Quality of light – is laser necessary for effective photobiostimulation?

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Is true laser, with its unique qualities of coherence, collimation and monochromaticity, necessary for effective photobiostimulation, or is a simpler form of light sufficient? Doubt has been cast on the importance of coherence and collimation in influencing biostimulation. It is hypothesised that monochromaticity (or singularity of wavelength) is the only characteristic of laser necessary for photostimulation. If wavelength is the important factor in phototherapy, the clinician must consider which wavelengths are capable of producing specific effects within living tissues. In addition, it is important to distinguish the quality of light provided by a unit and whether it will give the desired results without a large financial outlay. This article reviews the unique properties of laser, discusses their contribution to photobiostimulation and looks at apparatus which provide these properties.

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Low Level Laser Therapy (LLLT) has become a popular means of applying visible and near infra-red light for treatment of a variety of musculo-skeletal and dermal conditions. These include the stimulation of wound healing, including burns (Enwemeka 1988 and 1990, Lam et al 1986, Rochkind et al 1989), the reduction of pain (Snyder-Mackler et al 1989, Walker 1983), the treatment of rheumatoid arthritis (Palmgren et al 1989) and the stimulation of microcirculation (Skobelkin et al 1990).

Much has been published about the effects of laser and authors have questioned the varied results (Basford 1989a and 1989b, King 1990). It is not the purpose of this article to address what is already available in these reviews but to bring together some of the less well known data and attempt to answer some of the questions regarding the effectiveness of low powered lasers.

It is often asked whether the three unique properties of laser are, together, able to cause responses in living tissue which cannot be created by any other means. There is doubt whether collimation, coherence and monochromaticity are necessary to create a photochemical reaction within an organism, or whether monochromaticity alone is sufficient. If the latter is true then, with the great number of laser units currently available, it seems that the unit which will produce efficient and effective results at a reasonable cost to the clinician is one that contains a non-laser, monochromatic diode.

In considering the purchase of a low power laser unit, the clinician should be familiar with what makes light useful and which apparatus will give optimum delivery of therapeutic light. Some laser apparatus currently available may not include light featuring all of the characteristics mentioned previously. The implications for use of the different types of lasers currently available on the market will be discussed.

The added possibility that certain biological effects can be stimulated by using one wavelength in preference to another is the subject of ongoing research, much of it so far inconclusive. An attempt is made to bring together some of the more relevant information on this subject.

By reviewing currently available information, clinicians will be assisted in making an objective and critical evaluation of laser therapy, and laser units, in relation to their own clinical requirements.

Unique properties of laser

The unique qualities which give laser its potential clinical efficacy, and which distinguish it from polychromatic, ordinary light, are:

Coherence – the photons, stimulated during the excitement of the lasing medium, all travel in phase with one another. This means that there is parallelism of the beam.

Collimation – because there is parallelism of the beam, even at great distances, the laser beam has little divergence.

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Monochromaticity – the laser light is from one source, of one wavelength and of a single colour (Ohshiro and Calderhead 1988).

As laser responds in the same fashion as ordinary light, it is subject to refraction, reflection and scatter (Ohshiro and Calderhead 1988). As a result, laser light will lose its collimation and coherence within the first few micrometres of the skin surface (Keijzer et al 1989).

Karu (1989a) has stated that, to achieve a photochemical effect, it does not matter whether the light used is coherent or non-coherent. Karu (1989a) and El Sayed and Dyson (1990) maintain that it is not necessary to have true laser as a source of monochromatic light to cause photochemical responses within human soft tissues.

Karu (1989a) has commented that there is a special sensitivity of cells irradiated with red light, despite these cells being bathed by a background of white light (the spectrum of which contains a red component of approximately the same power). Karu (1988 and 1989a) feels that clinicians have forgotten that medicinal curing with red light was used even in ancient times and that such therapy has now been rediscovered with laser. She believes that the observed effects of lasers, attributed in the early days of laser (and even now) to the unique quality of coherence, have no physical grounds because both coherent and non-coherent red light have been found to be equally effective clinically. It is postulated that the laser properties of collimation and coherence are negligible in photostimulation. The only requirement for biostimulation with light is monochromaticity.

However, Mester et al (1985) have also compared the effects of monochromatic polarised (and non-polarised normal) light with laser light. They found that the effect of non-coherent light was only 74 to 80 per cent as efficient as laser light. Berki et al (1988) found that monochromatic, non-coherent light had no effect on phagocyte activity and immunoglobulin secretion, whereas laser at the same wavelength and energy output did affect these functions. Why does this discrepancy exist? Obviously, much work still needs to be done to clarify this aspect of low level laser therapy.

Wavelength

If collimation and coherence are not essential, what is it that makes wavelength so important?

Wavelength partly determines the penetration depth of laser. Visible light is more readily absorbed than infrared wavelengths (El Sayed and Dyson 1990, Wright et al 1990) but due to refraction, reflection and back-scatter, the different wavelengths are difficult to localise to specific areas within irradiated tissue (Anderson and Parrish, 1981).

Pigment-specificity can affect penetration and absorption. Because they are highly pigment-specific, it is generally accepted that short wavelengths (eg helium-neon, 632.8nm) of LLLT will achieve only superficial penetration into soft tissue. Visible light laser of short wavelength (between 400nm and 700nm) is highly absorbed by melanin, haemoglobin and myoglobin (Wilson and Jacques 1990).

Infrared wavelengths have little pigment-specificity and the prime absorbing media are proteins and water (Ohshiro and Calderhead 1988, Wilson and Jacques 1990). It is believed that peak tissue penetration occurs in the near-infrared range between wavelengths of 700nm to 1200nm. There is evidence that, due to extremely low water absorption, there may be an optimal penetration window occurring between the wavelengths of 820nm and 840nm (Kubota and Ohshiro 1989). The concept of penetration and absorption of laser light is dealt with in more detail in the accompanying review of factors affecting low level laser therapy (Laakso et al, 1993).

What wavelengths will stimulate particular responses in tissues? This has not yet been conclusively determined. Researchers have not investigated all possible wavelengths and, in most instances, choice of wavelength has been influenced by the equipment available. Indeed, it would not be feasible to investigate all possible wavelengths.

Karu, over a period of years (1987, 1988, 1989a and 1989b), has conducted extensive research regarding wavelength specificity. Review of her work carried out mainly on cell cultures, illustrates the diversity of results which have been achieved. Karu has found that it is possible for individual bands of the spectrum to be antagonistic, eg blue and red, and ultraviolet and red. That is,when irradiation with these respective wavelengths is spatially or temporally sequenced, the effects may cancel each other by either stimulation or inhibition (Karu 1989b). Similarly, irradiation with light of one and the same wavelength can stimulate or inhibit functioning of the respiratory electron transport chain, which is the vital link in the photobiological response. Also, individual components of the solar spectrum may act very differently from total white light and photosensitivity to various visible light wavelengths can occur at the level of the whole organism as well as at the cellular level.

More specifically, Karu (1989b) has examined the effect of near-IR light at 890nm and blue light at 404nm on the growth of Escherischia coli and found no difference in effect. Similarly, when comparing the effects of blue (404nm), green (near 560nm), red (near 620nm) and far red (near 700nm and 760nm) light on cell growth, the effects were no different.

In work studying the effect of the red and green regions of the electromagnetic spectrum on DNA synthesis (Karu 1989b), the maximum effect occurred at 610nm and 630nm. RNA synthesis was found to be stimulated more using 578nm light, whereas it was scarcely affected with 633nm light.

Karu's work is best summarised in her words: "... it is possible to conclude that irradiation with monochromatic visible light in the blue, red and far red regions can enhance metabolic

processes in the cell. The photobiological effects of stimulation depend on the wavelengths, dose and intensity of the light." (Karu 1989a, p.692).

Other workers have also investigated the effect of varying wavelengths on cell functions. El Sayed and Dyson (1990) compared a number of different wavelengths and their effects on mast cell number and degranulation. They found that 660nm, 820nm, 940nm and 950nm wavelength emitters (superluminous diodes) produced statistically significant increases in both of these parameters in partial thickness wounds in rats. In comparing these same wavelengths over intact skin, mast cell numbers increased but degranulation was unchanged. No effect was observed when using wavelengths of 870nm and 880nm.

Lam et al (1986) observed that both 632.8nm (helium-neon) and 904nm (gallium-arsenide) laser enhanced procollagen production in human skin fibroblast cultures by approximately four-fold on average. Young et al (1989) found that 660nm, 820nm and 870nm light stimulated fibroblast proliferation above control levels. They also found that 880nm-wavelength light caused inhibition of these factors.

Such disparate results are quite typical and representative of the work reported in the field of low level laser therapy. It may be best to summarise the research investigating wavelength-specificity by suggesting that incoherent red light is the most cost-effective and technically the simplest light for general use in the spectral range between 600nm and 850nm (Karu 1989b). This means that clinicians would be served equally as well by monochromatic or near-monochromatic light, as they would be by a true laser of an equivalent wavelength.

Types of laser

In considering the above evidence, the physiotherapist is led to ask which of the currently available laser units will give the clinician optimal results, with minimal financial outlay.

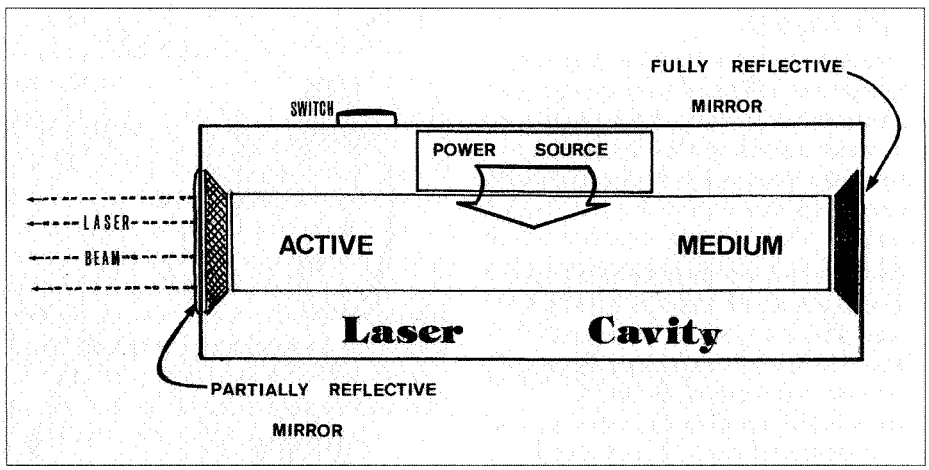

Figure 1.
Essential components of a conventional laser.

Conventional laser

Helium-neon laser is an example of this type of laser. Few current-day physiotherapy lasers are of the conventional type. Conventional lasers require some essential components ie an active medium, power source and a cavity with fully and partially reflective mirrors at each end of the cavity (Figure 1) (Kert and Rose 1989). The laser is activated by stimulation of the active medium by the power source. The active medium determines the wavelength of the laser. Laser produced in this way is a very pure, monochromatic, highly collimated and coherent beam of light.

The beam from a conventional laser is emitted in a continuous fashion unless a mechanism is used to interrupt it (Bourgelais and Itzkan 1983, Kert and Rose 1989, Ohshiro and Calderhead 1988). Continuous wave laser can be interrupted or pulsed by means of a shutter. Resultant irregularity of pulses is corrected by a technique termed Q-switching, a feature generally not employed in physiotherapy lasers.

Laser light will diverge minimally despite its temporal and spatial coherence (Bourgelais and Itzkan 1983). Divergence can be reduced with lenses so that the beam may provide its highest attainable energy density. The beam cross-section can be circular, rectangular or square.

Conventional laser systems require precision in design and production. The ultimate cost to the user is high because construction time is protracted. A conventional laser has a life of between 20,000 and 50,000 hours and limited repair options depending on its configuration. Conventional lasers vary greatly in price but in general are more expensive than other types of low power lasers. If a monochromatic or near-monochromatic light source is all that is required to provide effective photostimulation, it is difficult to justify the purchase of an expensive conventional laser unit. Is there an alternative?

Semiconductor diode lasers

Semiconductor diode lasers have become more compact and arguably more efficient alternatives in the application of laser light. Semiconductor laser diodes are most commonly seen in the therapeutic lasers used in physiotherapy. The diode of the laser, embedded in the tip of the laser probe, contains a minute crystal chip (less than 1mm^2 in size) made up of alternating layers of active and inactive substances, eg gallium, aluminium, phosphides and arsenide. When electrically excited, the facets between the layers of the chip are activated and laser light is emitted (Philips 1988, Figure 2).

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The beam of a diode laser is conical in shape and elliptical in cross-section and may diverge up to 20 degrees (Wheeler and Slater 1990). Diode lasers may have integrated optics which produce collimated and focused light beams.

Laser diodes are considered to have a life-expectancy of 100,000 to 600,000 hours (Philips 1988, Wheeler and Slater 1990) and can be made in a range of wavelengths, although generally the wavelength is not as pure as conventional laser. The spectral bandwidth is usually narrow (Kolari 1985), perhaps 5nm-10nm either side of the quoted wavelength. Unlike helium-neon lasers, semiconductor laser diodes do not require a high voltage supply and so can be used in portable, battery-operated devices. It is also possible to pulse the light at various frequencies depending on the crystal chip and the electronics of the unit.

Electrically, the laser diode is a very reliable but sensitive device and should be handled with as much care as the soundhead of an ultrasound unit. Savings made in assembly and replacement costs (diodes cost less than $200) make diode lasers a potentially more cost-effective alternative to conventional laser units.

Monochromatic light emitting diodes

Some so-called laser devices may be marketed with monochromatic light emitting diodes (LEDs). Good quality, monochromatic LEDs are sometimes termed superluminous diodes or photodiodes. Such diodes have a spectral bandwidth of wavelength usually less than 15nm (that is, near-monochromatic), with an angle of divergence similar to semiconductor laser diodes. Poorer quality LEDs may have a spectral bandwidth of more than 50nm and beam angle of divergence of more than 30 degrees. Light emitting diodes do not have collimation and coherence as properties and some form of optics may be used to focus the beam. Ordinary LEDs can cost less than ten dollars.

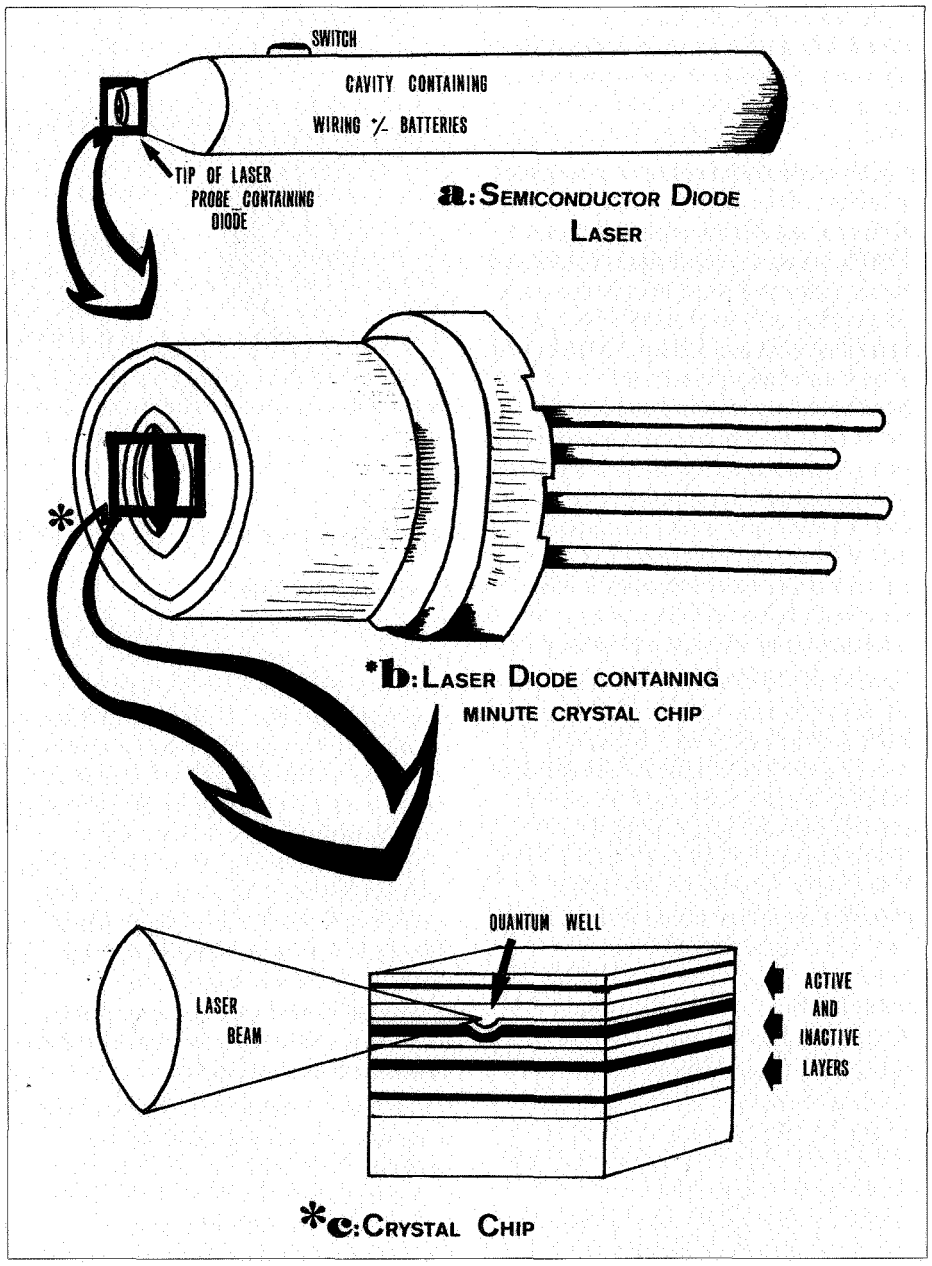

Figure 2.
Semiconductor diode laser probe, showing:
a) laser housing, with diode embedded in probe tip
b) enlargement of a laser diode
c) crystal chip with laser beam emission from quantum well.

Karu (1989b) has emphasised the fact that monochromatic light is necessary for photostimulation but that a broad spectral band (between 50nm and 150nm ie, near-monochromatic light) is sufficient for gaining desirable results. If monochromaticity is accepted as the only laser property necessary for photostimulation, then, from a cost-effective point of view, the clinician should choose a unit with a near-monochromatic LED. This would necessitate a change in terminology because the light emitted from such a diode would no longer be true laser light. It would also

necessitate a change in the philosophy of both the manufacturer and the clinician. If clinicians demand the less expensive, near-monochromatic diode unit, potentially capable of achieving an effective physiological response similar to that obtained by a more expensive diode laser or conventional laser, the manufacturer should respond to the demand. Justification of the demand would require more objective, scientific evidence to confirm or refute the argument that true laser is not necessary in stimulating biological processes.

Diode authenticity

It is not always possible to tell by looking at a laser whether it utilises a true laser diode or an LED with integrated optics. Some simple tests may help determine the type of diode contained in a laser.

If the laser is of a visible wavelength, by pointing the beam at a plain, pale-coloured wall, it is possible to observe if the light has speckle (Rubinztein-Dunlop 1991). This phenomenon is indicative of true laser light. It shows as a spot of light, almost sparkling in character, with high and low modes or points of brilliance. A simple LED does not exhibit this characteristic.

If the laser is infrared, or invisible, an infrared viewer or infrared phosphor card (capable of discriminating for the wavelength of laser being tested) may allow determination of the speckle characteristic. If there is any doubt about the output of the laser, the manufacturer should be consulted. Further assistance may be sought from a laser testing facility, where the beam profile can be examined via a monochromator. This will determine if the diode is a true laser diode or a simple LED.

These tests may also help to determine if there has been any damage to the diode. A fractured visible laser diode may behave in the manner of an ordinary LED. A broken infrared laser diode may not emit any light at all.

It is appropriate to ask if clinicians should go to these lengths to determine the type of diode incorporated in a laser unit. Would it not be simpler to demand from the manufacturer or supplier, a mandatory indication on all diode laser apparatus of the type of diode incorporated in the device? This would not only avoid unnecessary expense but may also help to explain why there are such conflicting results in clinical and laboratory studies of laser. The effectiveness of this modality cannot be determined until quality and quantity of laser treatment is standardised in a similar way to other light therapy such as ultraviolet light therapy. The development of standards for therapeutic laser would facilitate the comparison of results of laser research.

Discussion

In general, the research to date is preliminary and more work is required to satisfy the hypothesis that true laser (that is, coherent, collimated and monochromatic light) is not necessary to stimulate biological processes and that the only requirement is a monochromatic or near-monochromatic source of light. Further research should investigate whether laser as an entity can be conveniently replaced by non-coherent, non-collimated, monochromatic or near-monochromatic light which could be supplied by relatively inexpensive, non-laser, monochromatic or near-monochromatic diodes.

When discussing the research which has investigated wavelength-specificity, it should be understood that any conclusions are qualified by the uncertainty of many factors. Much of the research has been carried out on cell cultures. Cell culture media are artificial when compared with cell communities in the living organism. It is open to question whether results gained in vitro can be reasonably used to extrapolate potential effects when using laser in vivo. In addition, doses used in previous research have varied as widely as the wavelengths studied. Attempting to make relevant comparisons among much of the research is difficult when these parameters differ from one experiment to the next.

Because true laser light may not be necessary to elicit photobiostimulation, the clinician must proceed cautiously when choosing a laser unit or when considering laser as a treatment. It might be argued that laser apparatus, at best, provides a more compact and convenient way to apply light, and the resultant photostimulation, than other means.

Conclusion

This review has introduced the issue of light quality, and the case of laser-specificity versus wavelength-specificity in producing effective photobiostimulation of cells. Whether the effects gained by laser could be obtained as easily by cheaper (near-monochromatic) light emitting sources is yet to be fully established. The weight of research evidence to date indicates that there are few convincing arguments for the use of true laser. Photostimulation occurs using both true laser light and near-monochromatic but non-coherent, non-collimated light. On this basis, it seems unnecessary for the clinician to spend large sums of money on laser apparatus when simpler and inexpensive light sources may suffice. The issue of which wavelengths in the electromagnetic spectrum are most likely to result in therapeutically optimal biostimulation remains unresolved and further work is necessary to clarify this.

The lack of firm evidence in the literature to date should warn the clinician not to accept blindly any hyperbole from the manufacturer or sales representative. Zusman (1991) alerts the physiotherapist to the possibility of opportunism by both the laser manufacturer and clinicians using laser. It is timely to renew healthy scepticism when assessing the need for purchase of a laser unit.

Understanding how laser units are designed and manufactured may help avoid the problems associated with the variable responses observed when applying LLLT. The effectiveness of

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this modality cannot be determined until quality and quantity of laser treatment is standardised. Once standardisation of both apparatus and treatment parameters has been achieved, uniformity of results can be obtained.

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