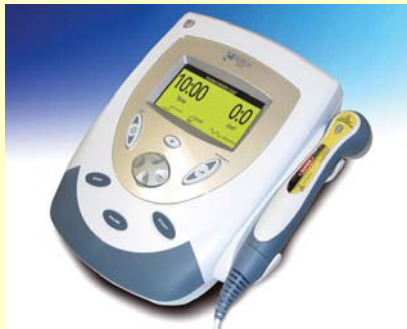


Lesson 1: Production of Laser Energy

Introduction

The acronym "LASER" stands for Light (photons) Amplification by Stimulated Emission of Radiation. Low level laser therapy (LLLT) is the best and most widely accepted descriptor of the type of lasers used in rehabilitation. The instrument itself is considered a "therapeutic laser". LLLT has historically been classified as a non-thermal modality.¹ Non-thermal modalities are those physical agents that do not raise the subcutaneous tissue temperature greater than 36.5°C. Therefore the therapeutic effects of LLLT are not associated with a heating response, but rather a photochemical response. When light (photons) enters the cell, certain molecules called chromophores react to it, and trigger a photochemical reaction that leads to desirable physiologic effects. LLLT is simply another form of energy (physical agent) that can be used to create physiological changes in tissue.

Fig 1-1. Chattanooga Vectra Genisys Low level Laser Therapy Device (class 3b device)



Courtesy of Chattanooga Group, Hixson, TN

Classification of Lasers

Some of the confusion regarding LLLT is associated with the wide spread use of lasers in medicine and industry. There are a wide range of applications for laser technology in industry and medicine. Laser devices are classified based on their power output, measured in milliwatts (mW), and their relative risk for causing biological damage (most notably retinal damage when the eye is directly exposed to the beam). The 5 classes of laser are 1, 2, 3A, 3B, and 4. They are listed in order of increasing power and risk for biological damage (see Fig 2). Classes 1 and 2 include many everyday devices such as laser pointers, laser printers, grocery scanners, and CD players. Class 3a devices include some laser pointers and some of the very low powered LLLT devices. Class 3b devices include the higher powered LLLT that are quickly becoming the standard in the rehabilitation field.

LLLT devices are generally classified as class 3a and 3b laser devices.

The Class 4 devices are high powered lasers that include surgical lasers, often referred to as “hot lasers”. This class of laser devices has various surgical applications, most notably making precise surgical incisions with less scarring and damage to surrounding tissue. The type of lasers used in rehabilitation should not be confused with high powered lasers used in surgical applications. Although the term “cold laser” is not the preferred term for LLLT devices it is understandable why the term was coined to differentiate them from the high powered lasers used in surgery.

The power levels (mW) available within LLLT devices varies between manufacturers. One advantage to using a higher powered class 3b lasers over the lower powered class 3a devices is the higher powered devices will take less time to deliver a specific dose of laser energy when compared to a lower powered device.



Eye Safety

The laser beam should never be directed towards the eye. Both the patient and the clinician should wear protective goggles that are wavelength specific to the device that they are using. It is important to note that lasers in the infrared spectrum are invisible to the human eye, hence the unprotected eye will not have the normal protective blink reflex.

LASER CLASSIFICATION (Fig 1- 2)

Class	Power level	Power (mW)	Example
Class 1	Very low	< 0.5 mW	Laser printer, CD players
Class 2	Low	< 1 mW	Laser pointer
Class 3A	Low	< 5 mW	Laser pointer, very low power LLLT devices
Class 3B	Medium	< 500 mW	Low level Laser Therapy (LLLT)
Class 4	High	> 500 mW	Surgical lasers

Brief History of the Development of Laser

Albert Einstein is credited with providing the basic science and theory necessary for the development of laser. It was not until 1960 that the first laser was developed in the United States by a physicist named Theodore Maiman.² As will be discussed later, all laser devices require an active medium; Maiman used a ruby crystal as the amplifying medium within the lasing chamber to produce the “ruby laser”. The ruby laser emits visible red light.

In the 60's and 70's a Hungarian physician named Endre Mester experimented with using the ruby laser (red light) to destroy implanted tumors in laboratory rats. At the time, Mester believed that the ruby laser was a “high powered, tissue destroying laser”. He was not able to destroy tumors in his experiments; however, the research did lead to an important discovery. Mester observed that the surgical incisions in the group of rats that received laser consistently healed faster than the control group that was not treated with laser.³ This led Mester to refocus his research agenda on the application of LLLT for the acceleration of tissue healing. His research went on to show faster healing of experimental skin defects, diabetic skin ulcers, venous insufficiency ulcers, and bedsores.³⁻⁵

Endre Mester is credited with the discovery that LLLT can accelerate soft tissue healing. He is often referred to as the “father of low level laser therapy.”

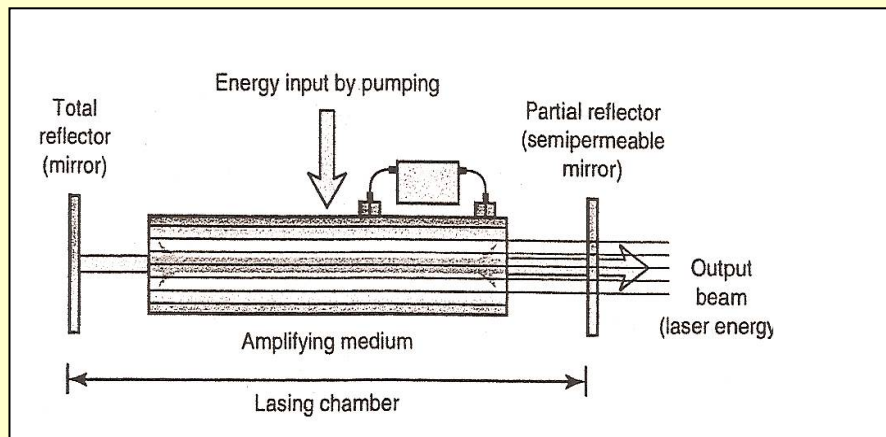
Production of Therapeutic Light

How is the light energy produced and emitted from the laser applicator? This first step in understanding this process is to identify the 4 components of a laser and the role of each in the production of laser energy.

There are 4 main components to a laser (see figure 1-3 below)

- 1) Laser Chamber
- 2) Lasing Medium
- 3) Pumping system (energy input to the laser)
- 4) Applicator (laser probe)

Fig 1-3 Components of the Laser

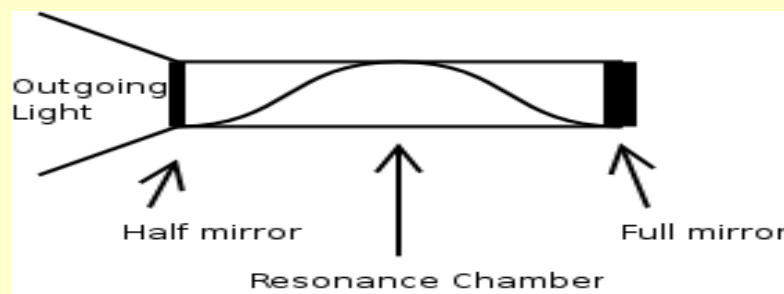


Saliba E. Low level laser therapy. In: Denegar CR, ed. Therapeutic Modalities for Musculoskeletal Injuries. Champaign, IL: Human Kinetics; 2006.

I. Laser Chamber

The laser chamber is also known as an optical resonance cavity. The chamber is a tube that has mirrors on both ends. The end that the laser beam emits from is semipermeable compared to the other end which is totally reflective. The laser chamber houses the lasing medium.

Fig 1-4 Schematic Laser Chamber

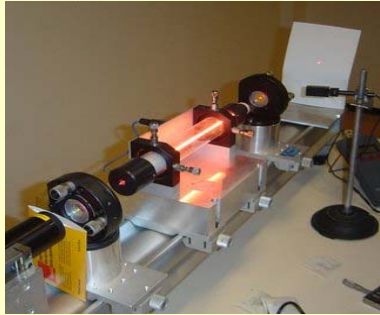


II. Lasing Media

Laser devices utilize what is known as a lasing medium within the lasing chamber. It is the excitation of the atoms within this lasing medium that allows for amplification of light. There are a variety of lasing media that can be used for LLLT applications. The earlier generations of laser devices used media such as the ruby crystal, Helium-Neon (HeNe),

and Gallium –Arsenide (GaAs). The type of lasing medium is significant in that its properties determine the laser's wavelength. Wavelength is an important factor for the appropriate application of LLLT. The definition and clinical relevance of wavelength will be discussed later.

Figure 1-5 Lasing media (HeNe) within a lasing chamber

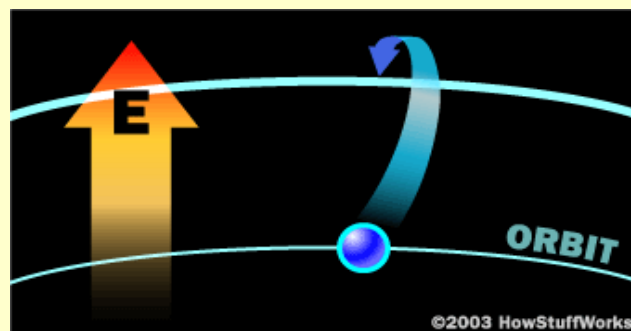


Contemporary lasers use semiconductor technology and commonly use Gallium Aluminum-Arsenide (GaAlAs) as the lasing media. There are several advantages to this newer technology; for instance, manufacturers are able to customize laser applicators to a specific wavelength by modifying the ratio of gallium and aluminum in the medium. In addition, GaAlAs lasers typically have higher power outputs which translate into shorter treatment times.

III. Pumping System

The purpose of the pumping system is to supply energy input into the lasing medium within the chamber. When the power source (electricity or battery) applies energy into the lasing medium, the atoms within the medium are stimulated within the enclosed lasing chamber. It is this pumping up of the medium inside the enclosed chamber that stimulates its atoms to an excited state. In an excited-state atom, one of the electrons is temporarily promoted to a higher energy level (see figure 1-6).

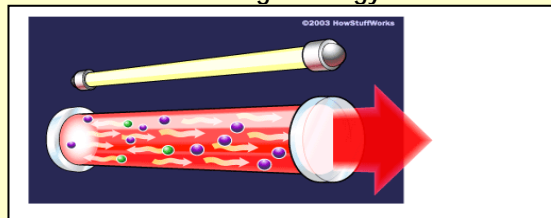
Fig 1-6 Promotion of electron to higher energy levels (orbits)



Movement of the majority of atoms to their excited state is known as *population inversion*. As the electrons return to lower energy levels, light energy (expressed in *photons*) is released. Exactly one photon is emitted for each electron that returns to the lower energy level. The collision of photons with excited atoms causes a domino effect in which more and more photons are released. This process is referred to as *stimulated emission*.

Light amplification is facilitated by the use of mirrors on each end of the lasing chamber. The photons are reflected back and forth within the chamber (“ping-pong” effect), resulting in more collisions with excited-state atoms, more stimulated emission events and a greatly increased number of photons. When the concentration of photons is sufficiently high, light is emitted through the semipermeable mirror at one end of the chamber. This emitted light is the laser beam.

Fig 1-7 Stimulated Emission of Light Energy from Laser Chamber



IV. Laser Applicator

The laser applicator, also sometimes referred to as a probe, is used to direct the photons (light energy) into the patient. Contemporary laser applicators look similar to therapeutic ultrasound applicators and many have an activation switch to initiate the dose of laser energy that the practitioner set within the device. In the early years of LLLT single diode applicators were the standard. Eventually cluster applicators were developed to treat larger areas more efficiently and also to facilitate adding other non-laser light therapy products such as superluminescent diodes (SLDs) and light emitting diodes (LEDs) into the laser applicator. SLDs and LEDs will be discussed later in the course. It is important to note that not all light therapy products are lasers. The specific criteria required for a light therapy device to be classified as a laser will be discussed in the next lesson.

Figure 1-7 Pictured (L to R) single diode applicator, 9 diode cluster applicator, 13 diode cluster applicator, and a 33 diode cluster applicator.



Courtesy of Chattanooga Group, Hixson, TN

References:

www.walt.nu

www.laser.nu

1. Baxter D. Low intensity laser therapy. In: Kitchen S, Bazin S, eds. *Electrotherapy: Evidence-Based Practice*. London: WB Saunders; 2003.
2. Belanger AY. *Evidenced-Based Guide to Therapeutic Physical Agents*. Philadelphia, Pa: Lippincott Williams & Wilkins; 2003.
3. Mester E, Ludany M, Sella M. The stimulating effect of low power laser ray on biological systems. *Laser Rev*. 1968;1:3.
4. Mester E, Spry T, Sender N, Tita J. Effect of laser ray on wound healing. *Am J Surg*. 1971;122:523-535.
5. Mester E, Mester AF, Mester A. The biomedical effects of laser application. *Laser Surg Med*. 1985;5:31-39.

LESSON 2: CHARACTERISTICS OF LASER RADIATION

PHYSICS OF LOW LEVEL LASER THERAPY

A laser beam is essentially a beam of light. While regular white light from a light bulb scatters light of multiple wavelengths in multiple directions, laser light is a very concentrated beam of light of a single wavelength (monochromatic), with all light waves aimed in a single direction (collimated) and all in phase with each other (coherence).

Key Point:

There are 3 characteristics that must be met for a light source to be classified as a true laser. It must be:

- 1) Monochromatic
- 2) Coherent
- 3) Collimated

Monochromatic

The term monochromatic implies that the beam produced contains only one color, and by definition one wavelength and one frequency of light. To summarize, monochromatic light contains the same color, same wavelength and same frequency throughout the beam.

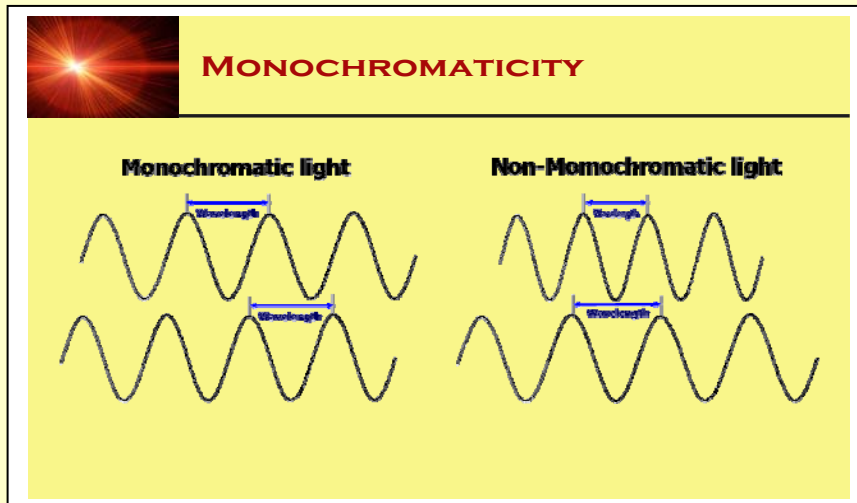


Figure 2-1: Note: the wavelengths are identical when the two monochromatic waves are compared. As illustrated above this is not the case with non-monochromatic light sources.

Coherent

The term coherent implies that all the waves within the beam are in phase. The light waves match identically in timing and spacing. In other words the waves are synchronized.

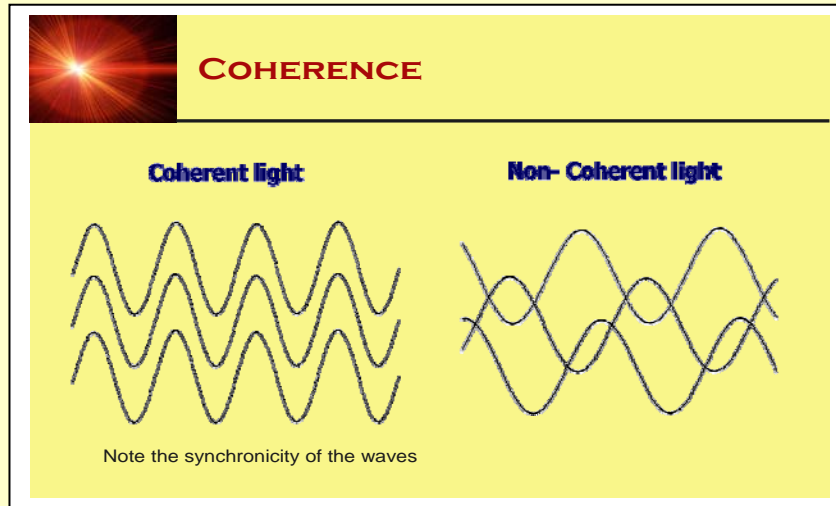
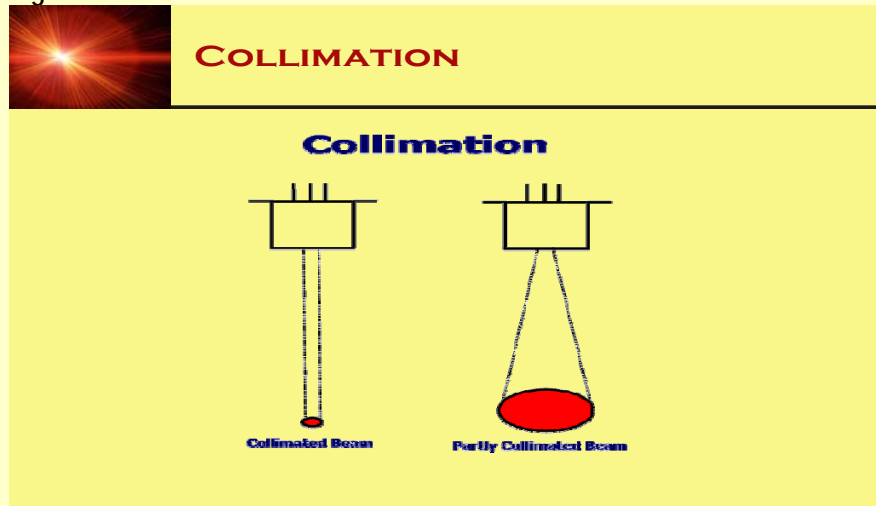


Fig 2-2 Coherent verse non-coherent light

Collimated

The term collimated implies that the beam is non-divergent. The light (photons) is focused with almost no divergence. Collimated light sources (laser) move through tissue with less divergence when compared to non-collimated light sources.

Figure 2-3 Collimation



Electromagnetic Spectrum

As stated earlier, LLLT is simply another form of energy that is applied to human tissue to stimulate a physiologic response. Similar to many other therapeutic modalities it resides on the electromagnetic spectrum. Therapeutic modalities are arranged on the electromagnetic spectrum based on their wavelength and frequency. The wavelength and frequency are inversely proportional.⁶ Simply put, this means that the longer wavelengths have a lower frequency and the shorter wavelengths have a higher frequency. See Fig 2-4.

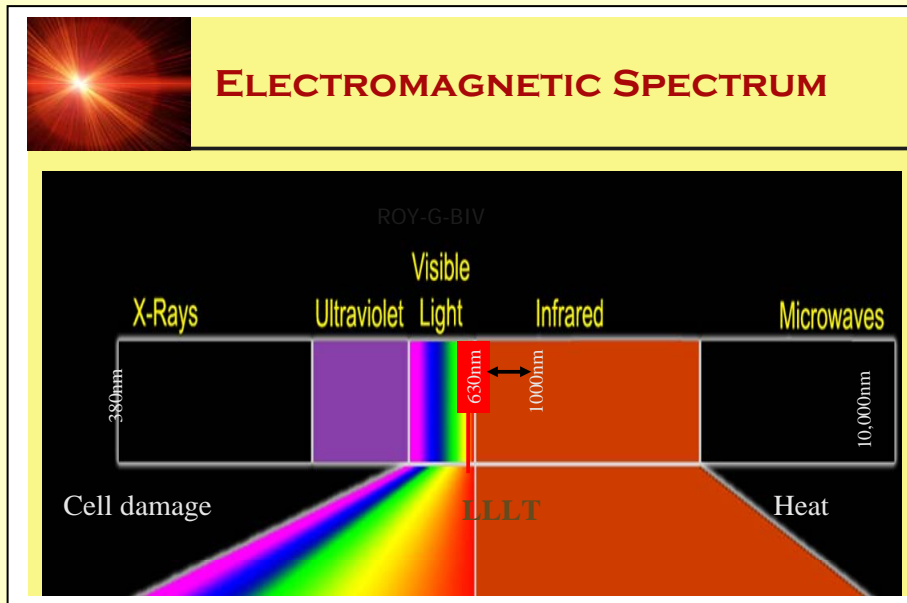


Figure 2-4 Note wavelengths in the 600 to 1000 nm range are typically used in LLLT. Also note the as wavelengths increase beyond the visible range, the light energy is no longer visible to the human eye (infrared).

More on Wavelengths

Wavelengths between approximately 600 -1000 nanometers (nm) are commonly used for the application of LLLT in rehabilitation. Based on the diagram above (fig 2-4) it is clear that the shorter wavelengths in the 400-700 nm fall into the **Visible Light Range**. The colors of light within this range have historically been recalled using the Pneumonic ROY-G-BIV (Red, Orange, Yellow, Green, Blue, Indigo, and Violet). Wavelengths in the 700-1000 nm range fall into the **Infrared Range**. The infrared range is not visible to the human eye. The eye does not have a protective blink response to wavelengths in the infrared range, which could put the unprotected eye at risk for retinal damage should the laser beam be inadvertently directed toward the eye.

The color of laser beams within the visible light range (“ROY-G-BIV”) is determined by the wavelength (nm) at which it resides on the electromagnetic spectrum (see fig 2-5)

Fig 2-5 Visible Light Wavelength and Perceived Color

Wavelength Range (nanometers)	Perceived Color
340-400	Near Ultraviolet (UV; Invisible)
400-430	Violet
430-500	Blue
500-560	Green
560-620	Yellow to Orange
620-700	Orange to Red
Over 700	Near Infrared (IR; Invisible)

It is the characteristics of the lasing medium that dictate the wavelength and by definition the color of a laser beam. For example the laser device that Endre Mester used in his early wound healing research was a ruby laser. The wavelength of this early laser device was 694.3 nm.³ This wavelength produces red light and was found to be effective for superficial soft tissue healing such as skin wounds.⁷

Light Sources used in the delivery of Light Therapy

The following section will discuss the fundamental differences between the various light sources that have been marketed under the category of “light therapy devices”. These include:

- Low Level Laser Therapy (LLLT)
- Super Luminous Diode (SLD)
- Light Emitting Diode (LED)
- Cluster Applicators (combinations of the above light sources)

It is important to note that not all cluster applicators contain laser diodes. This varies between manufacturers and sometimes within the manufacturer’s line of “light therapy” products. A cluster applicator can be classified as a low level laser device only if it contains a laser.

Low level laser Therapy (LLLT) devices

These devices have at least one true laser diode and, therefore have the capacity to emit a monochromatic, collimated, and coherent light beam. The laser beam is highly focused and typically higher powered than the SLD or LED. The depth of penetration into tissue is greater (up to 5 cm), than the SLD and LED. Clinically, it is believed to be the light source of choice to treat deeper lying tissue. The laser property of collimation allows the laser beam to maintain a small spot size (less

divergence) over greater distance. ⁸

Super Luminous Diodes (SLDs)

Super luminous diodes are not true lasers. They emit a beam of light that is fairly monochromatic and moderately collimated. However, the SLD can not be referred to as a laser because it does not meet the third criteria of being coherent. The clinical significance of coherence is still being investigated and is a current area of debate in the literature.

The super luminous diode emits light which is **non-coherent**.

The SLD light beam is less focused than the laser diode, but more focused than the LED. Super luminous diodes typically have lower power levels (mW) than laser diodes. The SLD depth of penetration (up to 1 cm) is less than the laser diode, but greater than the LED. Hence, in clinical practice it is best suited for the treatment of superficial tissue.

Light emitting diode (LED)

Light emitting diodes, like SLDs are not true lasers. They emit a beam of light that is non-collimated (less focused) and non-coherent. Light emitting diodes have lower power levels (mW) than laser diodes. The LED depth of penetration (up to several mm) is the least of the three light sources. In clinical practice it is indicated for the treatment of very superficial tissue.

The light emitting diode (LED) produces light which is **non-coherent**.

Cluster applicators

Cluster applicators include multiple diodes. They are best suited to treat larger areas more efficiently. It is important to know what light sources are included in the cluster.

For example one commonly used cluster applicator includes a total of 9 diodes (4 LEDs, and 5 laser diodes).



Courtesy of Chattanooga Group, Hixson, TN

Fig 2-6 Characteristics of Light Sources

	LED	SLD	Laser
Power	Low	Medium	High
Focus of light beam	Scattered	Moderately focused	Very focused
Penetration	Several mm	Up to 1 cm	Up to 5 cm

Gallo JA, Wijting Y. Low Level Laser Therapy: Clinical Mentoring Series. Gulf Breeze:FL: CIAO Publishing;2006.

Traditional Perspective on Light Sources

SLDs and LEDs can be useful in treating superficial tissues. One such example is the treatment of wounds. In comparative studies lasers have been shown to be more effective for the treatment of deep tissue.
(*Swedish Laser Medical Society*)

Summary

The effectiveness of the various light sources in clinical treatment must be judged on the available research. It is important to note the type of light source used in the study being reviewed or cited. For example one cannot generalize studies that investigated laser diode(s) to support equivalent effectiveness of SLDs and LEDs. Since the majority of early research utilized laser diodes, the body of literature testing the effectiveness of SLDs and LEDs will continue to evolve and shed light on the debate over the effectiveness of the various light sources.

References:

Electrotherapy News (Prof Tim Watson): Electrotherapyonline.co.uk

3. Mester E, Ludany M, Sella M. The stimulating effect of low power laser ray on biological systems. *Laser Rev.* 1968;1:3.
6. Atkins PW. *Physical Chemistry*. New York, NY: W.H. Freeman and Company; 1990.
7. Low J, Reed A. *Laser Therapy*. In *Electrotherapy Explained*. Philadelphia, Pa: Butterworth Heinemann;2003.
8. Baxter DG. *Therapeutic Lasers*. Philadelphia Pa: Churchill Livingstone;1994.

Lesson 3: Parameters of LLLT

The objective of this lesson is to become familiar with the treatment parameters associated with dosing LLLT.

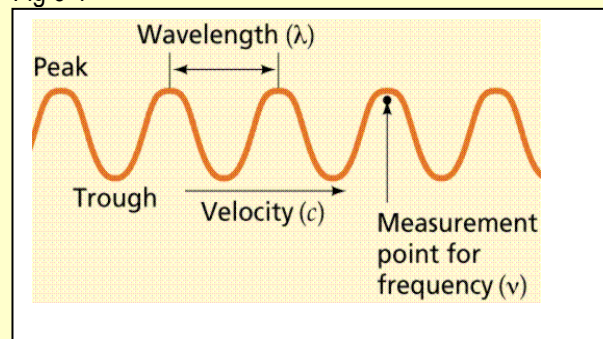
Treatment Parameters in LLLT

- o Wavelength (nm)
- o Power (mW)
- o Continuous or Pulsed
- o Energy density (J/cm^2)
- o Treatment duration (sec or min)

Wavelength

Wavelength is the distance between two peaks of a wave. The symbol for wavelength is denoted by the symbol lambda (λ).

Fig 3-1

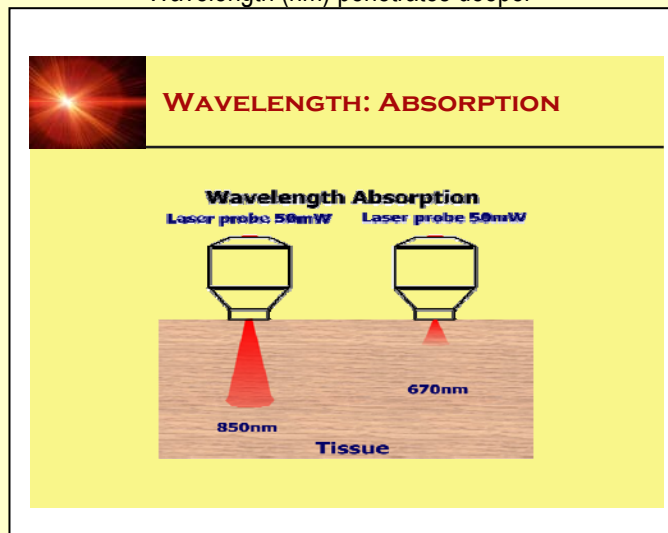


Wavelength is measured in nanometers (nm). The wavelengths used in rehabilitation are in the 600 – 1000 nm range. Wavelength is one of the key factors that dictate depth of penetration. The shorter wavelengths in the 600-700 range have been found to be effective in the treatment of superficial target tissues such as skin wounds. While deeper muscle, ligament and tendons are best treated with the longer wavelengths in the 700-1000 nm range. These longer wavelengths are barely absorbed in the epidermis and dermis allowing more of the energy to penetrate to deeper subcutaneous tissue.^{2,9} Remember that wavelengths in the infrared range (invisible light) have longer wavelengths than those in the visible light range.

Clinical implications:

- Use longer wavelengths for deeper target tissue

Fig 3-2: When power (mW) is the same the longer Wavelength (nm) penetrates deeper



Short Wavelengths (visible light)

The shorter wavelengths used in LLLT are considered to be those in the approximate range of 620-695 nm range (visible light). Two classic examples of lasers with short wavelengths include the Helium-Neon (HeNe) laser which has a wavelength of 632.8 nm and the ruby laser with a wavelength of 694.3 nm. Both of these lasers emit red light and are typically lower powered lasers compared to contemporary LLLT devices. Although these lasers are less commonly used in contemporary practice, much of the early research was done using these types of LLLT devices. The depth of penetration of these shorter wavelength devices is up to 1 centimeter.²

Clinical Implications:

The shorter wavelengths are best suited for the treatment of superficial target tissue. Based on the work of Mester and others, the shorter wavelengths have been advocated for the treatment of skin wounds. Superluminescent diodes and LEDs can also be used to treat superficial tissue.

Longer Wavelengths (Infrared)

The longer wavelengths used in LLLT are considered to be those in the approximate range of 760 – 1000 nm. Examples of two contemporary LLLT devices that fall into this category are the Gallium- arsenide (GaAs) laser (904 nm) and the Gallium aluminum arsenide (GaAlAs) laser (780 - 890 nm laser).

The gallium aluminum arsenide (GaAlAs) laser has become one of the most common contemporary LLLT device. The ratio of gallium and aluminum can be varied during manufacturing to create devices of different wavelengths. These LLLT devices commonly have higher power levels (≥ 100 mW). This allows for shorter treatment times to deliver a given dose of laser energy. The parameter of power will be discussed in detail shortly. The longer infrared wavelengths are best suited to treat deeper target tissue. The depth of penetration is up to 5 cm.²

Figure 3-3 Example of a contemporary Gallium aluminum arsenide LLLT device



Courtesy of Chattanooga group, Hixson, TN.

Clinical implications:

LLLT devices with longer wavelengths with higher power (mW) are best suited to treat deeper muscle, tendons, and ligaments.

Power

Power is defined as the rate at which energy is produced. It is measured in Watts.

$$1 \text{ Watt} = 1 \text{ Joule/second}$$

The power of the LLLT device is measured in milliwatts (mW). It is typically preset in the device. The power output is labeled on the device, it can commonly be found on the coaxial cable leading to the applicator or on the applicator itself. As discussed in the first module, the LLLT devices typically utilize power of less than 500 mW. The higher power levels in new generation LLLT devices decrease necessary treatment time, and enhance the depth of penetration.¹⁰

Key Point:

Depth of penetration can be enhanced by using:

- Longer wavelengths (infrared)
- Greater power (mW)
- Collimated beam (Laser not SLD, LED)

As with other therapeutic modalities such as therapeutic ultrasound and shortwave diathermy the power can be delivered in continuous or pulsed mode. The power can be decreased by pulsing the laser beam. Selecting a duty cycle that pulses the laser beam will decrease the net power (mW) delivered.

Power Density

Power density describes the average power per unit area of the beam (spot size). It is measured in W/cm^2 or mW/cm^2 . This unit of measurement is familiar since it is used in ultrasound therapy. The power density is determined by dividing the power level of the laser by the area of the beam (spot size). Keep in mind that the area of the beam is fixed. Smaller beam areas will result in a higher power density because the light is concentrated over a smaller area.

$$\begin{aligned} \text{Power Density} &= \text{Power} \div \text{beam area (spot size)} \\ (\text{mW}/\text{cm}^2) &= \text{mW} \div \text{cm}^2 \end{aligned}$$

Energy (Joules)

Energy is the power multiplied by the treatment time. It is measured in Joules (J). It is important to remember that the amount of energy delivered in Joules does not account for the area of the laser beam or the area of the surfaces being treated. This is why it is not the preferred method of measuring the dose of LLLT delivered in patient care.

$$\begin{aligned} \text{Energy} &= \text{power} \times \text{treatment time (sec)} \\ \text{Joules (J)} &= \text{Watts} \times \text{Sec} \end{aligned}$$

Example: you are using a 50 mW LLLT device and you treat for 1 min (60 sec). what is the total energy (J) delivered)?

Answer:

Step 1. 50 mW needs to be converted to 0.05 W

Step 2. 0.05 W x 60 sec = 3 J of energy

The table below (3-3) illustrates an important concept in LLLT. Increasing the power (mW) decreases the necessary treatment time. Conversely, when using lower powered laser devices it will take longer to deliver a given amount of energy to the patient.

Fig 3-3.

Relationship of power (mW), time (sec), and energy (J)

mW	sec	Joules (energy delivered)
50	80	4
100	40	4
500	8	4

Clinical implication: Choose a device that has sufficient power level to deliver treatments efficiently.

Energy Density (Dosage) Joules/ cm²

Energy density is a unit of measurement that describes the amount of energy delivered per unit area. It is measured in Joules/cm². This is the preferred method of dosing LLLT. It represents the actual amount of energy delivered to each cm² of the treatment area.

$$\text{Energy Density} = (\text{Power output} \times \text{treatment time}) \div \text{beam area (spot size)}$$
$$\text{J/cm}^2 = (\text{W} \times \text{sec}) \div \text{cm}^2$$

The Good News about Dosing Calculations

Contemporary LLLT devices are programmed to perform all calculations for the clinician. The clinician simply needs to enter the number of Joules per centimeter squared (J/cm^2) they want to deliver to the patient. The device factors the power (mW) as well as the area of the beam (spot size) and then automatically determines the amount of time that it will take to deliver that treatment. Hence, there is no math involved.

Take home Message: always
dose and document LLLT in
 J/cm^2

There are over 2000 published studies on LLLT. The methodology and quality of these studies varies dramatically, however it is important to note that a large percentage of these studies demonstrated positive therapeutic outcomes, including over 100 double blind studies.¹¹ Optimal dose response relationships for different tissues and conditions continues to be studied. Acceleration of tissue healing continues to be one of the most researched areas of LLLT. Acceleration of tissue healing has been shown with doses in the range of 0.5 - 8.0 J/cm^2 .^{5,11,12,13} General treatment guidelines, based on the available literature, will be discussed in lesson six.

Putting it all together

While it is unlikely that clinicians will have to perform the calculations described below during the course of daily patient care, when reviewing the LLLT research it is common to have to use these calculations, since authors often do not report the dosage in the appropriate unit of measurement (J/cm^2). Going through the exercise will enhance your understanding of the concepts discussed previously. You may want to go back and briefly review the formulas discussed earlier in this lesson.

Based on the information provided one can determine the power density and the energy density.

- *Power = 10 mW*
- *Beam Area = 0.125 cm^2*
- *50 sec treatment*

Calculations

- $\text{Power Density} = \text{Power} \div \text{beam area}$
- $\text{Power Density} = 10 \text{ mW} \div 0.125 \text{ cm}^2 = 80 \text{ mW}/\text{cm}^2$
- $\text{Energy Density} = (\text{power} \times \text{time}) \div \text{beam area}$
**hint: remember to convert Milliwatts (mW) to Watts (W)*

- Energy Density = $(0.01 \text{ W} \times 50 \text{ sec}) \div 0.125 \text{ cm}^2$
- Energy Density = 4 J/cm^2

Pulsed output Mode

The power on most LLLT devices can be periodically interrupted for a very brief period on time. This is called “pulsing”. When pulsed mode is used the average power delivered will decrease proportional to the pulse frequency that is selected. Setting the pulse frequency determine the number of laser pulses delivered per second during a pulsed LLLT treatment. Pulse frequency is measured in Hertz (Hz). When a low pulse frequency is selected the pause between laser pulses is greater so less power is delivered. When high pulse frequencies are selected there is less of a pause between laser pulses e.g. it is closer to continuous output. The term average (or mean) power is used to describe the net power delivered after factoring for both the on and off time of the beam.

Fixed Pulsed Devices

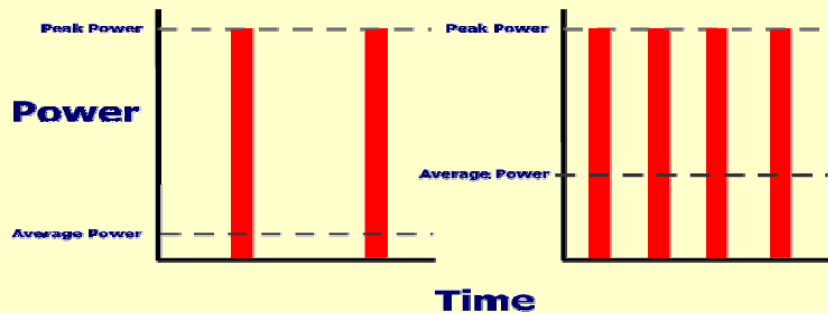


Fig 3-4 Note how the average power increases as the pulse frequency increases

“Pulsing” is a familiar concept in therapeutic modalities. Both therapeutic ultrasound and short wave diathermy have pulsed mode options. In those modalities it is intended to minimize the heating effect and while capturing the non-thermal tissue healing properties. Since LLLT is defined as a nonthermal modality the rationale of minimizing thermal effects can not be used. Optimal pulsed LLLT frequencies for clinical application in the treatment of specific conditions and tissues have yet to be established in the research. There is a limited understanding of the physiologic relationship of using one pulse frequency over another during clinical applications. From a molecular biology standpoint, there is some evidence that specific pulsing frequencies may have a positive effect on macrophage responsiveness.¹⁴ Additional research is necessary in this area. It has been theorized that acute injuries should be treated with low pulse frequencies (<100 Hz)¹, subacute injuries with higher pulse frequencies, and chronic conditions should be treated with continuous mode. There is some evidence in the molecular biology LLLT research that specific pulsing frequencies may have a positive effect on

macrophage responsiveness.¹⁴ There is also some support in the LLLT animal research. Dyson and young found better wound healing of surgical skin lesions in mice with a 700 Hz infrared pulse (HeNe 632.8 nm) when compared to a 1200 Hz pulse frequency.¹⁵

Expert Opinion on Pulsed LLLT

“In the literature there are many examples showing that different pulse frequencies give different biological effects. However, although research clearly shows pulsing is of importance, there is little knowledge about the clinical implication of specific pulse frequency.”

Professor Jan Tuner

Guest editorial, Swedish Laser Medical Society, www.laser.nu
Tuner J, Hode L. Laser therapy; clinical practice and scientific background. Grangesberg: Prima Books; 2002.

Electrotherapy News (Prof Tim Watson): Electrotherapyonline.co.uk

1. Baxter D. Low intensity laser therapy. In: Kitchen S, Bazin S, eds. *Electrotherapy: Evidence-Based Practice*. London: WB Saunders; 2003.
2. Belanger AY. *Evidenced-Based Guide to Therapeutic Physical Agents*. Philadelphia, Pa: Lippincott Williams & Wilkins; 2003.
5. Mester E, Mester AF, Mester A. The biomedical effects of laser application. *Laser Surg Med*. 1985;5:31-39.
9. Smith KC. The photobiological basis of low-level laser radiation therapy. *Laser Ther*. 1991;3:19-24.
10. Bjordal JM, Couppe C, Chow RT, Tuner J, Ljunggren EA. A systematic review Low level laser therapy with location-specific doses for pain from chronic joint disorders. *Aust J Physiother*. 2003;49:107-116.
11. Tuner J, Hode L. Medical indications : wound healing. In *Laser Therapy: Clinical Practice and Scientific Background*. Grangesberg: Prima Books; 2002.
12. Dyson M, Agaiby A, Ghali L. Photobiomodulation of human T-lymphocyte Proliferation. *Lasers Med Sci*. 2002;17(4):A22.
13. Hopkins TJ, McLoda TA, Seegmiller JG, Baxter DG . Low level laser therapy Facilitates superficial wound healing in humans: A triple-blind, sham-controlled study. *J Athl Train*. 2004;39:223-229.
14. Rajaratnam S, Bolton P, Dyson M. Macrophage responsiveness to laser . *Therapy with varying pulse frequencies*. *Laser Therapy*. 1994;6:102-112.
15. Dyson M, Young S. Effects of laser therapy on wound contraction and cellularity in Mice. *Lasers Med Sci*. 1986;1:125.

Lesson 4: Physiological Effects of Low level Laser Therapy (LLLT)

The objective of this lesson is to become familiar with the physiologic effects associated with the application of LLLT.

Physiologic Effects of LLT Related to Tissue Healing

Acceleration of tissue healing¹⁶⁻²⁹

- Acceleration of inflammatory phase of healing allowing for earlier initiation of the proliferative phase of tissue healing^{16,27}
- Stimulates increased fibroblastic activity leading to increased collagen synthesis^{17,18, 28,29}
- Increases protein synthesis²⁷
- Promotes revascularization of wounds²⁰
- Enhances the production of type I and type III procollagen mRNA³⁰
- Increased tensile strength of collagen³¹
- Increased ATP production as a result of absorption of photons by chromophores.³² Enhanced ATP production fuels the metabolic pathways necessary to synthesize DNA, RNA, and proteins for tissue repair.
- Stimulation of macrophages, fibroblasts, and lymphocyte activity are biological processes that are activated through the application of LLLT.³² These biological processes are essential to the tissue healing process.

Physiologic Effects related to Increased Circulation

There is support for the commonly held assertion that LLLT increases microcirculation.^{4,32} The extent of these increases of microcirculation has not been completely established. However, it is likely that small, but clinically significant increases in the perfusion blood to healing tissue occur during LLLT treatments. Tuner and Hode refer to this as increased microscopic circulation to differentiate this subtle increase in blood flow from the more substantial increase in blood flow produced by heating modalities.¹¹

Physiologic Effects of LLLT Related to Pain Modulation

Pain reduction (analgesia)^{1,2}

The exact mechanisms involved in pain reduction through the application of LLLT continue to be investigated. The photochemical stimulation of endogenous opiates³³, nitric oxide³⁴, and serotonin³⁵ has been reported in the literature as plausible mechanisms. Low level laser therapy has also been shown to modulate prostaglandin levels which may lead to a decrease in the chemical inflammatory mediators that irritate free nerve endings.³⁶ Lastly, as with many therapeutic modalities LLLT has been shown,

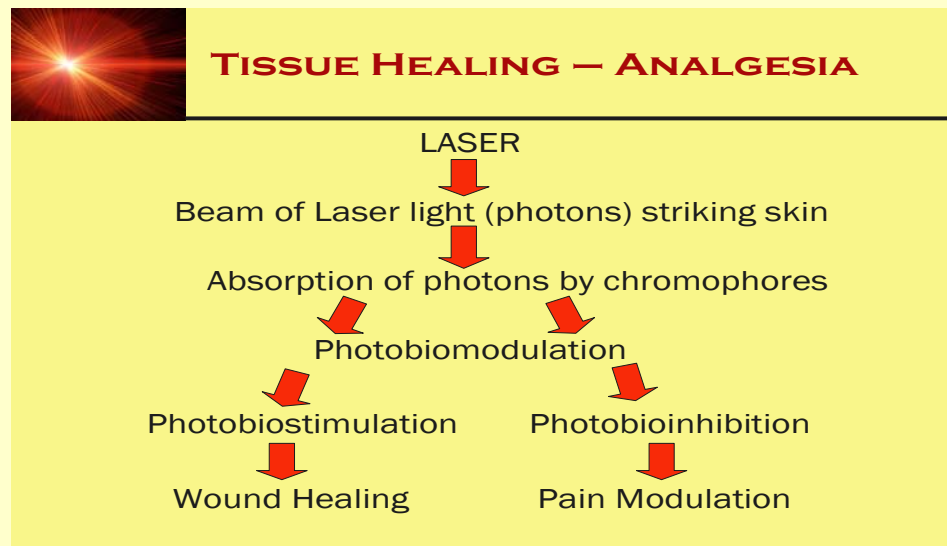
in some instances, to alter nerve conduction velocities, leading some researchers to conclude that there is a possible gating mechanism involved (gate control theory).² It is likely that a combination of two or more of the above physiologic mechanisms are involved in the reduction of pain associated with the application of LLLT.

Physiologic Effects of LLLT Related to Anti-inflammatory properties

Decreased Inflammation³⁶

It has been theorized for some time that LLLT has anti-inflammatory properties. A 2006 study in the *British Journal of Sports Medicine* confirmed this commonly held assertion with in vivo data to support the claim that LLLT suppresses inflammation. In this study Bjordal et al reported a decrease in prostaglandin levels and pain in the Achilles tendon of subjects with Achilles tendonitis.³⁶

Fig 4-1 Overview of Proposed Physiologic and Therapeutic Effects of LLLT²



Summary

Low level Laser Therapy has a photobiomodulation effect in tissue. Simply put, this means that a photochemical reaction is responsible for the physiologic effects of LLLT. This reaction can cause either photobiostimulation or photobioinhibition depending on the dosage of LLLT applied to tissue (see fig 4-1). Lower dosages are associated with photobiostimulation and higher doses are associated with photobioinhibition.⁸

References:

Electrotherapy News (Prof Tim Watson): Electrotherapyonline.co.uk

1. Baxter D. Low intensity laser therapy. In: Kitchen S, Bazin S, eds. *Electrotherapy: Evidence-Based Practice*. London: WB Saunders; 2003.
2. Belanger AY. *Evidenced-Based Guide to Therapeutic Physical Agents*. Philadelphia, Pa: Lippincott Williams & Wilkins; 2003.
4. Mester E, Spry T, Sender N, Tita J. Effect of laser ray on wound healing. *Am J Surg*. 1971;122:523-535.
8. Baxter DG. *Therapeutic Lasers*. Philadelphia Pa: Churchill Livingstone;1994
16. Kana JS, Hutschenreiter G, Haina D, Waidelich W. Effect of low-power density laser radiation on healing of open skin wounds in rats. *Arch Surg*. 1981;116:293-296.
17. Halevy S, Lubart R, Reuvani H, Grossman N. Infrared (780 nm) low level laser therapy for wound healing: in vivo and in vitro studies. *Laser Ther*. 1997;9:159-164.
18. Akai M, Usuba M, Maeshima T, Shirasaki Y, Yasuika S. Laser's effect on bone and cartilage: change induced by joint immobilization in an experimental animal model. *Lasers Surg Med*. 1997;21:480-484.
19. Ozawa Y, Shimizu N, Kariya G, Abiko Y. Low-energy laser irradiation stimulates bone nodule formation at early stages of cell culture in rat calvarial cells. *Bone*. 1998;22:347-354.
20. Houghton PE, Brown JL. Effect of low level laser on healing in wounded fetal mouse limbs. *Laser Ther*. 1999;11:54-69.
21. Enwemeka CS, Cohen E, Duswalt EP, Weber DM. The biomechanical effects of Ga-As Laser photostimulation on tendon healing. *Laser Ther*. 1995;6:181-188.
22. Reddy GK, Gum S, Stehno-Bittel L, Enwemeka CS. Biochemistry and biomechanics of healing tendon. Part II: Effects of combined laser therapy and electrical stimulation. *Med Sci Sports Exerc*. 1998;30:794-800.
23. Reddy GK, Stehno-Bittel L, Enwemeka CS. Laser photostimulation accelerates wound healing in diabetic rats. *Wound Repair Regen*. 2001;248-255.
24. Shamir MH, Rochkind S, Sandbank J, Alon M. Double-blind randomized study evaluating regeneration of the rat transected sciatic nerve after suturing and postoperative low-power laser treatment. *J Reconstr Microsurg*. 2001;17:133-137.
25. Bibikova A, Oron U. Attenuation of the process of muscle regeneration in the toad gastrocnemius muscle by low energy laser irradiation. *Lasers Surg Med*. 1994;14:355-361.
26. Loevschall H, Arenholt-Bindslev D. Effect of low level diode laser irradiation of human oral mucosa fibroblasts in vitro. *Lasers Surg Med*. 1994;14:347-351.
27. Woodruff LD, Bounkeo MS, Brannon MS, et al. The efficacy of laser therapy in wound repair: a meta-analysis of the literature. *Photomed Laser Surg*. 2004; 22:241-247.
28. Abergel RP, Lyons RF, Castel JC, Dwyer RM, Uitto J. Biostimulation of wound healing by lasers: Experimental approaches in animal models and in fibroblast cultures. *J Derm Surg Oncol*. 1987;13(2):127-133.
29. Enwemeka CS. Ultrastructural morphometry of membrane-bound intracytoplasmic collagen fibrils in tendon fibroblasts exposed to He:Ne laser beam. *Tissue Cell*. 1992;24:511-523.

30. Saperia D, Glassberg E, Lyons RF, et al. Demonstration of elevated type I & III procollagen mRNA level in cutaneous wounds treated with helium-neon laser. Proposed mechanism for enhanced wound healing. *Biochem Biophys Res Comm.* 1986;138:1123-1128.
31. Enwemeka CS, Reddy K. The biological effect . of laser therapy and other Physical modalities on connective tissue repair process. *Laser Ther.* 2000;12.
32. Cameron MH. *Physical Agents in Rehabilitation: from research to practice.* St Louis:Saunders;2003.
33. Laakso L, Cramond T, Richardson C, Galligan JP. Plasma ACTH and beta-endorphin levels in response to low level laser therapy (LLLT) for myofascial trigger points. *Laser Therapy.* 1994;6:133-142.
34. Mrowiec J, et al. Analgesic effect of low-powered infrared laser radiation in rats. *Pro SPIE.* 1997;3198:83-89.
35. Mizokami T, Aoki K, Iwabuchi S, et al. Laser Therapy; a clinical study: relationship Between pain attenuation and the serotonergic mechanism. *Laser Therapy.* 1993;5:165-168.
36. Bjordal JM, Lopes-Martins RA, Iversen VV. A randomised controlled trial of low level Laser therapy for activated Achilles tendonitis with microdialysis measurement of periteneous prostaglandin E2 concentrations. *Br J Sports Med.* 2006;40:76-80.

Lesson 5: Indications and contraindications

Indications:

The food and drug administration (FDA) has evaluated and cleared several LLLT devices for the following conditions

- Carpal tunnel syndrome
- Neck and shoulder pain of musculoskeletal origin

In addition, the FDA has cleared the use of Infrared light for:

- Increase in local circulation
- Relief of minor muscle and joint aches
- Pain and stiffness
- Relaxation of Muscles
- Muscle Spasms
- Minor pain and stiffness associated with arthritis

Low level laser therapy research studies have indicated that it is likely to be beneficial in the following:

- Wound healing (diabetic ulcers, venous ulcers, bedsores)
- Musculoskeletal conditions (tendon, ligament, and muscle injuries)
- Trigger points
- Inflammatory conditions (tendonitis, bursitis, arthritis)
- Acute pain
- Chronic Pain
- Chronic joint disorders
- Neuralgia (nerve pain)
- Diabetic Neuropathy

The list of possible indications is not exhaustive. It highlights the most common general indications in the rehabilitation field. For a comprehensive review of possible indications for LLLT the reader is referred to the Laser Therapy Handbook by Tuner and Hode¹¹ The text sites over 53 specific indications for the application of LLLT. It is important to not that many of the indications are "off label" applications and others are outside of the scope of practice of the rehabilitation professional.

Note: Using LLLT devices for applications not cleared by the FDA is considered an “**off label application**”. It is essential that clinicians familiarize themselves with the manufacturer issued user manual. The manufacturer supplied indications and contraindications often differ from those in the LLLT literature.

Contraindications

Low level laser therapy is a new therapeutic modality to most clinicians in the United States. Therefore, like other therapeutic modalities questions regarding contraindications and safety are among the most common. Fortunately, LLLT has proven to be a safe therapeutic modality in the many clinical trials and patient care settings through the world. It has been used since the 1960's initially in animal research, and from 1970's to the present it has been used safely in human subjects to treat many different conditions. No significant adverse effects have been reported in over 2,000 publications. Tuner and Hode¹¹ reviewed five studies that were specifically designed to determine if over-radiation in animal models created tissue damage; even with dosage levels many times higher than those used in clinical practice no adverse effects were noted. This being said staying within research-based guidelines is essential for optimal outcomes. For example, exceeding recommended dosages in the treatment of open wounds may inhibit biostimulation and delay wound healing (e.g. “more is not better”)

Perhaps the biggest contraindication is lack of adequate training in the appropriate use of LLLT. Because of the “newness” of LLLT in the United States many clinicians fall into this category. Most clinicians' concerns regarding safety and appropriate dosing are easily addressed in an appropriate LLLT continuing education program and ongoing self study of the peer reviewed research on the topic.

Clinicians who are properly trained in the indications, contraindications, dosing and administration of LLLT are unlikely to experience any issues related to adverse side effects. In summary, relative to other modalities used in the field of rehabilitation, LLLT is amongst the safest. To date, the modality with the highest instance of adverse effect is the hot pack (burns).

Why all the confusion about LLLT contraindications?

The fact is that there are some inconsistency between various texts, manufacturer user manuals, and other related resources on the topic. The clinician must interpret the available information and make a clinical decision that they feel is well supported. It is also important to realize that some contraindication lists will include additional contraindications that are less in the category of physiologic research-based contraindications, and more in the category of medico-legal contraindications designed to be especially conservative.

The list of contraindications below is derived from the consensus of seven commonly used textbooks the topic of LLLT. Keep in mind that manufacturer user manuals often contain additional contraindications and precautions.

Contraindications :

- Cancer (tumors or cancerous areas)^{1,2,7,8,11,32,37,38}
- Direct irradiation of the eyes^{1,2,8,32,37}
- Photophobia or abnormally high sensitivity to light^{1,2,8,37}
- When using photosensitizing medication^{1,8,37}
- Direct irradiation over the fetus or the uterus during pregnancy^{1,2,7,8,11,37,38}
- Direct irradiation over the thyroid gland^{11,32,37,38}
- Symptoms of unknown cause¹¹
- Over hemorrhaging lesions^{1,2,7,32,37}

A few words about LLLT over open growth plates

No studies have identified any adverse effects from the use of LLLT on open growth plates. It is sometimes listed as a contraindication in manufacturer's operator manuals and in textbooks. That being said it may be a prudent recommendation for medico-legal and precautionary measures to not irradiate directly over growth plates. However, LLLT is not contraindicated in children and can be used in over areas other than growth plates.

A few Words about Tattoos or dark pigmented skin

Tattoos and dark pigmented skin may absorb more light energy, and possibly create the potential for an adverse skin response. It is generally recommended that a "patch test be done in a small area. Furthermore, it is a good precautionary measure to decrease the dosage to 50-75% of the recommended dosage when treating in the region of a tattoo or over dark pigmented skin.

Summary

Low Level Laser Therapy is a safe therapeutic modality providing the clinician is properly trained. A complete understanding of the indications, contraindications, and safety precautions is essential in ensuring safe LLLT treatments.

References:

www.walt.nu

www.laser.nu

1. Baxter D. Low intensity laser therapy. In: Kitchen S, Bazin S, eds. *Electrotherapy: Evidence-Based Practice*. London: WB Saunders; 2003.
2. Belanger AY. *Evidenced-Based Guide to Therapeutic Physical Agents*. Philadelphia, Pa: Lippincott Williams & Wilkins; 2003.
7. Low J, Reed A. Laser Therapy. In *Electrotherapy Explained*. Philadelphia, Pa: Butterworth Heinemann;2003.
8. Baxter DG. *Therapeutic Lasers*. Philadelphia Pa: Churchill Livingstone;1994.
11. Tunner J, Hode L. *Laser Therapy: Clinical Practice and Scientific Background*. Grangesberg:Prima Books;2002.
32. Cameron MH. *Physical Agents in Rehabilitation: from research to practice*. St Louis:Saunders;2003.
37. Gallo JA, Wijting Y. *Low Level Laser Therapy: Clinical Mentoring Series*. Gulf Breeze:FL: CIAO Publishing;2006.
38. Saliba E. Low level laser therapy. In: Denegar CR, ed. *Therapeutic Modalities for Musculoskeletal Injuries*. Champaign, IL: Human Kinetics; 2006.

Lesson 6: General Dosing Guidelines and Application Technique

The purpose of this lesson is to become familiar with;

- 1) Appropriate application technique
- 2) Principles of dosing LLLT and instrumentation
- 2) General Research-based guidelines for dosing LLLT

Application Technique

The skin should be cleaned with alcohol prior to treatment. It is important to note that no coupling media is used during the delivery of LLLT (e.g. no lotions, gels, or ointments should be between the applicator and the patient's skin). A stationary technique should be used. This allows for the best transfer of energy. Maintaining firm direct contact with the intact skin to increase depth of penetration. Prior to activating the LLLT device both the patient and the clinician must put on the manufacturer provided protective eyewear.

Principles of Dosing and instrumentation

The dosage is the energy delivered in J/cm^2 . It is important to be certain that the LLLT device dosage screen indicates that the device is in J/cm^2 . If the device powers up in Joules (J) as the default parameter, simply press the button indicating J/cm^2 .

Delivering The Treatment

- 1) Choose a dosage (J/cm^2) based on the best available evidence (see General Dosing Guidelines). The device will automatically calculate the treatment time.
- 2) Choose either to leave the device on continuous mode or select a specific pulse Frequency (Hz)
- 3) Press the start button (screen will read "laser is armed")
- 4) Place the applicator in firm contact with the patient's skin and press the button on the applicator to deliver the treatment.
- 5) Treat the area under the probe with the number of seconds/minutes indicated. Repeat this procedure for every area to be treated. Depending on the size of the target area multiple applications may be necessary to cover all of the symptomatic area.

Research-based Dosing Guidelines

The dosing of LLLT should be based upon the best available literature. The type of condition being treated and the stage of tissue healing must be considered when determining the most beneficial parameters of LLLT. Table 6-1 was generated from a review of the available LLLT research. It outlines general treatment protocols for common clinical conditions.

TABLE 6-1 GENERAL TREATMENT PROTOCOLS AT A GLANCE

Gallo JA, Wijting Y. Low Level Laser Therapy: Clinical Mentoring Series. Gulf Breeze:FL: CIAO Publishing;2006.

Indication	Dosage	Frequency	Application
Inflammation	2 – 5 J/cm ²	5000 Hz	Over inflamed tissue
Neuralgia	10 – 12 J/cm ²	Continuous	Along course of nerve
Pain, acute	6 J/cm ²	Continuous	Over pain area or TP
Pain, chronic	12 J/cm ²	Continuous	Over pain area or TP
Soft tissue injury, acute	4 – 8 J/cm ²	<100 Hz	Over lesion
Soft tissue injury, chronic	12 J/cm ²	Continuous	Over lesion
Tendinitis/Bursitis	2 – 10 J/cm ²	5000 Hz	Over inflamed tissue
Trigger points	5-12 J/cm ²	Continuous	Over TP
Wounds, acute	8 J/cm ²	700 Hz	In and around wound bed
Wounds, chronic	1 – 6 J/cm ²	Continuous	In and around wound bed
Joint Disorders, chronic	Finger: 0.5 J/cm ² Knee: 6 J/cm ² Spine: 12 J/cm ²	Continuous Continuous Continuous	Over joint surface Over joint surface Over joint surface

Note: As a general guideline, use wavelengths in the visible range (600-700 nm) for superficial lesions, in the infrared range (700-1000 nm) for deeper lesions.

Conclusion

Low level laser therapy is an excellent addition to the rehabilitation professional's therapeutic intervention "toolbox". When combined with sound examination and treatment skills, LLLT has powerful physiologic effects that can accelerate tissue healing, and modulate pain.

References:

www.walt.nu

www.laser.nu

Electrotherapyonline.co.uk

37. Gallo JA, Wijting Y. Low Level Laser Therapy: Clinical Mentoring Series. Gulf Breeze:FL: CIAO Publishing;2006.