulekcioglu et al., 2003		
	I	Cetiner et al., 2006		
	II	Fikackova et al., 2007		
	II	Nunez et al., 2006		
Strength of evidence: Strong **Therapeutic effectiveness:** Substantiated				
Carpal tunnel syndrome	I	Naeser et al., 2002	I	Irvine et al., 2004
	I	Evcik et al., 2007	II	Ekim et al., 2007
	II	Weintraub, 1997		
Strength of evidence: Strong **Therapeutic effectiveness:** Substantiated				
Fewer Than 5 Studies				
Orofacial/ maxillofacial pain	I	Ong et al., 2001	I	Hansen et al., 1990
	II	Pinheiro et al., 1997		
	II	Pinheiro et al., 1998		
Lymphedema	I	Catari et al., 2003		
	I	Kaviani et al., 2006		
	II	Dirican et al., 2011		
Fibromyalgia	I	Gur et al., 2002		
	II	Matsutani et al., 2007		
Trigeminal pain	I	Eckerdal et al., 1996		
	I	Walker et al., 1987a		
Muscle soreness			I	Craig et al., 1996
			I	Craig et al., 1999
Clonus	I	Walker, 1985		
Postsurgical pain	I	Moore et al., 1992		
Neurogenic pain	I	Kreczi et al., 1986		
Fibrotic lumps	III	Nussbaum, 1999		
Raynaud's phenomenon	I	Hirschl et al., 2004		
Strength of evidence: Pending **Therapeutic effectiveness:** Pending				

ALL CONDITIONS
Strength of evidence: Strong
Therapeutic effectiveness: Substantiated

B. DOSIMETRIC PARAMETERS, FORMULAS, AND UNITS

Correct measurement and reporting of dosimetric parameters still remains a major problem in the field of LLLT (Enwemeka, 2011; Jenkins et al., 2011). For example, there is clear evidence that common measurements, such as power density (mW/cm^2) and energy density (J/cm^2), may only be just two of several parameters that should be documented with each case. To improve the situation, recommendations have been made by the World Association for Laser Therapy (WALT) to help LLLT researchers and clinicians better understand and report all necessary parameters for a repeatable study or treatment (Jenkins et al., 2011; waltza.co.za). Table 11-5 lists key recommended dosimetric parameters, with their formulas and units, that practitioners need to consider and document when delivering LLLT to their patients. These parameters are laser type, wavelength, delivery mode, peak power, mean power, beam irradiation area, power density, irradiation duration per point, energy density, treatment surface area, number of irradiation per treatment session, total number of treatments, dose per point, dose per treatment, and cumulative dose. To further guide the practice of LLLT based on evidence, WALT has published dosage recommendations on its website that were last updated in 2010 (waltza.co.za). These dosage recommendations are summarized in Table 11-6. As shown, the recommendations apply the use of diode-type lasers for the management of tendinopathies and arthritic disorders. The table shows that the minimum dose per point, expressed in joules (J), should be a minimum of 4 J for GaAlAs and a minimum of 1 J for GaAs lasers. It also

TABLE 11-5 KEY LOW-LEVEL LASER THERAPY DOSIMETRIC PARAMETERS*

Parameter	Synonym	Formula	Units
Laser type	*Gaseous:* HeNe *Diode:* GaAlAs; GaAs		
Wavelength (λ)			nm
Delivery mode	Continuous Pulsed		
Peak power (P_p)	Radiant power		mW
Mean power (Pm)		$Pm = P_p \times F \times PD$, where • P_p = peak power in watts • F = frequency in Hertz • PD = pulse duration in seconds	mW
Beam irradiation area (A)	Probe spot size		cm^2
Power density (P_d)	Irradiance	$P_d = P_p / A$ $P_d = P_m / A$	mW/cm^2
Irradiation duration per point (T)			sec
Energy density (E_d)	Fluence	$E_d = P_d \times T$	J/cm^2
Treatment surface area (S)			cm^2
Number of irradiated points per treatment	NbIpTr		
Total number of treatments	ToNbTr		
Dose per point (D_p)	Energy delivered per point	$D_p = P_p \times T$ $D_p = P_m \times T$	J
Dose per treatment (D_t)	Total energy delivered during one treatment session	$D_t = D_p \times$ nb of irradiation points	J
Cumulative dose (D_c)	Total energy delivered over the total number of treatments	$D_c = \Sigma D_t$	J

*Adapted from World Association for Laser Therapy (waltza.co.za).

TABLE 11-6 DOSAGE RECOMMENDATIONS FROM THE WORLD ASSOCIATION FOR LASER THERAPY*

	For Tendinopathies and Arthritic Disorders	
	GaAlAs 780–860 nm	GaAs 904 nm
Irradiation duration per point*	20–300 s	30–600 s
Dose per point*	Min 4 J	Min 1 J
Power density per point	Max 100 mW/cm^2	
Treatment frequency	Daily for 2 wk or every other day for 3–4 wk	

GaAlAs, gallium-aluminum-arsenide; GaAs, gallium arsenide.
*Range from ±50% of given values.
From World Association for Laser Therapy (waltza.co.za), revised 2010.

shows that the irradiation duration per point should range between 20 and 600 seconds and that power density per point should be a maximum of 100 mW/cm^2. The dosimetric approach used in the case studies presented in this chapter complies with WALT dosimetric parameters and dosage recommendations.

C. DOSIMETRIC EXAMPLES

Dosage measurement in the field of LLLT, as exemplified earlier, can be complex and often confusing. To help in clarifying and reducing the complexity of the situation, two dosimetric case examples are presented in Table 11-7 and Table 11-8, respectively. In both cases, a diode-type laser is used (GaAlAs). The first example is concerned with the delivery of LLLT in the continuous mode and the second example with the pulsed mode. In each case, parameters related to the application of all three applicators—wand, cluster, and array pad—are shown. To facilitate the understanding of these two examples, let us focus or track the dosimetric parameters and dosage associated with the *cluster probe*.

1. Continuous Mode

The case example presented in Table 11-7 indicates that a cluster probe made of 36 diodes is used for the delivery of continuous LLLT. The cluster probe contains 32 LDs at 880 nm, and 4 LEDs at 660 nm, for a total number of 36 diodes. This GaAlAs laser thus delivers a mix of laser and nonlaser lights to the tissues. The total peak power (P_p) of this cluster probe is 1,400 mW (32 diodes × 40 mW + 4 diodes × 30 mW). The cluster beam's irradiation area (A) has a value of 20 cm^2, and the treatment surface area (S) is measured at 40 cm^2. This means that two irradiations per treatment are necessary in order to cover the full treatment surface area (2 irradiations per treatment = 40 cm^2/20 cm^2). Power density (P_d) is 70 mW/cm^2 (1,400 mW/20 cm^2), of which value is below the 100 mW/cm^2 value recommended by the WALT (see Table 11-5). The application method is stationary with no contact with the exposed skin surface. The practitioner, based on WALT's recommendations (see Table 11-6), wants to deliver a dose per point (D_p) of 7 J. At first sight, it appears that the peak power of this cluster is too high because it can deliver the dose (7 J) in 5 seconds only (7 J = 1,400 mW × 5 s)—much too short an application duration value for effective therapy according to WALT, which recommends that irradiation duration *per point* be between 20 and 300 s (see Table 11-6). Practitioners need to recall that energy, in the present case, is delivered over a much greater surface area (A = 20 cm^2), not over a point, or 1 cm^2, as presented by WALT. If we divide the cluster probe peak power (P_p) by its beam irradiation area (A), we then obtain a power density of 70 mW/cm^2, a value that is below WALT's recommended value of 100 mW/cm^2. Thus, each square centimeter of tissue gets 70 mW, in which case 7 J is achieved at every square, or per point, in 100 seconds (7 J = 70 mW × 100 s). This longer irradiation duration value is now within the WALT guideline (i.e., between 20 and 300 s). As stated earlier, two irradiations per treatment session are needed because the cluster's beam irradiation area (A) is half the treatment surface area (S). This yields a dose per treatment (D_t) equal to 280 J (280 J = 7 J/point × 20 points × 2 applications; 1 point = 1 cm^2). With a total number of eight treatment sessions, the total amount of energy delivered to the tissues, or cumulative dose of light received by the tissues in this case example, is equal to 2,240 J (2,240 J = 280 J × 8).

2. Pulsed Mode

The dosimetric approach for this case example, using pulsed mode, is similar to the one used for continuous mode presented earlier. For the sake of comparison, let us also track the cluster probe values. As shown in Table 11-8, all dosimetric parameters are identical to the previous case with the exception that the laser energy is now pulsed at a frequency (F) of 2,000 Hz, each pulse having 0.0002 s duration (PD). This pulsing yields a mean power (P_m) of 560 mW (560 mW = 1.4 W × 2,000 Hz × 0.0002 s). The

TABLE 11-7 EXAMPLES OF LOW-LEVEL LASER THERAPY DOSIMETRIC MEASUREMENTS FOR CONTINUOUS MODE

	Continuous Mode GaAlAs Laser		
Parameter	**Wand Probe**	**Cluster Probe**	**Array Pad**
Number of diodes	2	36	185
Types of diodes	1 LD 1 LED	32 LD 4 LED	140 LD 30 SLD 15 LED
Wavelength	*LD:* 820 nm *LED:* 600 nm	*LD:* 880 nm *LED:* 660 nm	*LD:* 904 nm *SLD:* 780 nm *LED:* 640 nm
Diode's power	*LD:* 40 mW *LED:* 10 mW	*LD:* 40 mW *LED:* 30 mW	*LD:* 30 mW *SLD:* 50 mW *LED:* 20 mW
Total peak power (P_p)	50 mW	1,400 mW	6,000 mW
Beam irradiation area (A)	0.5 cm^2	20 cm^2	300 cm^2
Treatment surface area (S)	4 cm^2	40 cm^2	260 cm^2
Number of irradiated points per treatment	4	40	300
Power density (P_d)	100 mW/cm^2	70 mW/cm^2	20 mW/cm^2
Energy density (E_d)	6 J/cm^2	7 J/cm^2	8 J/cm^2
Application technique	Stationary with contact	Stationary with no contact	Stationary with contact
Dose per point (D_p)	6 J	7 J	8 J
Irradiation duration (T) per square centimeters or point*	60 s	100 s	400 s
Dose per treatment (D_t)	24 J	280 J	2,400 J
Total number of treatments	6	8	3
Cumulative dose (D_c)	144 J	2,240 J	7,200 J

GaAlAs, gallium-aluminum-arsenide; LD, laser diode; LED, light-emitting diode; SLD, superluminous diode.
***Use the Online Dosage Calculator: Low-Level Laser Therapy.**

mean power density (P_d) value now equals 28 mW/cm^2. This example shows that to deliver the same dose per point (D_p), dose per treatment (D_t), and cumulative dose (D_c) as with the continuous mode, the irradiation duration needs to be longer (from 100 s to 250 s) because of the reduced laser power density resulting from pulsing the beam of energy.

3. Dosage Charting

Current guidelines (waltza.co.za) state that clinical dosage should be expressed, as exemplified earlier, in joules as opposed to joules per square centimeter (J/cm^2), often seen in several electrophysical agent textbooks. WALT suggests that reporting dosage in joules per square centimeter should be confined to studies with small animals and cell cultures, where the treated surface areas are small. When much larger surface areas are treated, as is often the case in humans, the recommendation is to report dosage in joules (Bjordal et al., 2010; waltza.co.za). WALT further recommends documenting, for each clinical case, both the dose per point as well as the cumulative dose of laser energy delivered to the treated soft tissues, as exemplified earlier, also in joules (waltza.co.za). To document LLLT dosage *only* in term of energy density (J/cm^2), or dose per point (J), is incomplete and *can be misleading*. For example, Table 11-9 demonstrates that although energy density or

TABLE 11-8 EXAMPLES OF LOW-LEVEL LASER THERAPY DOSIMETRIC MEASUREMENTS FOR PULSED MODE

	Pulsed Mode GaAlAs Laser		
Parameter	**Wand Probe**	**Cluster Probe**	**Array Probe**
Number of diodes	2	36	185
Types of diodes	1 LD 1 LED	32 LD 4 LED	140 LD 30 SLD 15 LED
Wavelength	*LD:* 820 nm *LED:* 600 nm	*LD:* 880 nm *LED:* 660 nm	*LD:* 904 nm *SLD:* 780 nm *LED:* 640 nm
Diode's power	*LD:* 40 mW *LED:* 10 mW	*LD:* 40 mW *LED:* 30 mW	*LD:* 30 mW *SLD:* 50 mW *LED:* 20 mW
Total peak power (P_p)	50 mW	1,400 mW	6,000 mW
Frequency (F)	3,000 Hz	2,000 Hz	1,000 Hz
Pulse duration (PD)	0.0002s	0.0002 s	0.0005 s
Mean power (P_m)	30 mW	560 mW	3,000 mW
Beam irradiation area (A)	0.5 cm^2	20 cm^2	300 cm^2
Treatment surface area (S)	4 cm^2	40 cm^2	260 cm^2
Number of irradiated points per treatment	4	40	300
Power density (P_d)	60 mW/cm^2	28 mW/cm^2	10 mW/cm^2
Energy density (E_d)	6 J/cm^2	7 J/cm^2	8 J/cm^2
Application technique	Stationary with contact	Stationary with no contact	Stationary with contact
Dose per point (D_p)	6 J	7 J	8 J
Irradiation duration (T) per centimeter or point*	100 s	250 s	800 s
Dose per treatment (D_t)	24 J	280 J	2,400 J
Total number of treatments	6	8	3
Cumulative dose (D_c)	144 J	2,240 J	7,200 J

GaAlAs, gallium-aluminum-arsenide; LD, laser diode; LED, light-emitting diode; SLD, superluminous diode.
***Use the Online Dosage Calculator: Low-Level Laser Therapy.**

dose per point is the same (7 J or 7 J/cm^2) for all four case examples, the dose per treatment and cumulative doses are quite different. This illustrates why it is preferable to document, for each clinical case, all three dosages in joules, because the bottom line is that dosage must represent the amount of light energy (joules) delivered over the entire treated surface area of tissue and not only over 1 cm^2 of it.

D. ONLINE DOSAGE CALCULATOR: LOW-LEVEL LASER THERAPY

As described in Chapter 10 on shortwave diathermy, an **Online Dosage Calculator** is provided with the objective to lessen the burden associated with recalling those formulas and doing similar hand calculations. Upon entering

TABLE 11-9 EXAMPLES OF LOW-LEVEL LASER THERAPY DOSAGE DOCUMENTATION

Applicator	Beam Irradiating Area (A)	Treatment Surface Area (S)	Number of Irradiated Points	Number of Treatment Sessions	Dose per Point or Energy Density	Dose per Treatment	Cumulative Dose
Wand	1 cm^2	1 cm^2	1	10	7 J	7 J	70 J
	1 cm^2	4 cm^2	4	10	7 J	28 J	280 J
Cluster	20 cm^2	40 cm^2	40	10	7 J	280 J	2,800 J
Array pad	300 cm^2	300 cm^2	300	10	7 J	2,100 J	21,000 J

the dosimetric parameters, the calculator will provide the precise irradiation duration required to deliver the desired dose per point, as well as the amount of the dose per treatment and cumulative dose given to each patient during the course of LLLT.

V. APPLICATION, CONTRAINDICATIONS, AND RISKS

Prior to considering the application of LLLT, practitioners must first check for contraindications, consider the risks, and then go through key application steps and procedures designed to optimize treatment safety, efficacy, and effectiveness. Note that the listed contraindications apply to both continuous and pulsed modes. In addition, recall that LLLT can be applied safely over metallic implants and on patients with pacemakers. To facilitate quantitative dosimetry, readers are invited to use the **Online Dosage Calculator: Low-Level Laser Therapy.**

APPLICATION, CONTRAINDICATIONS, AND RISKS

Low-Level Laser Therapy

IMPORTANT: Prior to treatment, test whether the laser device is functioning by applying the applicator over the test photoelectrical cell mounted on the device console. The rationale behind such testing is that infrared lasers generate invisible light, and exposure to the laser beam generates no sensation. *Both patients and practitioners must wear protective glasses or goggles,* which filter the wavelength range emitted by the laser device during therapy. Use a closed room to deliver therapy. Avoid unnecessary exposure to surrounding staff and patients. Shown, as examples, are applications of LLLT using a cluster (Fig. 11-8) and a wand (Fig. 11-9) probe.

See **online video.**

STEP	RATIONALE AND PROCEDURE
1. Check for contraindications.	*Over the eye*—damage to the retina
	Over a malignant lesion—further enhancement and spread of lesion
	Over the abdominal and pelvic area of women who are pregnant—interference with normal development and growth of the fetus
	Over a hemorrhagic area—exacerbating the condition by laser-induced vasodilation (Baxter, 2002)
	Over the thyroid gland—interfering with normal function of the thyroid gland (Navratil et al., 2002)
	In patients with epilepsy—inducing an epileptic seizure (Navratil et al., 2002)
	Note: Metal and plastic implants, as well as pacemakers, are not contraindicated and can be used safely.

STEP	RATIONALE AND PROCEDURE

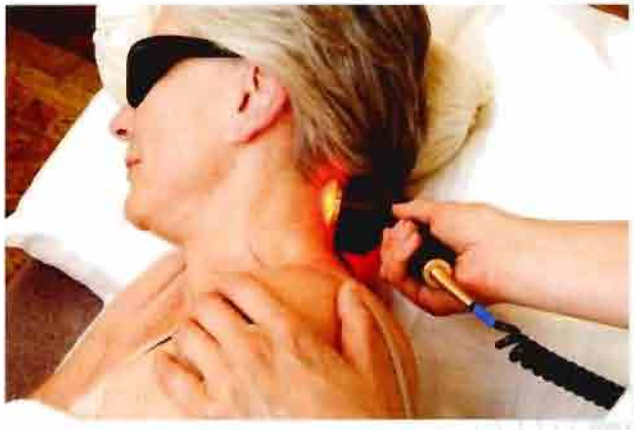

FIGURE 11-8 Application of low-level laser therapy using a cluster probe over the cervical area. (Courtesy of THOR Laser, Inc.)

FIGURE 11-9 Application of low-level laser therapy over the knee area with both patient and operator wearing laser protective goggles. (Courtesy of DJO Global.)

2. Consider the risks.	*Over an infected area*—risk of stimulating or inhibiting bacterial activity *Over bruised muscle*—risk of enhancing brusing (Gabel, 1995) *Over testicular region*—risk of affecting fertility *Over sympathetic ganglia, vagus nerve, and cardiac region in patients with heart disease*—risk of adverse heart effects (Baxter, 2002) *Over photosensitive skin areas*—risk of adverse reaction. A test dose is recommended before application (Baxter, 2002) *Over bone epiphyseal region of growing children*—risk of affecting bone growth
3. Position and instruct patient.	Ensure comfortable body positioning. Inform the patient that he or she may feel nothing during treatment.
4. Prepare treatment area.	*Normal skin:* Cleanse the exposed skin with rubbing alcohol to remove impurities. Shave excessive hair if necessary. *Wounded skin:* Wash and debride the wound. Wear protective gears like goggles, mask, gown, and gloves to prevent contamination.
5. Estimate location, depth, and surface area of lesion.	Locate the pathologic soft-tissue lesion, estimate its depth (in centimeters) from the skin surface, and measure its surface area (in square centimeters). Information about tissue depth will guide the selection of laser (see later discussion). Measurement of lesion's surface area will guide the selection of applicator's size (see later discussion).
6. Select device type.	Choose between a *cabinet* (in clinic therapy) and a *portable* (bedside or home therapy) type of device. Diode-type lasers have replaced the gaseous type because they are much less expensive to manufacture. Consequently, the remaining elements of this protocol relate *only on the application* of diode-type lasers (GaAlAS and GaAs). Plug line-powered devices into ground-fault circuit interrupter (GFCI) receptacles to prevent macroshock (see Chapter 5).

STEP	RATIONALE
7. Select light range.	Choose between red or infrared, or a mix of both lights. Select laser, superluminous, or light-emitting diodes. • *Red light:* Select diodes emitting within the 600–750 nm range. • *Infrared light:* Select diodes emitting within the 750–1 mm range. The deeper the target tissue, the more infrared light should be used because it is more penetrating.
8. Select applicator type and size.	Choose between the wand, cluster, or array pad applicators. Select the wand probe for small, cluster probe for medium, and array pad for larger treatment areas.
9. Select application technique.	Choose between stationary with contact, stationary with noncontact, gridding, and scanning. • *Stationary with contact:* The applicator makes contact with the skin and is kept in place for the entire irradiating duration or treatment. This method eliminates photonic reflection off the skin surface and minimizes beam divergence because of the probe's close proximity to the treated area. • *Stationary with noncontact:* The applicator makes no contact with the skin and is kept in place for the entire irradiating duration or treatment. The applicator-irradiating surface is maintained at a few millimeters (less than 1 cm) for the skin surface. This method is recommended when patients cannot tolerate the pressure exerted by the applicator on the treated surface. • *Gridding:* This technique, also called *point-by-point,* consists in making a grid by mapping the entire treatment surface area with 1-cm^2 squares to guide the point-by-point application. Each square centimeter corresponds to one point, thus the related term *point-by-point technique.* The grid can be made either visually or with a plastic sheet and a pen. Gridding is used with the wand probe, because its tip or irradiating area is often less than 1 cm^2. • *Scanning:* The entire treatment surface area is scanned (noncontact) using wand- and cluster-type probes. This scanning action may be done by manipulating the wand probe (up-and-down and side-to-side movements). It can also be done automatically by means of robotic displacements of the diodes within the cluster probe positioned over the treatment area.
10. Set dosimetry.	Choose between the *continuous* or *pulsed* mode of delivery. Determine the dose (J) of energy that you want to deliver to the tissues per application. Use Table 11-7 (continuous mode) or Table 11-8 (pulsed mode) as dosimetric templates. Use the dosage recommendations from the WALT as a guideline (see Table 11-6). To facilitate dosimetry, use the **Online Dosage Calculator: Low-Level Laser Therapy.**
11. Position the applicator.	Apply the following two laws governing application (see Chapter 10 for details): • *Lambert's cosine law:* Keep the laser beam as perpendicular as possible to the exposed treated surface area to minimize light reflection. • *Inverse square law:* If noncontact is used, keeps the distance separating the applicator and the exposed skin surface as small as possible, and constant from one application to the next.
12. Put on protective laser goggles.	*Both patients and practitioners must wear protective glasses or goggles,* which filter the wavelength range emitted by the laser device during therapy.
13. Apply treatment.	Ensure adequate monitoring.
14. Conduct post-treatment procedures.	Inspect the exposed treatment area, and record any adverse reaction. Clean and disinfect the applicator faceplate (if contact) to prevent cross-contamination between patients. Ensure optimal device function. True power outputs specified by some manufacturers may be much less than advertised, leading to improper dosimetry (Nussbaum, 1999). Power decreases as the device (diodes) ages, thus requiring routine check and calibration measurements (Jenkins et al., 2011). Lock the laser device, and store the key in a safe place for further use.
15. Ensure post-treatment equipment maintenance.	Follow manufacturer recommendations. Immediately report defects or malfunctions to technical maintenance staff. Keep in mind that lasers are very susceptible to de-calibration over time.

CASE STUDIES

Two case studies follow that summarize the concepts, principles, and applications of LLLT discussed in this chapter. Case Study 11-1 addresses its use for chronic cervical osteoarthritis pain affecting a middle-aged male taxi driver. Case Study 11-2 is concerned with the application of LLLT for an Achilles tendinosis affecting a young male college athlete. Each case is structured in line with the concepts of evidence-based practice (EBP), the International Classification of Functioning, Disability, and Health (ICF) disablement model, and SOAP (subjective, *o*bjective, *a*ssessment, *p*lan) note format (see Chapter 2 for details).

CASE STUDY 11-1: CERVICAL OSTEOARTHRITIS

EVIDENCE-BASED CLINICAL DECISION MAKING PROTOCOL

1. Formulate the Case History

A 48-year-old male taxi driver, diagnosed with chronic cervical osteoarthritis, consults about his condition. His main complaint is severe neck pain during head movements, particularly when driving his car for relatively long periods without rest. Physical and radiographic examinations suggest that the pain is caused by bilateral osteoarthritic changes affecting facet joints at the C2–C5 level. Physical examination also reveals a loss of 20 degrees of flexion and 10 degrees of extension. There is also a loss of 35 degrees of right head rotation and 25 degrees of left rotation. The patient is looking for an alternative to his current cocktail of analgesic and anti-inflammatory drugs, which in addition to not giving him adequate pain relief is adding to his gastric problems. He fervently wants to reduce the number of pills he is taking. A few months ago, he tried transcutaneous electrical nerve stimulation (TENS) therapy for a period of 6 weeks but received no satisfactory pain relief. He also tried hot pack therapy, but that did not provide lasting pain relief either. Surgery is not indicated. The patient's goals are to reduce his pain level when driving at work for long hours and improve his head mobility.

2. Outline the Case Based on the ICF Framework

CERVICAL OSTEOARTHRITIS		
BODY STRUCTURES AND FUNCTIONS	**ACTIVITIES**	**PARTICIPATION**
Pain	Difficulty rotating his head	Difficulty in driving a car
Joint stiffness		

PERSONAL FACTORS	**ENVIRONMENTAL FACTORS**
Middle-aged man	Car driving
History of health problems	Stressful job
Low education	

3. Outline Therapeutic Goals and Outcome Measurements

GOAL	**OUTCOME MEASUREMENT**
Decrease pain	Visual Analogue Scale (VAS)
Reduce drug intake	Pill count in personal diary
Increase cervical range of motion (ROM)	Goniometry
Improve head function	Neck Disability Index (NDI)

4. Justify the Use of Low-Level Laser Therapy Based on the EBP Framework

PRACTITIONER'S EXPERIENCE	RESEARCH-BASED INDICATION	PATIENT'S EXPECTATION
Moderately experienced in LLLT	*Strength:* Strong	No opinion on LLLT
Has never used LLLT in similar cases	*Effectiveness:* Substantiated	Just wants pain relief
Believes that LLLT can be beneficial		

5. Outline Key Intervention Parameters

- **Treatment base:** Private clinic
- **Device type:** Cabinet model (GaAlAs). LLLT is selected because there is evidence to show its effectiveness for chronic pain, and because all previous therapies (medication, TENS, and thermotherapy) have failed to provide adequate relief. Infrared light (904 nm) is used because penetration and absorption by deep tissues in needed. Only one irradiation per treatment is needed because the beam irradiating area fully covers the treatment surface area. Dosage documentation and values complies with WALT recommendations.
- **Application protocol:** Follow the suggested application protocol for LLLT in *Application, Contraindications, and Risks* box, and make the necessary adjustments for this case.
- **Patient's positioning:** Lying prone
- **Application site:** Over the painful posterior neck area
- **Application method:** Stationary with noncontact
- **Applicator type:** Handheld cluster with 36 diodes
- **Diode type and wavelength:** 24 LDs: 904 nm;12 LEDs: 660 nm
- **Delivery mode:** Continuous
- **Peak power*:** 1,200 mW
- **Beam irradiation area:** 20 cm^2
- **Treatment surface area:** 18 cm^2
- **Power density*:** 60 mW/cm^2
- **Dose per point*:** 6 J
- **Application duration*:** 100 s
- **Number of irradiation per treatment:** 1
- **Dose per treatment*:** 120 J
- **Treatment frequency:** Daily; 5 days/week
- **Intervention period:** 2 weeks (15 days)
- **Cumulative dose*:** 1,200 J
- **Concomitant therapies:** Neck manipulation combined with a regimen of ankle flexibility and strengthening exercises

***Use the Online Dosage Calculator: Low-Level Laser Therapy.**

6. Report Pre- and Post-Intervention Outcomes

OUTCOME	PRE	POST
Pain (VAS score)	7/10	2/10
Drug intake (number of pills)	40 pills/week	10 pills/week
Cervical ROM	*Loss:* F 20 degrees; E 10 degrees; RR 35 degrees; LR 25 degrees	*Loss:* F 5 degrees; E 5 degrees; RR 15 degrees; LR 5 degrees
Improve neck function (NDI score)	32/50	12/50

7. Document Case Intervention Using the SOAP Note Format

S: Middle-aged male taxi driver presents with chronic cervical osteoarthritic pain causing difficulty with head mobility, particularly while at work. Previous drug, TENS, and thermotherapy treatments provided mild pain relief and inadequate functional results.

O: *Intervention:* LLLT (GaAlAs; 904 and 660 nm) applied over the posterior neck area; Pt lying prone; method and applicator: stationary with noncontact—cluster probe; dosage: D_p: 6 J; D_t: 120 J; D_c: 1,200 J; treatment schedule: daily, 5 days/week, for 15 days. *Pre–post comparison:* Decrease pain VAS score (7/10 to 2/10), decrease drug intake by 75%, improved cervical range of motion and improved neck function (NDI score 32/50 to 12/50).

A: No adverse effect. Treatment very well tolerated. Pt satisfied with results.

P: No further treatment required. Patient discharged.

CASE STUDY 11-2: ACHILLES TENDINOSIS

EVIDENCE-BASED CLINICAL DECISION MAKING PROTOCOL

1. Formulate the Case History

A 20-year-old college basketball player consults for painful activity- and sports-related symptoms from the right Achilles region. Pain, lasting for 2 months now, is located in the Achilles tendon. There is crepitation and tenderness during palpation. Ankle dorsiflexion is limited to 5 degrees. He has difficulty with jumping and running. He takes over-the-counter analgesic and anti-inflammatory drugs occasionally. Pain and functional limitation persists despite previous treatments, which included cryotherapy and thermotherapy. The playoff season is fast approaching, and he is desperate to get better.

2. Outline the Case Based on the ICF Framework

CERVICAL OSTEOARTHRITIS		
BODY STRUCTURES AND FUNCTIONS	**ACTIVITIES**	**PARTICIPATION**
Pain	Difficulty jumping and running	Difficulty playing competitive basketball
Joint stiffness		

PERSONAL FACTORS	ENVIRONMENTAL FACTORS
Young healthy man	College student
Athletic	Sports scholarship
Competitive	

3. Outline Therapeutic Goals and Outcome Measurements

GOAL	OUTCOME MEASUREMENT
Decrease pain	Visual Analogue Scale (VAS)
Increase ankle dorsiflexion ROM	Goniometry
Improve ankle function	Lower Extremity Functional Scale (LEFS)

4. Justify the Use of Low-Level Laser Therapy Based on the EBP Framework

PRACTITIONER'S EXPERIENCE	RESEARCH-BASED INDICATION	PATIENT'S EXPECTATION
Moderately experienced in LLLT	*Strength:* Strong	Read on the Internet about LLLT
Occasionally has used LLLT in similar cases	*Effectiveness:* Conflicting	Wants full recovery before playoffs
Is curious to see if LLLT can be beneficial		Believes that LLLT may be effective

5. Outline Key Intervention Parameters

- **Treatment base:** Private clinic
- **Device type:** Cabinet model (GaAs). LLLT is selected because there is evidence to show its effectiveness for tendinopathies, and because previous therapies (medication, cryotherapy, and thermotherapy) have failed to provide adequate therapeutic effects. Infrared light is used because penetration and absorption by deep tissues in needed. Four irradiations per treatment are needed to cover or treat the entire treatment surface area. Dosage parameters comply with WALT recommendations.
- **Application protocol:** Follow the suggested application protocol for LLLT in *Application, Contraindications, and Risks* box, and make the necessary adjustments for this case.
- **Patient's positioning:** Lying prone
- **Application site:** Over the painful Achilles tendon area
- **Application method:** Stationary with contact; visual gridding
- **Applicator type:** Handheld wand with 3 diodes
- **Diode type and wavelength:** 1 LD of 820 nm; 2 LDs of 720 nm
- **Delivery mode:** Pulsed
- **Mean power*:** 80 mW
- **Beam irradiation area:** 1 cm^2
- **Treatment surface area:** 4 cm^2
- **Power density*:** 80 mW/cm^2
- **Dose per point*:** 4 J
- **Application duration*:** 50 s
- **Number of irradiations per treatment:** 4
- **Dose per treatment*:** 16 J
- **Treatment frequency:** daily; 5 days/week
- **Intervention period:** 2 weeks
- **Cumulative dose*:** 160 J
- **Concomitant therapies:** A regimen of eccentric exercises combined with static stretching of the triceps surae

***Use the Online Dosage Calculator: Low-Level Laser Therapy.**

6. Report Pre- and Post-Intervention Outcomes

OUTCOME	PRE	POST
Pain (VAS score)	6/10	1/10
Ankle ROM	*Loss:* dorsiflexion 5 degrees	*Loss:* dorsiflexion 0 degrees
Lower limb function (LEFS score)	48/80	64/80

7. Document Case Intervention Using the SOAP Note Format

S: Young athletic Pt presents with right Achilles tendinopathy causing difficulty with regular activities, particularly while playing competitive basketball. Previous drug, cryotherapy, and thermotherapy provided temporary pain relief but limited functional benefit.

O: *Intervention:* LLLT (GaAs; 820 and 720 nm) applied over the Achilles tendon area; Pt lying prone; applicator and application: wand probe, stationary with contact; dosage: D_p: 4 J; D_t: 16 J; D_c: 160 J; treatment schedule: daily, 5 days/week, for 10 days. *Pre–post comparison:* Decrease pain VAS score (6/10 to 1/10), full ankle dorsiflexion, and improved lower limb function (LEFS scores from 4880 to 64/80).

A: No adverse effect. Treatment very well tolerated.

P: No further treatment required. Patient discharged. Asked to better warm up the lower limbs before competitive basketball.

VI. THE BOTTOM LINE

- There is strong scientific evidence to show that LLLT can induce significant photobiologic effects on human superficial and deep soft tissues.
- LLLT is the delivery of electromagnetic energy, within the red visible and near-infrared band of the electromagnetic spectrum, for therapeutic purposes.
- All laser (LD) and nonlaser (LED, SLD) lights are capable of generating therapeutic photobiologic effects on soft tissues.
- LLLT energy is absorbed by chromophores triggering photobiomodulation effects.
- Monochromacity appears to be the key property behind the photobiologic effects of LLLT, because both coherence and collimation are lost as soon as the beam of light enters the skin.
- Near-infrared light is more penetrating than red visible light.
- Optimal energy delivery is achieved when the four laws governing application are applied.

- Using the **Online Dosage Calculator: Low-Level Laser Therapy** removes the burden of hand calculation and promotes the adoption of quantitative dosimetry.
- The dosage recommendations from the WALT provide adequate guidelines for dosimetry.
- Dose per point (D_p), dose per treatment (D_t), and cumulative dose (D_c) should be measured, recorded, and expressed in joules.
- Metal and plastic implants, as well as pacemakers, are not contraindicated in LLLT and can be exposed to light energy safely.
- Until the photobiologic effects associated with pulsed LLLT are better defined, using continuous LLLT remains the gold standard.
- The overall body of evidence reported in this chapter shows the strength of evidence behind LLLT to be *strong* and its level of therapeutic effectiveness *substantiated.*

VII. CRITICAL THINKING QUESTIONS

Clarification: What is meant by low-level laser therapy (LLLT)?

Assumptions: You assume that the therapeutic optical window of LLLT is within the visible red and invisible infrared band of the electromagnetic spectrum. How do you justify making that assumption?

Reasons and evidence: What leads you to believe that monochromacity may be the key property behind the therapeutic effects of LLLT?

Viewpoints or perspectives: How will you respond to a colleague who says that the use of LLLT is well justified today for the treatment of cutaneous wounds and tendinopathies?

Implications and consequences: What are the implications and consequences of (1) using a wand instead of a cluster, or an array pad, applicator, (2) if neither the operator nor the patient wears protective goggles when delivering or receiving LLLT, and (3) if the lasers are not regularly calibrated?

About the question: What is the estimated penetration depth of red and infrared lasers used to deliver LLLT to soft tissues? Why do you think I ask this question?

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