Low power laser therapy – an introduction and a review of some biological effects

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This report gives a brief introduction to the characteristics of therapeutic low power laser devices. Absorption, tissue penetration and physiological mechanisms of laser irradiation are discussed. The biological effects of low power laser light are reviewed in the areas of collagen metabolism, woundhealing, inflammation and pain control. Contraindications, precautions and side effects of low power laser irradiation are discussed.

KEY WORDS: Laser, Acupuncture, Chiropractic.

Ce compte-rendu est une brève introduction aux caractéristiques des moyens thérapeutiques utilisant le rayon laser à faible puissance. L'absorption, la pénétration des tissus et les mécanismes physiologiques de l'irradiation au laser y sont discutés. Les effets biologiques de la lumière au laser à faible puissance sont examinés dans les domaines du métabolisme du collagène, de la cicatrisation, de l'inflammation et du contrôle de la douleur. Contre-indications, précautions, et effets secondaires de l'irradiation au laser à faible puissance sont discutés.

MOTS-CLEFS: laser, acupuncture, chiropraxie

Introduction

The initial period of development of laser devices was found in research laboratories, but more recently they have gained clinical acceptance and become commercial items for the consumers as well as the researchers. The laser industry is only in its beginnings but already shows a tendency towards tremendous growth: the volume of the total civil laser market in the western world amounted to approximately 4.4 billion US dollars for 1984. This is an increase by 30% when compared to the previous year.[1]

In the medical field, dermatology, opthalmology and endoscopic surgery had been the main areas employing the use of lasers so far. This has been especially true for the high power or hot lasers. The use of the low power, cold or soft lasers is gaining increasing popularity within physical therapy. The clinical application of the low output laser encompasses areas concerned with acute and chronic pain reduction, enhanced tissue healing and regeneration, and acupuncture therapy.

History

Actinotherapy is the area of physical therapy that deals with the healing effects of light. Glancing back into history it has been used since the earliest times. The oldest of the sacred books of India, the Rig-Veda, allegedly written as far back as 4000 years B.C., describes among other remedies the healing power of the Sun God Sanitir.[2,3] The favorable effect of sunrays on certain disorders was also known to Hippocrates (late 5th century B.C.) and other ancient Greek physicians who practised heliotherapy in special designed roofless buildings facing the sun.[4] Throughout the Middle Ages red light was used to treat small pox. The sick were placed in a room illuminated by a dim red light filtered through thick red curtains. Thus the sixteenth century physician John Godestone cured the small pox of the son of King Edward I by wrapping him in bright red sheets and placing him in a bed with red linen in a room with red curtains.[5] The Danish physician and Nobel prize winner Niels Ryberg Finsen (1860-1904), later known as the "Father of Actinotherapy", also employed red light to treat the suppuration and scarring that occur with small pox.[6]

The theoretical foundations of laser have been known through Albert Einstein since 1917, and realization took place between 1950 and 1960.[7]

The first studies on the biological and physiological effects of low power laser on tissues had been conducted in 1965 by Endre Mester of Hungary, who is the pioneer of low power laser therapy.

In Europe the therapeutic use of the cold laser reaches back for the last 15 years, while it has only been introduced to North America during the early eighties.

Characteristics of Laser

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation. Lasers can be classified into two general groups:

1 high power (hot) laser
2 low power (cold, soft) laser

The difference is based on the optical energy of the laser. High power lasers cause thermal changes and destroy tissues. Some typical examples include the Carbon-dioxide-laser (CO_2-laser), the Argon-laser, and the Neodym-Yttrium-Aluminum-Garnet-laser (Nd-YAG-laser). The CO_2-laser serves almost exclusively as an "optical scalpel" for cutting and coagulating of tissue in surgery. The radiation emitted by the Argon-laser is only weakly absorbed by water. This property makes it especially useful for reaching surfaces that lie behind an aqueous medium, as it may be the case in "welding" a detached retina. With the Nd-YAG laser one is able to coagulate tissues to a depth of 5 mm, which makes it a good tool for stopping hemorrhages or for obliterating unwanted growth. Since this type of laser can be transmitted through fiberoptics, it is employed to gain access to more distant, internal areas of the body: tumors of the bladder can be destroyed via the urethra, and bleeding from gastrointestinal ulcers or esophageal varices can be treated by inserting the laser fiberoptics through an endoscope.[4]

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In contrast to the hot laser, the low power lasers are not capable of inducing thermal changes in the target tissues and they exert a stimulative effect rather than a destructive one. Some examples include: the Kryptonlaser, which is used in laser light shows; the Helium neon-laser (He Ne-laser), used in grocery stores to read the price labels, surveying and alignment, and superficial tissue stimulation; the Gallium arsenide-laser (Ga As-laser) which is generally known as Infra-Red-Laser (IR-laser) and is used in subcutaneous stimulation.[8]

This paper will concentrate on the He Ne- and the IR-laser since they are generally used in the physical low power laser therapy setting, have a high level of safety, and are readily available to various health professionals.

Laser radiation is produced when electrons of the electrically excited atoms making up the active medium return to their ground energy state. Emitted photons collide with other excited electrons which in turn causes further emission of photons. By travelling in synchronicity the photons cause a chain reaction, known as population inversion and a light characteristic of the active medium is produced.[8] (Figure 1). The mirrored ends of the tube reflect the light back and forth which causes further collisions and emissions and eventually increases the strength of the beam. Only 3-5% of the light produced is allowed to escape through the partially silvered mirror in one end of the tube.[8]

Lasers are named after their active medium from which they are produced. In the case of the IR-laser it is a solid (gallium arsenide) and in case of the He Ne-laser it is a gas.

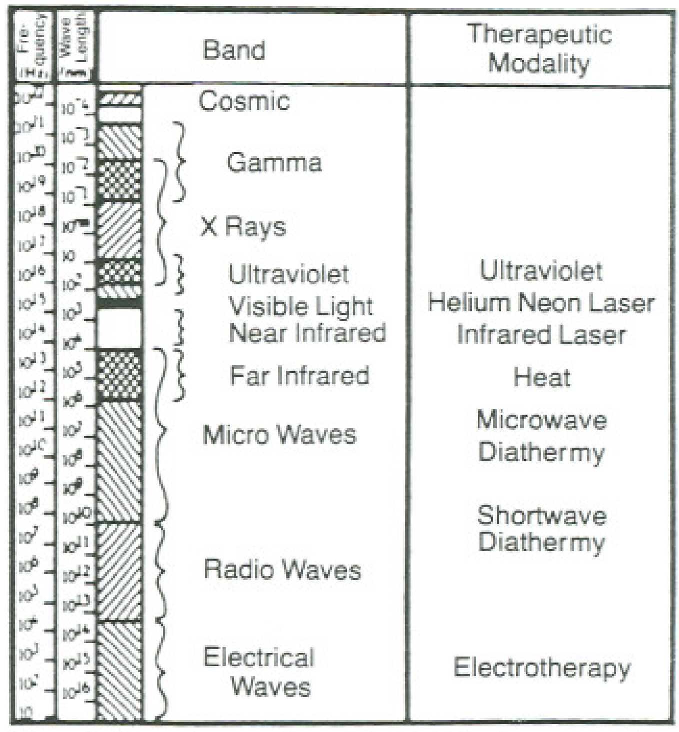

Figure 1: Known therapeutic wavelengths of the electromagnetic spectrum
(reproduced with kind permission from author[8])

A laser beam differs from normal light in the following aspects:[5,7,9]

1 Intensity: the power capacity of laser radiation can go as high as billions of kilowatts per square centimeter – enough to evaporate any existing matter on this planet.
2 Monochromaticity: this refers to the specificity of light in a single defined wavelength. Therefore, only one characteristic wavelength or color of light is emitted. This is a very important characteristic of laser since it leads to the selective excitation of different tissues.
3 Coherence: this refers to the phase relationship (i.e. all the photons arrive at the target in phase) the resulting photon-tissue impact value is high, allowing for effective stimulation at a relatively low power level.
4 Lack of Divergence: as a result of coherence the photons travel in extreme parallelism. Their impact foci are very small which allows for exact focusing of the energy.

Laser light is located in a narrow spectral band of visible and invisible radiation (Figure 2). The He Ne-laser beam is visible at 632.8 nm and is continuous while the IR-laser light is invisible at 904 nm and is pulsed.

Laser energy is measured in joules per square centimeters of tissue area, and laser power is expressed in milliwatts. Cold lasers have an average power output of 1-2 milliwatts.

Absorption and tissue penetration of laser

When laser contacts the surface of the skin, common physical

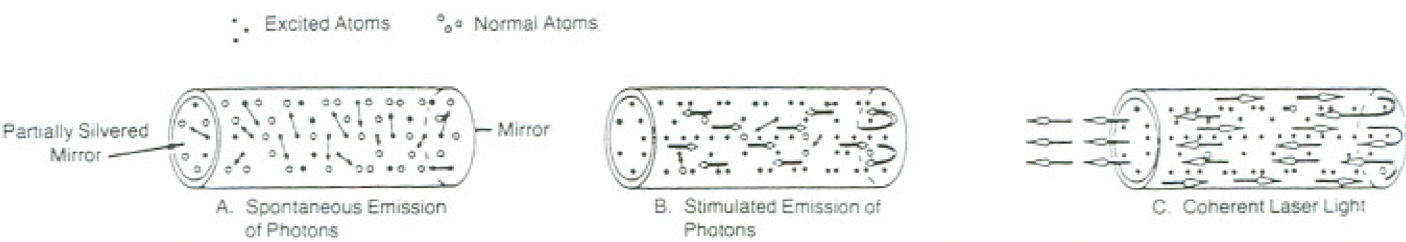

Figure 2: Formation of helium neon laser

(reproduced with kind permission from author[8]) phenomena can occur, including reflection, absorption and dispersion.[6] A prerequisite for absorption is that the wavelength of the irradiated light is suited to the absorbing material. The resonance of human tissue is such that it absorbs the light of the laser quite well. This is based on the theory that human tissue cells oscillate at a frequency that is very similar to that of laser light.[9] The thickness of the dermis, the presence or absence of muscular, adipose, or osseous tissues are all important when investigating the penetration of tissues by laser radiaton.

In 1981 the Dermatology Department of Harvard Medical School studied the transmittance of nonionizing radiation in human tissues,[10] and found that essentially no visible light of wavelengths shorter than 500 nm is transmitted through the chest or the abdominal wall, but that blue light of 10^{-5} to 10^{-4} can reach the brain and testes. Transmittance of all tissues increases progressively with wavelengths from 600 nm to 814 nm, whereby bony structures appear to transmit more than soft tissue per unit thickness. It is assumed that more than one-third of the photons at 600 nm reach a depth of 0.5 mm. Beneath the skin surface at a depth of 0.3-0.5 mm lies the subpapillary venous plexus. This is a horizontal sheath of vascular networks enveloping the entire human body, and is the primary influence of general skin coloration. Conceivably, photochemotherapy or photodependant drug release and activation can be made to occur in this plexus by using wavelengths of 400-600 nm. This group further says that for potential photochemical reactions to occur in deeper tissue a choice of wavelength between 600 and 800 nm is the most logical.

Studies with the He Ne-laser[6,7,11] have shown that direct absorption of the energy occurs at approximately 3 mm of soft tissue thickness and that indirect penetration can occur up to 1 cm. Since the light of the He Ne-laser is of a red colour, it will penetrate deeper into pale tissues than into red tissues (i.e. oral cavity), where absorption will occur more rapidly. The He Ne-laser is, therefore, primarily used for direct skin stimulation and for the stimulation of acupuncture points that have a superficial location.

The pulsed IR-laser appears to penetrate to depths of 1-5 cm in soft tissues.[8,12] It is, therefore, less absorbed in the dermis and more in the deeper and denser tissues, such as ligaments, tendons, muscle and may be the periosteum. A recent study[13] has shown that IR-laser irradiation at a power of 10 milliwatt will result in a penetration depth of 18 mm in the bone axis direction and 6 mm in the cortico-medullar direction. Laser irradiations of lower power output were measured to reach to a depth of approximately 1 mm of bone thickness. When considering the results of this study, one has to be aware that it was done in vitro and involved specimens devoid of surrounding soft tissue structures.

Physiological mechanisms of laser

Several theories exist, trying to explain the basic physiological events that occur at a cellular level when laser irradiation is applied to the organism.[5,6,9,12,14,15] In the literature the three most often encountered theories are:

1 Bioluminescence theory – according to Russian researchers DNA replication emits light at 630 nm. Since this is very close to the wavelength of the He Ne-laser light, it is postulated that laser may accelerate DNA replication via photic stimulation. Laser irradiation at this frequency is said to be non mutagenic since it is not in the range to alter the genetic program by affecting chromosomal ultrastructure. The latter is more likely to occur at ultra-violet light irradiation at 300 to 400 nm.

2 Cellular oscillation theory – the laser beam carries electromagnetic oscillations of a definite frequency. When it reaches the tissues the electromagnetic oscillations gradually "swing and excite" single cells. This is thought to eventually intensify the biochemical processes that ultimately regulate the performance of various vital organs. Soviet scientists go on to say that the cell itself begins to emit light similar to the rays of the laser, when the resonance sets in.

3 Biological field theory – connections between tissues and organs in the intact organism are not limited to humeral effects and nervous control mechanisms alone. Rather, there exist unique biological fields around every cell, tissue and organ and higher structural levels (organism, organ) exerting a normalizing influence on lower levels (tissue, cells). The resonance effect of the low power laser is thought to restore the normal energetic status of the organism, that is, restore its normal physiological state.

It is evident that all three theories seem to share one basic premise: laser causes activation of the cell which in turn leads to an intensification of biochemical processes. It is within this context that the Arndt-Schulz law becomes important with respect to low power laser application. This biological law states that "weak stimuli excite physiological activity, moderately strong ones favour it, strong ones retard it and very strong ones arrest it."[16]

The physiological mechanisms and effects of low power laser are best established in the areas of collagen metabolism, woundhealing, inflammation and pain control.

Collagen metabolism

The most recent studies on procollagen production and fibroblast activation have been conducted by Abergel.[17,18,19] He tested the effects of low power laser irradiation, using both the He Ne- and the IR-laser on collagen production by human skin fibroblasts in culture. The cells were subjected to laser treatment at various energy densities and the treatment schedule included one daily exposure on several consecutive days. The procollagen production was monitored by the synthesis of ^{3}H-hydroxyproline following the incubation of the cultures with ^{3}H-proline. DNA replication was assessed by ^{3}H-thymidine incorporation. The results indicated that procollagen production was enhanced by both lasers approximately 4-fold in average. The highest enhancement of 36-fold was noted in cultures which initially synthesized procollagen at a relatively low level, while a lesser effect was achieved in cultures which already actively synthesized procollagen. Abergel assumes that there is probably a maximum synthetic capacity by the fibroblasts which cannot be further increased. To determine the mechanisms of the bio-stimulation of collagen synthesis by low energy laser, experiments designed to measure the activity of enzymes were performed.

Prolyl-hydroxylase is an important enzyme in the metabolic pathway leading to collagen formation. It is elevated when collagen synthesis is elevated. However, no changes were noted in the activity of prolyl-hydroxylase after exposure of the fibroblasts to laser.

Collagenase is involved with the extracellular degradation of collagen. Therefore, another hypothesis to explain the increase in collagen synthesis was through inhibition of the catabolic pathway. However, the activity of collagenase measured by degradation of radioactive collagen substrate remained unchanged after laser exposure.

Another possible mechanism to explain the stimulation of collagen production is by stimulation of cell proliferation. DNA replication was measured by the incorporation of ^{3}H-thymidine into DNA. Treatment of cells with the He Ne-laser did not affect DNA replication, while the IR-laser reduced ^{3}H-thymidine incorporation. Thus, Abergel was not able to explain the increased procollagen production on the basis of enhanced cell proliferation.

Researchers from Italy[20] observed the effects of the He Ne-laser on collagen with the aid of an electron microscope. They examined human fibroblasts in biopsies taken from healing trophic lower limb ulcers after laser irradiation treatment, as well as human fibroblasts kept in a culture medium. When comparing the irradiated fibroblasts in culture with the controls it was found that no cell damage had occured with respect to cell morphology and structure, but rather there was mitochondrial and rough endoplastic reticulum hypertrophy with enlarged cisternae. Numerous microfibrils were present, especially close to the Golgi apparatus. The biopsies from the irradiated ulcer when compared to their controls showed very similar results: considerable hypertrophy of the secretion apparatus, with an increase in the Golgi complex, and a quantitative and qualitative increase of mitochondria, as well as an accumulation of fibrillar material in the outer part of the cytoplasm.

These signs of a protein synthesis activation seem to indicate that low power laser irradiation may have a direct influence on the fibroblast itself. This study and the previous one show that collagen neosynthesis could be attributed to the increase in tissue regeneration. Whether this regeneration process is due to a direct effect of the laser beam on the fibroblast or an indirect consequence, such as an increase in blood supply or a combination of both remains to be shown. Abergel[18] postulates that the mechanism might be an acceleration of the m-RNA transcription rate of the collagen gene.

Woundhealing

If low power laser seems to have an effect on collagen metabolism, what about woundhealing?

There are several animal studies employing rabbits, mice, rats and guinea pigs, that show that low power laser has a stimulatory effect on woundhealing.[12,21,22,23,24,25] Most involve mechanically induced wounds and epithelial burn injuries. The common findings from all these studies are, that the irradiated animals form granulation tissue up to 25% plus compared to the non-treated animals with enhanced epithelialization and increased phagocytosis. One study[23] looked at the breaking strength of rat skin incisions and found that the animals that were exposed to 2.2 joules / cm^2 for three minutes twice daily for 14 days, demonstrated a 55% increase in breaking strength over the control rates ($p<0.01$). However, 28 days post-op the difference in breaking strength diminished to a nonsignificant increase of 16%. When the dosage was doubled a nonsignificant 17% increase in breaking strength was observed at 14 days post-op.

Although all these results show an acceleration of woundhealing, there seem to exist optimal exposure conditions for this to occur, and these exposure conditions seem to depend on the principles of the Arndt-Schulz Law.

In one study it was found that the laser beam increases the vascularization of newly formed tissue in healing wounds.[25] The explanations provided for this were: irradiation may activate the vessels adjacent to the wound, it may increase the phagocytic capacity of macrophages, accelerating their activity to clear the way for the advancing vessels, or it may loosen the fibrin network of the clot.

These findings suggest that low power laser seems to have a stimulating effect on regenerating epithelium. It is interesting to note that some postulate, that this stimulatory effect if continued with repeated exposures over periods of great duration, may eventually be the starting point of neoplastic growth.[22,24] However, to the author's knowledge no low power laser irradiation induced neoplasia has been reported in the literature so far.

Laser can also have a bioinhibitive effect on fibroblast function. However, this involves a Nd-YAG laser with a penetration depth of approximately 10 cm and a wavelength of 1.06 nm. These attributes place this more powerful laser somewhere in between the cold and the hot lasers. This type of laser has been shown to selectively suppress collagen production in keloid fibroblast cultures.[26] Clinical studies with adequate follow-up periods indicate flattening and softening of the keloids.

Inflammation, edema and pain

At the site of tissue injury a number of inflammatory agents are generated in response to phagocytic processes and other irritants. Among these are highly reactive superoxide radicals. These combine with local arachidonic acids to produce prostaglandin-E. Prostaglandin-E is a fatty acid that causes the breakdown of ATP to cyclic AMP and induces changes in nociceptor membrane potentials. This change decreases the sensitivity threshold of the nociceptor and thus lead to an increase in its firing rate.[8] Apart from being involved with pain production, prostaglandins also cause increased vasodilation and further propagate the inflammatory process.

Essman did extensive research on the effect of the He Ne-laser upon mouse skin and mouse skin injury and investigated superoxide dismutase activity of irradiated tissues.[27] The function of superoxide dismutase seems to be that of protecting aerobic organisms against the deleterious effects of superoxide.[28] Superoxide dismutase exerts protective effects against a variety of inflammatory agents or events by acting as a scavenger of superoxide radicals. Essman found that successive daily He Ne-laser exposure resulted in a significant increase in superoxide dismutase activity and suggested that laser irradiation affords a potential antinflammatory effect. Since superoxide dismutase inhibits prostaglandin formation it may not only be effective as an antinflammatory agent but also may be involved in the reduction of pain and edema.

One theory explains intracellular edema reduction through low power laser by the photons ability to cause rotational changes in the lipids and proteins that make up the cell membrane transfergates.[29] This is supposed to allow for a rebalancing of the intracellular and extracellular osmotic pressures and a drainage of excess intracellular fluids into the lymphatic system. The biological effect of the He Ne-laser on functional and micromorphological alterations of cell membranes in vitro studies has been supported elsewhere.[30]

It has already been mentioned above that superoxide dismutase may indirectly cause a decrease in pain sensation by affecting superoxide radicals and resulting in a reduction of prostaglandin formation. Another mechanism for pain control postulates that laser biostimulation causes a photochemical change converting prostaglandins to prostacyclin endoperoxide which reduces the sensitivity of free nerve endings.[31] In one double blind study, 19 out of 26 chronic pain patients suffering from trigeminal neuralgia, postherpetic neuralgia, sciatica, and osteoarthritis experienced pain relief after laser exposure of the skin overlying the radial, medial and saphenous nerves, and in some cases, irradiation of the appropriate painful nerve. The subjects who were exposed to laser had a large increase in the urinary excretion of 5 hydroxy-indoleacetic acid, which is a degradation product of serotonin.[32] This may implicate possible central descending inhibitory systems.

It has been shown that the stimulation of specific acupuncture points with the He Ne-laser or the IR-laser demonstrated significant pain relief.[7,11,33,34,35]

Contraindications, precautions, and side effects

The low power laser is basically a very safe therapeutic tool, as long as one regards certain rules.

Do not stare into the beam, since this may cause permanent damage to the retina. Various opinions exist on the exposure duration needed before non-reversible changes result. One study examined the ocular damage thresholds for both the He Ne-laser and the IR-laser using Rhesus Monkeys as subjects.[36] It was suggested that at a wavelength of 1064 nm (IR-laser) retinal damage resulted from shock waves that were produced by a transient heating of melanin granules. At 532 nm (He Ne-laser) a photochemical damage, in the form of bleaching of pigment, to the outer segment membranes was superimposed upon the photomechanical damage from shock waves. Others stated that no definite damage to the retina occurs until a dose of 2.8J/ms is reached.[37] In this case fluctuation of ionic concentrations, pyknosis, and vacuolation of the outer nuclear layer, and variations in the quantities of phagosomes are features of retinal damage.

Avoid overstimulation. Trelles advises that exposing tissues to laser energy densities above 8-9 joules/cm^2 of tissue area should be avoided.[29]

Other contraindications are pregnancy and tumorous tissue. This is mainly for medico-legal reasons, since no conclusive studies regarding these issues have been conducted so far. Irradiation of benign or malignant neoplastic tissue should be avoided in all cases, since it may stimulate tumor growth and expansion.

The only side effects that have been reported are post-treatment dizziness or nausea in approximately 2% of the patients.[6] Some think that this may be due to a vasovagal type of reaction.[9]

Conclusion

The biomedical effects of low power laser irradiation have been investigated in various other areas. Some of the more interesting settings include immunosupression-immunostimulation, autoimmune disease, and nerve regeneration.[38,39,40,41] However, little published work exists with respect to these and greater efforts have to be made to insure their validity and further development.

This paper concentrated on the basic physiological effects and mechanisms of the He Ne-laser and IR-laser in the areas of collagen metabolism, woundhealing, inflammation, and pain control. The clinical applications that arose from these studies at a cellular level are widespread and include some entities such as, the treatment of ligamentous and tendinous injuries, bursitis, arthritic disease, improved woundhealing, acupuncture point therapy, and pain control in general.

The use of the low power laser as a physical therapy modality is becoming increasingly popular with various centers and practitioners in private practice. Although clinical results seem very promising, and the low power laser fits perfectly into the realm of "high-tech" therapy, one has to be careful not to regard it as a panacea. To this point of time laser has not been able to replace many of the current techniques and physical modalities. However, it can be used on conjunction to improve the health care available to patients and we, as health care providers, need to be aware of its possible uses and versatility.

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