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PHOTOBIOMODULATION, THE PHYSIOLOGICAL RESPONSE OF MUSCULOSKELETAL SYSTEM TO LOW POWER LASERS: A REVIEW

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ABSTRACT

Lasers, as a source light energy has gained its importance in various applications in the field of medicine. The low power lasers also called as low level lasers are known to bring about a series of changes in the organs at the cellular and subcellular level. These changes collectively bring about various changes like wound healing, tissue regeneration, controlled secretion of cytokines, expression of gene proteins and various other physiological and biochemical actions. This review is intended to understand the physiological actions of lasers and their beneficial effects on musculoskeletal system.

Key Words: Photobiomodulation, Musculoskeletal system, Bloodless, Unpigmented tissue

INTRODUCTION

The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation." A laser form of light is very useful when compared to other sources of light because it emits light coherently. Coherence is of two types' spatial coherence and temporal coherence. Laser can be focused to a spot; this property is called spatial coherence. This property is used laser cutting and lithography. Temporal coherence is property which enables Laser to emit light with a narrow spectrum. They can emit a single color of light and also to pulses of light. Laser has a number of applications. They are used various biomedical and non-biomedical applications. Non biomedical applications include there use in printers, barcode scanners, optical communication, cutting, welding materials, and laser lighting in entertainment . When it comes to biomedical applications lasers are used in the tattoo removal, laser surgeries, diagnostic procedures, therapeutic uses, and as an adjuvant therapies in several disorders .

Low Level Laser Therapy (LLLT) is treatment modality in which the energy delivered to the tissue is low so that the temperature of it does not rise above the normal body temperature. LLLT is known to bring about photobiomodulation in the treated tissues. Physiological actions of cold laser will be discussed under following headings : Tissue penetration of light, Target organelles, Activation of photoreceptor, Reduction of oxygen to free radicals and nitrite to nitric oxide, Increase in ATP and AMP.

Tissue penetration of light: Does the laser penetrate tissue? Yes but the ability of a low level laser to penetrate the tissue depends mainly on absorption coefficient of the tissue and also several other factors. Tissues preferentially absorb light at varying wavelengths. Light has dual nature as described in Physics. When it is travelling, it is considered to be continuous wave but when it strikes a tissue or a surface it is considered as particle named as Photon: a pocket of energy . Laser photons that travel through a given tissue with a high absorption coefficient for its specific wavelength will lose energy through absorption easily. Because these photons are readily absorbed, this light travels for much shorter distance than those light wavelengths that are not absorbed. The absorption of photons from initial ray of laser eventually degrades the power of light with distance travelled. Absorption coefficient for the various tissues is lesser at the wavelength of light between 600 to 900 nm, which means better tissue penetration is seen in lasers with these wavelengths .

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Penetrating power of laser in the living tissue depends on properties of light and tissue. Light parameters include its wavelength, intensity, polarization, coherence of the source. Tissue properties are the tissue compression, pigmentation, fibrotic structure, hydration, composition, the appendages, and covering of the skin. It is obvious that for a laser beam of constant wavelength and energy, the depth of penetration depends on the tissue in which the laser photons have to 'submerge' . Laser scattering at the tissue surface also becomes one of the major factors which can affect its penetrating power. There is loss of energy at the laser -tissue interface. This loss of energy due to the skin barrier is estimated for some of the types of laser. This can range from 50 % to 90 %, and it depends on the source as well as type of laser. For example the loss is estimated to be around 50 % in infrared pulsed laser when compared to 90% in continuous HeNe (632nm) laser. The maximum penetration of infrared lasers is observed in "bloodless, unpigmented tissue" which is around 1cm . The increase in the total energy output of the laser for a given wavelength does not increase the penetration power significantly. Considering the tissue penetration is one of the most important features of the laser treatment to get the optimum clinical benefits.

The depth of penetration of laser using wavelengths from 630 nm up to 1100 nm is known to be up to 50mm. Bovine issue penetration of 808 nm and 980 nm lasers was conducted and it found that the energy density of 1mW/cm was achieved at the depth of 3.4 cm. It was determined that 808 nm of light penetrates as much as 54% deeper than 980 nm light in bovine tissue . A study was conducted by Esnou et al., on the human abdominal skin samples to estimate the depth of penetration of LLLT. The skin upto 0.784 mm thickness was harvested by dermatome following abdominoplasty. These samples were irradiated by a Gallium Aluminum Arsenide Laser (Wavelength 850 nm near infra-red invisible light, 100 mW, 24 kHz, using 0.28 mm diameter probe) and the transmitted radiation was measured. The intensity of laser radiation reduced by 66% after being transmitted through a 0.784mm sample of human abdominal tissue. In this study, most laser radiation was absorbed within the first 1mm of skin .

Target Organelles in the Cell: When LLLT is applied, there is a significant intracellular change. It is seen that on repeated applications of LLLT, there was favorable response in the cell. This is because the cell response to LLLT might depend on the different phases of cell division. And if sensitivity of cells is more in any of the phases of the cell division then repeated exposure makes it possible for all cells to be exposed to that particular phase and thus an optimum reponse . Application of Laser of 20 J/cm2 for three, six, and 10 laser applications provided progressively better photobiomodulation effect on intact epidermis and dermis of mice. It did not produce any damage which is revealed by electron microscopy . The response is usually – augmented by the production of intracellular structural and functional proteins. Though ribosome is the organelle for protein synthesis, it doesn't involve in absorbing light energy and there is no sufficient evidence supporting this fact . It is the same with vacuoles or storage substances. But there are studies which have demonstrated the changes in nucleus and mitochondria after laser exposure. Now it is found that mitochondria are first organelle to show the change which is succeeded by nucleus. "Power house of the cell": the mitochondria have the 'machinery' to absorb light energy. Mitochondria respond immediately because of the 'chromophobes' which are known to absorb light energy. They are also called as photoreceptors. The response of the tissues to given light energy depends on the phase of cell division and the number of the mitochondria in the cells .

Activation of photoreceptor: There are several photoreceptors in the mitochondria. Cytochrome C Oxidase (CCO) is known to be most prominent one . The mitochondrial CCO seems to be the primary photoreceptor involved in photobiomodulation as most of light was absorbed by them and minimal amount of light was absorbed by remaining pigments . In study by CCO inhibitor, potassium cyanide was used and then near infrared laser was used to treat the neuronal cell. It was found that cell did not respond for the laser treatment but the uninhibited cells responded. When considered these studies it is clear that mitochondrial CCO is a primary photoreceptor for photobiomodulation .

Reduction of oxygen to free radicals and nitrite to nitric oxide:

Mitochondrial CCO is known to possess two enzymatic activities . First one is reduction of oxygen to water and the second one is reduction of nitrite to nitric oxide. Reduction of oxygen to water results in production of reactive oxygen species (ROS) like superoxide (O), hydrogen peroxide (H O), and the hydroxyl ion (OH) . The Reactive oxygen species and Nitric Oxide are known to activate several signaling pathways inside the cell which leads to the synthesis of several structural and functional proteins .

Photobiomodulation increases bioavailability of nitric oxide by releasing it from intracellular storage structural heme proteins like hemoglobin or myoglobin. It has also been proposed that the beneficial effect of photobiomodulation may rest on its ability to photo-dissociate nitric oxide from CCO. Photodissociation of nitric oxide would restore oxygen consumption because nitric oxide inhibits mitochondrial respiration in normoxic cells, by binding to CCO. This explanation is applicable under normoxic conditions in which the effective wavelengths (670 nm & 830 nm) for photobiomodulation correspond to the oxidized heme a3 of CCO, and in which the nitric oxide is

produced predominantly by nitric oxide synthase .

Increased in ATP and AMP: The release of nitric oxide from CCO prevents the displacement of oxygen and allows unaffected cellular respiration. There is increased CCO enzyme activity, increased movements of electron across electron transport chain and increased ATP production . This causes increase in the energy levels of the cells as well as increased AMP that is involved in many signaling pathways . The exposure of rat liver isolates, to HeNe laser found that cellular respiration was upregulated when mitochondria were exposed to HeNe laser or other forms of illumination. Laser irradiation caused an increase in mitochondrial products such as ATP, NADH, protein, RNA, and a reciprocal augmentation in oxygen consumption . A similar effect is produced when tissue that contains mitochondria is exposed to low-level radiation like visible and near-infrared (NIR) light. It is absorbed by the organelle, and an upregulation of cellular respiration is observed.

Physiological action of laser

Overall actions of laser at cellular and tissue level can be summarized as follows: Laser increases nerve conduction, capillary dilatation, fibroblast migration, macrophage activity, and keratinocyte activity. It is also known to augment the production of several enzymes and nucleic acids. The exchange of ions across the membrane is increased. Overall clinical effects on LLLT (Low Level Laser Therapy) are reduced spasm, pain, increased blood circulation, and improved healing .

LLLT action on muscle: Muscle can perform work by contraction and relaxation. This process involves the utilization of the energy provided by ATP. On working continuously, muscle develops fatigue because of several factors like depletion of ATP, accumulation of muscle metabolites like ions, and lactic acid.

It is known that when LLLT acts on the muscle it increases ATP production and also cause vasodilatation. This enhances the muscle performance and delay in the onset of fatigue. It has been demonstrated that LLLT increases muscle performance, delays fatigue, and hasten repair of the damaged muscles . LLLT acts on several steps like ATP production, phosphocreatinine re-synthesis, and also lactate oxygenation in the mitochondria. It is also shown that LLLT of 810 nm is more effective in improving the muscle performance because of its deeper penetrability and optimum energy transfer .

LLLT and its pain reducing action: Acute inflammatory pain is a complex process that begins at the peripheral nociceptors. A greater understanding of the phenomenon of pain reduction by low-level laser therapy has been provided. Several types of low level lasers with different wavelengths and therapeutic regimens have been used, leading to difficulty in comparing the results and formulating a theory about their mechanism of action. At present, most of the studies are based on the photochemical and photophysical theories proposed by Karu. This photophysical theory suggests that laser radiation could produce analgesia acting on the K+ channel . He-Ne laser does not induce a photophysical effect, acting directly on the mitochondria without any effect on the cell membrane. LLLT is known to reduce the acute inflammatory pain in the rat bones .

Role of LLLT in knee Osteoarthritis: According to Alghadir et al 2014 there was a significant reduction in the pain and improvement in the function of knee joint that was treated with LLLT for osteoarthritis of knee. The duration of the treatment was for 4 weeks with a frequency of twice a week. LLLT was given to 8 points around the joint with dosage of 6 J/point for 60 sec, with a total dosage of 48 J/cm in each session. The LLLT device used was a diode laser with a power output of 50 mW, a wavelength of 850 nm, and a diameter beam of 1 mm .In a study done by Rayegani et al 2012, LLLT was given to knee joint more frequently for lesser duration, 5 times a week for 2 weeks. The effect of LLLT on pain and function was compared with the usual modality of treatment. It was found that improvement with LLLT was better than other modalities of treatment .

CONCLUSION

Looking at the benefits in medical and other fields, it is clear that laser therapy holds a potential for managing disease conditions which were difficult to manage with existing modalities of treatment. However the undesirable side effects on the tissue have to be explored extensively before a decision could be made about use of laser therapy in management of various disease conditions.

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