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Factors affecting Low Level Laser Therapy

Low Level Laser Therapy has been reported as causing many therapeutic reactions within living tissue, yet research studies have not been able to support conclusively the results which appear to occur clinically. If the physiotherapist accepts that light quality may have been a variable overlooked in previous studies, it is necessary to consider whether there are other factors which may have contributed to the variable and, at times, conflicting results. These factors include depth of penetration and resultant absorption. Factors such as power output, dose, pulse frequency and frequency of treatment will also influence the therapeutic action of laser. This review evaluates parameters common to most therapeutic lasers as well as other features including the multiple-diode probe. Issues which may help clinicians optimise their treatment when using Low Level Laser Therapy will be addressed.

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It has been documented that Low Level Laser Therapy (LLLT) may cause many reactions within the human body. There are already comprehensive reviews of published information (Basford 1989a and 1989b, Enwemeka 1988, King 1990, Kitchen and Partridge 1991) with some already having described the fundamental principles of LLLT (Kert and Rose 1989, Ohshiro and Calderhead 1988, Snyder-Mackler and Seitz 1990). This paper will clarify some of the parameters of laser which may affect the treatment of patients.

Of the factors that may influence clinical results, the following will be considered: the significance of wavelength, power output, dose, pulse frequency and frequency of treatment; any potential side-effects of laser; and whether multiple-diode laser probes are useful features or expensive gimmicks. By becoming familiar with laser parameters, the clinician will be able to choose those parameters which are appropriate to treatment requirements.

Wavelength – penetration and absorption

Anderson and Parrish (1981) have observed that "whenever skin is involved as the site for photobiologic reaction, its optical properties play some role... in affecting the response" Competing photochemical pathways within the skin, as well as the behaviour of light at the air/tissue interface and at subsequent tissue/tissue interfaces, have a profound effect on the transmittance of light within the skin. It is important to point out that the penetration depth of ordinary, near infrared radiation (wavelengths of 770nm and above) is very small (Ward 1986) with a possible maximum direct penetration of only a few millimetres.

Confusion surrounds the exact depths to which various wavelengths of laser are able to penetrate. When referring to laser, penetration depth may mean the depth to which the laser light will directly penetrate or the depth to which the effects of the laser's photonic energy will infiltrate. Laser light behaves in the same way as other electromagnetic radiation, where diminution of the radiation occurs in proportion to its direct penetration below the skin surface. However, indirectly, some wavelengths of laser are able to stimulate cellular responses capable of causing further, deeper penetration of light. That is, laser light will penetrate directly to a certain depth where, at some point, the effect of direct radiation will begin to diminish and chemical reactions set up within tissues as a response to photostimulation will result in forward directioning and deeper penetration of the laser effects (Keijzer et al 1989, Wilson and Jacques 1990).

For laser light in the therapeutic range (short infrared, approximately 620nm to 904nm), there is a distinction between penetration and absorption. Penetration of laser light into tissue is partly determined by its wavelength, by scatter and by absorption. Short wavelengths (in the visible range) scatter more than longer wavelengths and therefore penetrate less deeply. If a laser has deep penetration, its energy is unlikely to be absorbed by superficial structures. If a laser has good absorption, it will not penetrate very deeply. Kolari (1985)

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and Greathouse et al (1985) suggest that up to 99 per cent of laser light is absorbed within the first few hundred microns of the skin surface.

Helium-neon laser will directly penetrate to a depth of 0.8mm and, by scatter and reflection, indirectly to 8mm to 10mm of tissue (Kleinkort and Foley 1984). Longer wavelengths or infra-red laser light may penetrate up to 15mm into living tissue (Greathouse et al 1985, Kleinkort and Foley 1984, Kroetlinger 1980, Snyder-Mackler et al 1989).

The spread of photochemical action may indirectly result in laser affecting structures as deep as 5cm (Preuss et al 1982, cited by Castel 1985). LLLT may have a systemic effect which causes structures outside, and remote to, an area of irradiation to react in a similar way to the irradiated area (Chen and Zhou 1989, Rochkind et al 1989).

Perpendicular contact application of the laser probe to the skin surface during irradiation will enhance penetration depth by reducing reflection and scatter (Greathouse et al 1985, Ohshiro and Calderhead 1988). The depth of light penetration can be enhanced by a little compression of the tissues (Karu 1989b). Penetration depth might also be affected by the size of the beam, the apparent optimum beam size being reported as 4mm when calculated using the Monte Carlo Model (Keijzer et al 1989).

There is no reliable model for determining penetration and absorption of laser light. Shorter wavelengths (in the visible range) may be more appropriate for the treatment of superficial lesions and longer wavelengths (in the near infrared range) may be more useful for the treatment of deeper lesions. How much energy is needed and how much of it is being absorbed by cellular structures at various depths to cause a therapeutic photo-chemical reaction is not clear, and this must be determined if the credibility of LLLT is to be firmly established.

Power output of the laser apparatus

Penetration and absorption of laser light can also be affected by the power output (expressed in milliwatts – mW) of the laser apparatus.

Penetration of the light of laser depends on the mean output of the laser unit, not the peak power output. It does not necessarily rely on the duration of treatment to an area (Kert and Rose 1989). The greater the number of photons which penetrate the tissue at any one time, the greater the number of photons will be present at any given depth (Kert and Rose 1989). This can be better understood by assuming each photon is a packet of energy. Each packet stimulates a cell or cells. The longer the period over which irradiation takes place, the more packets of energy become available (or the more photons are emitted) and therefore the more cells are stimulated. If the power of a laser is relatively high (perhaps 15mW to 60mW), then the same number of packets of energy can be supplied in a shorter period of time.

Based on their study of the effects of LLLT on mast cells, Trelles et al (1989) reported that higher power densities with shorter irradiation times might be more efficient in the delivery of LLLT. A saturation point for absorption of energy must be reached eventually. This aspect of LLLT is still being investigated.

Dose

Dose, or energy density, for LLLT is expressed in joules per square centimetre (J/cm^2). Accurate calculation and recording of doses for all applications is imperative, so that treatments can be replicated.

If it is accepted that laser therapy conforms with the Arndt-Schultz Law (Ohshiro and Calderhead 1988), a therapeutic window of laser doses may exist between energy densities of O.5J/cm^2 and 4J/cm^2 (Hallman et al 1988, Kana et al 1981, Ohshiro and Calderhead 1988). Doses above these may result in bio-inhibition. The biostimulatory effects of low powered laser radiation are dose-dependent (Mester and Mester 1989) and with sufficient intensity, the stimulatory effect disappears and inhibition takes place. Karu (1989a) confirms that low doses regulate or accelerate electron transport and high doses cause photodynamic damage. Kubasova et al (1988) refer to the saturation of biostimulative effects induced by polarised light occurring at 4J/cm^2, implying that with saturation, cells are unable to absorb any more energy above this level.

Despite this evidence, some clinicians have used doses above 4J/cm^2. The justification for this is obscure, except where LLLT has been used in the treatment of rheumatoid arthritis, to utilise the bio-inhibitory abilities of laser to dampen the rheumatoid process. Therefore, doses outside the therapeutic window, eg 6J/cm^2 (Bliddal et al 1987) and 15J/cm^2 (Goldman et al 1980) have been chosen. Results in these studies have been mixed and inconclusive.

If high doses result in bio-inhibition, the safety of doses outside the therapeutic window must be questioned. While some indicate that these doses are safe (Kert and Rose 1989) the clinician must proceed with caution, as evidence exists from one experiment that with some lasers, "signs of destruction were....visible" at 7J/cm^2 (Mester et al 1985). High doses have also been implicated in the production of side effects, so these must be considered prior to the application of laser. Side effects will be addressed later in this review.

The literature indicates that there has been a cyclical development of dose parameters perhaps influenced by regional differences. The classical work done by the pioneer of therapeutic laser, Professor Endre Mester, suggested that 4J/cm^2 was the optimum dose for the treatment of wound healing and ulcers (Mester et al 1985). The North American experience would suggest that the total dose in one treatment session should not exceed 8J/cm^2 to 9J/cm^2 (Castel 1985), and for some patients be as little as 1J/cm^2 to 4J/cm^2 (Basford et al 1986).

Conversely, the work of Kert and Rose (1989) confirms what has been practised by Northern European, Mediterranean and Japanese clinicians for some time, namely that doses per point should remain within or close to the accepted window (Nissan et al 1986) but given repeatedly or over a wide area, thus ensuring that cumulative doses within a treatment session are high (in the order of 30J/cm^2 to 50J/cm^2). If a systemic effect is possible using low doses of LLLT, total irradiation of an affected region should not be necessary to obtain stimulatory effects (Castel 1985, Mester et al 1985).

When discussing the ability of light to cause photostimulation and the sometimes variable responses, Karu (1989b) has suggested that light quanta act only as triggers for regulation of cellular metabolism and this explains why comparatively low doses and low intensities of light are needed. She proposes that the intensity of the effect is determined by a cell's physiological state prior to irradiation. This may explain why biostimulation is not always possible and why there is great diversity of results reported in the literature. She has observed that when fresh wounds are irradiated, the effect of laser can be minimal or nonexistent. There is often no phototherapeutic response in cases where cell proliferation is active and regeneration is occurring at a maximal rate. A response is most likely to be observed in old wounds (Karu 1989a).

It is apparent that the issue of optimum dosage for LLLT is far from clear.

In summary, it would appear prudent to begin treatment with a low dose of laser energy, to continue treatment with the minimal dose that will achieve a therapeutic response, and to increase this dose slowly only if treatment is unsuccessful.

Side effects

Kleinkort and Foley (1984) have described the occurrence of nausea, dizziness and an initial exacerbation of pain, in a small percentage of patients having LLLT. These side-effects occur when selected doses are too high, and indicate that high doses should not be used. These side-effects may, however, be desirable in determining when a dose is sufficient in the treatment of particular conditions (Kert and Rose 1989). No adequate explanation has been offered as to why side-effects occur, beyond suggesting it is part of a systemic effect. Some studies do not refer to them at all. This is yet another dose-related variable of laser that needs some consideration by both the clinician and the research-worker.

Pulse frequency

Some laser units include the option of pulsing the light at various frequencies (pulses per second or Hertz - Hz). There is no conclusive evidence suggesting that there are certain interruption or pulsing frequencies of light which will enhance treatment results. As has occurred with LLLT in general, experimental confirmation lags behind the anecdotal clinical evidence. Choice of pulsing frequencies appears to have been dictated more by what was available on a laser unit than by any other factors.

Karu (1989b) showed only a negligible difference in the controlled work comparing wavelengths in the 500nm to 600nm region where high pulse repetition rates of light (more than 1000Hz) were compared with continuous emission of light. Similar results were obtained when 890nm light was pulsed at 3480Hz and 666Hz. The apparent effects at different pulse frequencies are due not to the change in pulsing frequency but to the change in intensity of the light, as intensities of light at various pulsing frequencies can differ by some orders of magnitude (Karu 1989b).

However, in research done by the same author and her colleagues (1990), it was found that "one of the critical parameters of laser radiation when acting on living cells, is the pulse duration and/or pulse repetition rate". A cut-off point for stimulation of Escherischia coli division rate when irradiated with a 950nm gallium-arsenide diode laser was noted near 1000Hz, ie stimulation occurred below this pulsing frequency but above this level inhibition was noted. This occurred in a setting where the variables of dose and average power were kept constant.

There is other evidence that lower pulsing frequencies of light (less than 1000Hz) might assist in conditions such as wound contraction (Dyson and Young 1985). These authors found that a pulse frequency of 700Hz accelerated wound contraction and wound bed cellularity, whereas a pulse frequency of 1200Hz decreased these factors. The possible effect of pulse frequencies has been acknowledged also by Zarkovic and co-workers (1989) in their work on infra-red laser irradiation and hypoalgesia in mice. Karu et al (1990) suggest that there may be different molecular mechanisms for stimulation depending on the pulse repetition rate. The pulsing frequencies which cause specific molecules to be excited have not been determined. It is possible that a range of pulsing frequencies over one site of irradiation may be necessary. This requires clarification.

Pulsing of light effectively reduces the intensity of the light. Pulsation of light appears to be significant only for high powered surgical lasers, although pulsed low level lasers are considered useful if their mean output is more than 20mW to 30mW (Kert and Rose 1989), thus achieving as much power output per pulse as possible. This idea satisfies the earlier requirement for delivering as many photons as possible close to the target tissue to allow stimulation of photochemical reactions.

Therefore, pulsation at the maximum pulse frequencies available on any laser unit is desirable and aids in reducing treatment time (Castel 1985).

Frequency of treatment

Review of the literature does not give clear indications on how often to treat with laser. Some workers have used daily treatments (Hallman et al 1988). Others have used single doses at four-day intervals (Castel et al 1986). Both

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Karu (1989a) and Mester et al (1985) have found that treatment every second day or twice a week achieves the most positive response. There is no consensus about the optimum frequency of treatment.

Those workers using high cumulative doses tend to treat less frequently than those using low total energy densities per treatment. There is a general consensus that to treat too often is neither desirable nor necessary. There is some evidence that LLLT has a cumulative effect over a number of treatments (Kert and Rose 1989).

The frequency of treatment for different conditions is another parameter that must be validated.

Multiple-diode probes

Some laser units incorporate the use of a mixture of several laser and/or non-laser diodes, of the same or different wavelengths, housed within the same applicator (Figure 1). Such appliances may be termed multiple-diode or cluster probes. They are not only potentially less expensive than purchasing an array of single probes of different wavelengths but also have practical implications in that a larger area can be treated in one application.

Research provides some objective support for the theoretical basis for the use of cluster probes. There may be a combination of wavelengths which may enhance the actions (Karu 1989b) or, in turn, negate the reactions caused by temporal spacing or irradiation with different wavelengths. Castel et al (1986) support this view, stating that optimal stimulation is obtained for healing when a combination of helium-neon and infra-red laser is applied to soft tissue injuries, although it is unclear whether these ideas are supported by research. Dyson and Young (1985) using a similar combination strategy, concluded that laser is beneficial in wound contraction and in increasing wound bed cellularity.

El Sayed and Dyson (1990) have shown that the effects of a cluster probe in experimental conditions are greater than those of individual single probe irradiations, suggesting that the different elements incorporated in cluster probes may be synergistic. These authors provide support for this statement by indicating that multisource irradiation, with scattering and angular diffusion within tissue, ensures that the intensity of the penetrating beam is reinforced by the overlapping partial intensity of the neighbouring diodes, thus increasing the efficiency of energy delivery to tissue. Whether an ordinary infrared lamp (with its range of wavelengths) could achieve comparable results is not discussed. Such claims must be validated.

Figure 1.
A multiple-diode/cluster probe (from Chattanooga Australia Pty Ltd).

Accurate quantification of the dose delivered is difficult with multiple-diode probes, especially when there are different powered diodes represented in the cluster.

Conclusion

Phototherapy, in general, provides the clinician with another treatment option and there is no doubt that LLLT units are convenient and efficient means by which to apply monochromatic light energy to living tissue. Photon/tissue interaction using LLLT is supported in some published studies, but not in others. This may be due to the number of factors which can be altered when applying LLLT, including pulse frequency, wavelength, power output and dose. With greater insight into the parameters used for LLLT, by utilising information currently available and by basing treatment on the guidelines in this review, the clinician should be able to choose more appropriately those parameters necessary for optimal results. As with all modalities, however, much research is still required. It must now become the researcher's task to establish the efficacy of LLLT by clarifying the factors outlined in this review, and the clinician's responsibility to justify the clinical efficacy of low level laser therapy.

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