

Therapeutic Light

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Light is a form of energy that behaves like a wave and also as a stream of particles called photons. The development of monochromatic light sources with single or a narrow spectra of wavelengths paved the way for studies, which continue to show that appropriate doses and wavelengths of light are therapeutically beneficial in tissue repair and pain control. Evidence indicates that cells absorb photons and transform their energy into adenosine triphosphate (ATP), the form of energy that cells utilize. The resulting ATP is then used to power metabolic processes; synthesize DNA, RNA, proteins, enzymes, and other products needed to repair or regenerate cell components; foster mitosis or cell proliferation; and restore homeostasis.

Other reported mechanisms of light-induced beneficial effects include modulation of prostaglandin levels, alteration of somatosensory evoked potential and nerve conduction velocity, and hyperemia of treated tissues. The resultant clinical benefits include pain relief in conditions such as carpal tunnel syndrome (CTS), bursitis, tendonitis, ankle sprain and temporomandibular joint (TMJ) dysfunction, shoulder and neck pain, arthritis, and post-herpetic neuralgia, as well as tissue repair in cases of diabetic ulcer, venous ulcer, bedsore, mouth ulcer, fractures, tendon rupture, ligamentous tear, torn cartilage, and nerve injury. Suggested contraindications include treatment of cancer; direct irradiation of the eye, the fetus, and the thyroid gland; and patients with idiopathic photophobia.

The Nature of Light

It is common knowledge that sunny days are exciting and dull ones, depressing. Not so well known is the fact that light—even in small amounts—produces a multitude of

clinical benefits, including tissue repair and pain control. This article discusses the nature of light energy, encapsulates the evidence supporting its effects on tissue repair and pain control, summarizes the mechanisms involved, and outlines the clinical conditions that benefit from therapeutic light.

Each wakeful moment we use sunlight or man-made light to see the world around us, yet it is not so well known that what we perceive as light is actually a form of energy that behaves like a wave and also as a stream of particles called photons. Photons behave differently from conventional particles. They have no mass and are not limited to a specific volume in space or time.

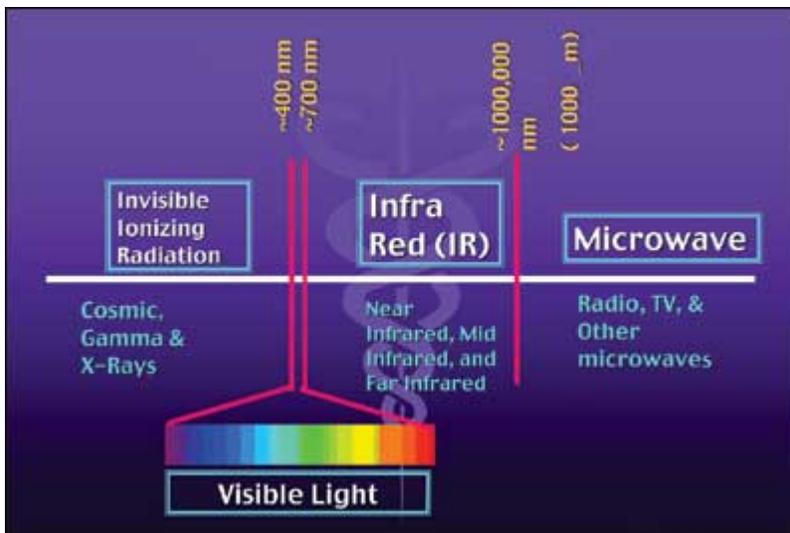


Figure 1. The electromagnetic spectrum showing the range of wavelengths and categories of light waves. Note that the spectrum of visible light is very narrow compared to the invisible spectrum, which includes gamma rays, x-rays, UV rays, infrared radiation, and radio waves.

Each photon gyrates and bounces at a unique frequency and exhibits electrical and magnetic properties. As a result, their waves are called electromagnetic (EM) waves. Not all photons are visible to the human eye. As shown in Figure 1, what we see as light is only a minute range of the spectrum of EM waves associated with photons. The entire spectrum includes radio waves, infrared radiation, visible light, ultraviolet rays, x-rays, gamma rays, and cosmic radiation. The photons of different regions of the EM spectrum vibrate differently and have different amounts of energy.

Thus, even though radio waves, infrared radiation, visible light, ultraviolet rays, x-rays, and gamma rays are photons, ie, light, they vibrate at different rates and differ in photon energy. Their waves have different wavelengths as well. A wavelength is the interval between two peaks of a wave (Figure 2), and relates to

the color of visible light. For example, blue, green, red, and violet light have different wavelengths. This difference becomes clearer when one compares red and infrared light. Red light is visible; infrared is not.

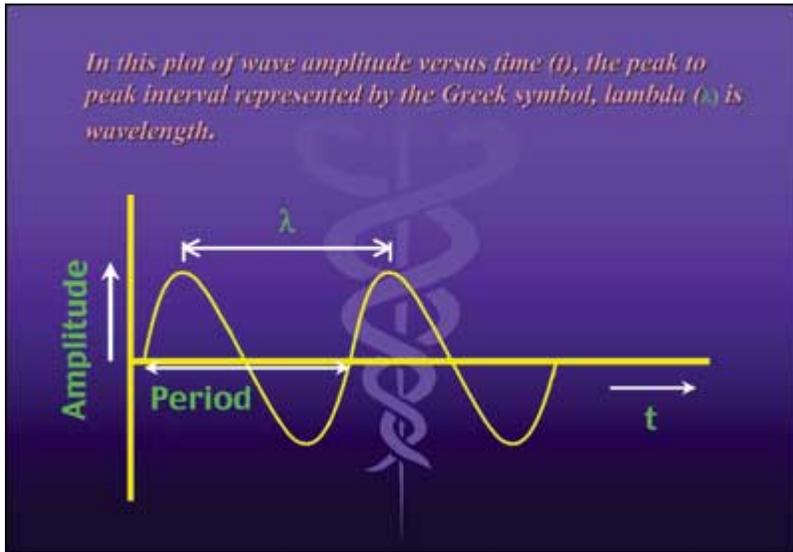


Figure 2. Illustration of the wave nature of light. Light is transmitted as sinusoidal wave. A plot of the amplitude and time is shown.

Light For Therapy

Since the photons of different regions of the EM spectrum differ in energy and vibration frequency, they produce differing effects on humans. For example, gamma rays, x-rays, and UV rays tend to ionize matter and damage tissue because their photons have high energy. In comparison, radio waves have much lower energy and longer wavelengths, and are relatively innocuous. Infrared and visible light fall somewhere in between. The evidence shows that red and near infrared (NIR) light have therapeutic benefits; as a result, most of the equipment being sold today have either red, NIR, or a combination of red and NIR light.

The development of single color (monochromatic) light sources with unique wavelengths enabled scientists to study the effects of various colors of light on tissues. This event occurred in 1960 when Theodore Maiman—using a technique earlier proposed by two teams of scientists, Charles H. Townes and Arthur L. Schawlow of the United States and Aleksandr Prokhorov and Nikolay Basov of Russia—developed a device that produced red light with a unique wavelength. The device was called LASER, because it was produced using a technique known as Light Amplification by Stimulated Emission of Radiation. Early research on this new form of light focused on high power (> 500 mW) lasers, resulting in the development of weapons grade lasers and the type of lasers used for surgery today.

As detailed below, serendipity, not a deliberate attempt, opened the field of therapeutic low power lasers.

Beginning from the late 1960s, Endre Mester, a Hungarian physician, began a series of experiments with monochromatic light. Like others of his era, Mester attempted to use "high power" laser to destroy tumors. Early in his experiments, he implanted tumor cells beneath the skin of laboratory rats and zapped them with a customized ruby laser—red light. To his surprise, the tumor cells were not destroyed by doses of what was presumed to be high-power laser. Instead, he observed that in many cases the skin incisions he made to implant the recalcitrant cells appeared to heal faster in treated animals compared to incisions of control animals that were not treated with light.

This casual observation led him to design an experiment to ascertain his suspicion that treatment with red light accelerated healing of the surgical skin incisions he made to implant the cells. The experiment was successful as it showed that treatment with red light indeed produced faster healing of the skin wounds. Baffled but fascinated by this development, he carried out other experiments in which he showed that experimental skin defects, burns, and human cases of ulcers arising from diabetes, venous insufficiency, infected wounds, and bedsores also healed faster in response to his laser treatment.¹⁻³ How could a device that was intended to destroy tumor cells promote tissue repair? It turned out that Mester's custom-designed ruby laser was weak and was not as powerful as he thought it to be. Instead of being photo-destructive, the low power light had no effect on the tumor. Indeed, it stimulated the skin to heal faster—just as sunlight may be beneficial in small amounts but destructive in high amounts. This fortuitous encounter opened the field of monochromatic light treatment.

Tissue Repair

Since Mester first uncovered the therapeutic value of red light, different wavelengths of light have been shown to promote healing of skin, muscle, nerve, tendon, cartilage, bone, and dental and periodontal tissues.⁴⁻¹⁵ When healing appears to be impaired, these tissues respond positively to the appropriate doses of light, especially light that is within 600 to 1,000 nm wavelengths.^{12,16-19} The evidence suggests that low energy light speeds many stages of healing. It accelerates inflammation,⁴ promotes fibroblast proliferation,^{5,6,20,21} enhances chondroplasia,⁶ upregulates the synthesis of type I and type III procollagen mRNA,²³ quickens bone repair and remodeling,⁸ fosters revascularization of wounds,⁸ and overall accelerates tissue repair in experimental and clinical models.^{4-15,19} The exact energy density (energy per unit area) necessary to optimize healing continues to be explored for each tissue.

However, there is emerging consensus that accelerated healing can be accomplished with doses ranging from 1.0 to 6.0 Jcm⁻².^{16-19,24} Indeed, recent

studies of human cases of healing-resistant ulcers suggest that this dose range results in healing of 55% to 68% of ulcers that did not respond to any other known treatment.²⁵⁻³³

In our recent (unpublished) clinical study, we used a double-blind randomized crossover experiment to examine the effects of 3.0 Jcm⁻² dose of 830 nm light applied twice weekly on slow-healing diabetic leg ulcers in patients that, for at least 4 weeks, did not respond to conventional treatment. Treatment was carried out for 10 weeks; 5 weeks of one treatment (sham or real), followed by 5 weeks of the other treatment (sham or real) that was not given during the initial 5 weeks. The sham treatment consisted of a standard ulcer care protocol followed by sham (fake) light treatment, while the actual treatment was carried out in the same manner but with real infrared 830 nm light.

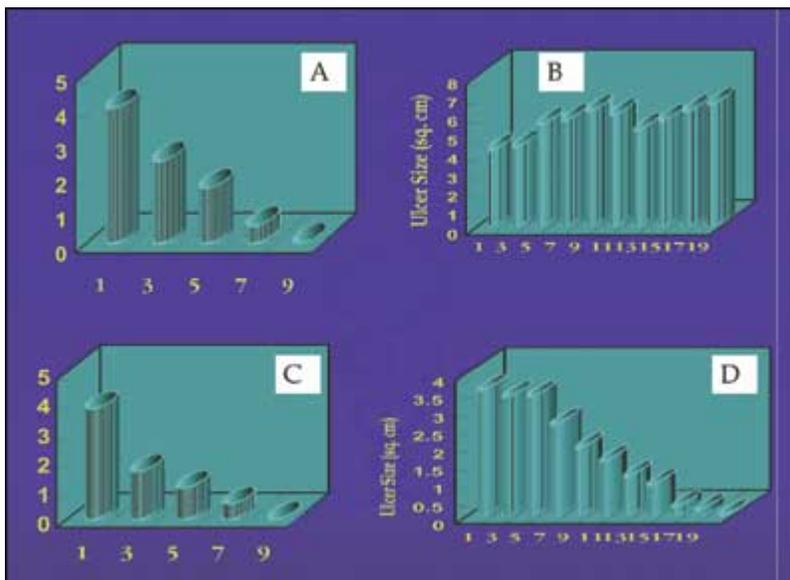


Figure 3: Graphs showing some of the cases treated with light. In these graphs, ulcer size is plotted on the Y-axis while the number of treatments given is shown on the X-axis. Plots [A] and [C] illustrate two ulcers that healed completely in 5 weeks without crossover, [B] shows an ulcer that was treated with fake 830 nm light before being treated with actual 830 nm infrared light. Note that complete healing was achieved only after crossover to actual treatment. Plot [D] shows an ulcer that did not respond to fake or actual treatment.

Four of the seven cases treated (57%) responded positively with total healing of the ulcers achieved within 5 to 10 weeks (Figure 3). The remaining three did not respond at all, suggesting that not all ulcers respond positively to this form of treatment. Two of these patients healed within the first 5 weeks, making crossover unnecessary. None of the ulcers healed with the sham treatment. This case study suggests that light therapy may be beneficial in treating healing-resistant ulcers that fail to respond to other known treatments.

Overall, the literature indicates that more than 50% of patients with ulcers that do not respond to any known treatments heal rapidly with low energy densities of light therapy.^{27,38,30-33} This noninvasive treatment could save hospitals and the nation the billions of dollars spent in treating chronic healing-resistant wounds each year.³⁴ Twenty-seven percent of patients with chronic leg ulcers have diabetes mellitus.³⁵ In 84% of these patients, ulcers resistant to healing are cited as the cause of lower limb amputation,³⁶ which in turn produces varying levels of disability.

Treating a patient with light adds energy to the target tissue. The amount of energy added to the tissue depends on factors, such as the power of the light source and the duration of treatment, in the same manner as the amount of energy used in one's home depends on how powerful the light bulbs and other home equipment are, and how long the lights and equipment are left on.

Light, at appropriate doses and wavelengths, is absorbed by chromophores such as cytochrome c, porphyrins, flavins, and other light-absorbing entities within the mitochondria and cell membranes of cells.³⁷ Once absorbed, the energy is stored as ATP, the form of energy that cells can use. A small amount of free radicals or reactive oxygen species—also known to be beneficial—is produced as a part of this process, and Ca^{++} and the enzymes of the respiratory chain play vital roles as well.³⁸

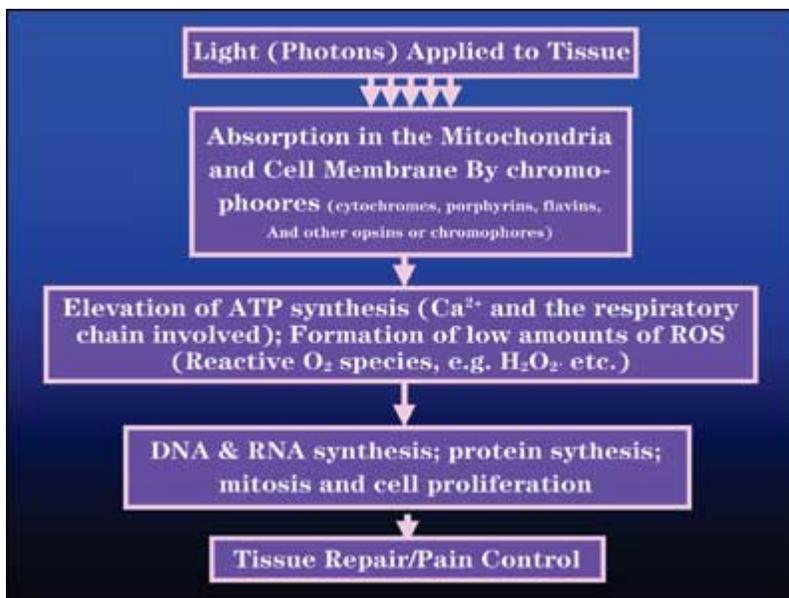


Figure 4. Schematic showing how light is absorbed by cells and the cascade of events resulting from light absorption. ATP is produced in this process and used to synthesize needed proteins, enzymes, and other tissue components.

The ATP produced may be used to power metabolic processes; synthesize DNA, RNA, proteins, enzymes, and other biological materials needed to repair or regenerate cell and tissue components;³⁹ foster mitosis or cell proliferation; and/or restore homeostasis. The result is that the absorbed energy is used to repair the tissue, reduce pain, and/or restore normalcy to an otherwise impaired biological process (see Figure 4).

Pain Control

The evidence that low power light modulates pain dates back to the early 1970s, when Friedrich Plog of Canada first reported pain relief in patients treated with low power light. But during this period the mood was neither right nor were minds ready to accept the idea that a technology that was being developed for destructive purposes—one that can cut, vaporize, and otherwise destroy tissue—could have beneficial medical effects. Thus, like Mester's findings, Plog's results were met with skepticism, particularly in the United States, where until the early part of 2002, the Food and Drug Administration (FDA) repeatedly declined to endorse low power light devices for patient care.

Works by other groups in Russia, Austria, Germany, Japan, Italy, Canada, and, more recently, Argentina, Israel, Brazil, Northern Ireland, Spain, the United Kingdom, and, of late, the United States, have produced a preponderance of evidence supporting the original findings of Plog by showing that appropriate doses and wavelengths of low power light promote pain relief.⁴⁰⁻⁵⁴ More recent reports include studies that indicate that 77% to 91% of patients respond positively to light therapy when treated thrice weekly over a period of 4 to 5 weeks.⁴²⁻⁴⁵ Not surprisingly, CTS is one of the first conditions for which the FDA granted approval of low power light therapy.

In addition to the mechanism detailed above, reports indicate that light therapy can modulate pain through its direct effect on peripheral nerves as evidenced by measurements of nerve conduction velocity and somatosensory evoked potential.⁴³⁻⁵⁵ Other reports indicate that light therapy modulates the levels of prostaglandin in inflammatory conditions, such as osteoarthritis, rheumatoid arthritis, and soft tissue trauma.^{56,57} Furthermore, works from the laboratories of Drs Shimon Rochkind of Tel-Aviv, Israel, and Juanita Anders of Bethesda, Md, indicate that specific energy fluences of light promote nerve regeneration, including regeneration of the spinal cord—a part of the central nervous system once considered inert to healing.⁵⁸⁻⁵⁹ The combination of these and other mechanisms perhaps accounts for the overall promotion of recovery from inflammatory conditions such as CTS⁴³⁻⁴⁵ and arthritis.^{48,49,56,57}

Clinical Considerations

Light technology has come a long way since the innovative development of lasers

more than 40 years ago. Other monochromatic light sources with narrow spectra and the same therapeutic value as lasers—if not better in some cases—are now available. These include light emitting diodes (LEDs) and superluminous diodes (SLDs). As the name suggests, SLDs are generally brighter than LEDs; they are increasingly becoming the light source of choice for manufacturers and researchers alike. The light source does not have to be a laser in order to have a therapeutic effect. It just has to be light of the right wavelength. Lasers, LEDs, SLDs, and other monochromatic light sources produce the same beneficial effects. Simply stated, light is light. The dose and wavelengths are critical. At present, it is believed that appropriate doses of 600 to 1,000 nm light promote tissue repair and modulate pain.

Indications and Contraindications

Indications: The FDA has approved light therapy for the treatment of head and neck pain, as well as pain associated with CTS. In addition to these conditions, the literature indicates that light therapy may be beneficial in three general areas:

1. Inflammatory conditions (eg, bursitis, tendonitis, arthritis, etc).
2. Wound care and tissue repair (eg, diabetic ulcers, venous ulcers, bedsores, mouth ulcer, fractures, tendon ruptures, ligamentous tear, torn cartilage, etc).
3. Pain control (eg, low back pain, neck pain, and pain associated with inflammatory conditions—carpal tunnel syndrome, arthritis, tennis elbow, golfer's elbow, post-herpetic neuralgia, etc).

Contraindications: There is a dearth of scientific evidence that light therapy, when used at appropriate doses, is contraindicated for any condition. However, experience and prudence suggest the following:

1. Cancer (tumors or cancerous areas)
2. Direct irradiation of eyes
3. Treatment of patients with idiopathic photophobia or abnormally high sensitivity to light.
4. Patients who have been pretreated with one or more photosensitivity enhancing agents, as for example, patients undergoing photodynamic therapy (PDT).
5. Direct irradiation over the fetus or the uterus during pregnancy.
6. 6. Direct irradiation of the thyroid gland.

Light can be destructive at high doses but therapeutic at appropriately low doses. Therefore, it is of paramount importance to use the right dose (fluence or energy per unit area treated), and frequency of treatment appropriate for each condition. A

detailed description of methods of treatment, doses suitable for the multitude of ailments that respond well to light treatment, and the rationale for each treatment is beyond the scope of this article but can be found in our recent publication.⁶⁰

Conclusions

Since the late 1960s when Endre Mester first demonstrated the beneficial effects of monochromatic light, accumulating evidence indicates that light therapy relieves pain and promotes healing of skin nerve, bone, muscle, tendon, cartilage, and ligament.

It has been shown that light energy is absorbed by endogenous chromo-phores—notably in the mitochondria—and used to synthesize ATP. The resulting ATP is then used to power metabolic processes; synthesize DNA, RNA, proteins, enzymes, and other biological materials needed to repair or regenerate cell and tissue components; foster mitosis or cell proliferation; and restore homeostasis. Other reported mechanisms of light-induced tissue repair and pain control include modulation of prostaglandin, alteration of nerve conduction velocity and somatosensory evoked potential, and hyperemia of treated tissues. The clinical benefits resulting from these demonstrated effects are pain control and tissue repair in the multitude of circumstances described in clinical studies.

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