Image provided courtesy of Dr R. Glen Calderhead

LOW LEVEL LIGHT THERAPY WITH LIGHT-EMITTING DIODES

Dr R. Glen Calderhead MSc PhD asks is it hype or is there hope?

As their name suggests, light-emitting diodes (LEDs) emit light... but what actually is 'light'?

Light is an energy form without which we would all quickly die: you could say that "Light is Life". A familiar light source is the sun and the energy that we call sunlight propagates from the sun in straight lines through space at unimaginably high speeds: approximately 300,000 kilometres per second (km/s), or for those still thinking in miles, 186,000 miles per second (m/s).

From London to Glasgow as the crow flies is approximately 560 km. Flying there in a passenger jet takes about 50 minutes from take-off to landing. If we could cover this at the speed of light it would take under 2 milliseconds (ms), literally shorter than the blink of an eye.

So, before talking about light-emitting diodes (LEDs) and their clinical applications in phototherapy, let's look briefly at some of the basic science which will help our understanding of the phenomenon we call light, and how it can be harnessed in medicine to rejuvenate skin, heal wounds and alleviate pain.

Nihil sub sole novum: "There is nothing new under the sun"

The use of light in medicine is by no means as recent as you might think. The Ancient Egyptians over 4,000 years ago were using sunlight together with the application of a crushed parsley-like herb on depigmented skin to repigment it. In the First Millennium BC, the Ancient Greeks in the person of Hippocrates, the 'Father of Medicine', credited sunlight with the happy nature of the Greek natives versus the glum northern sun-starved barbarians, and prescribed sunbathing as a cure for depression.

In slightly more modern times, physicians in the 18th Century followed Hippocratic teaching by treating "Melancholia" with red light therapy through shutting patients in large-windowed rooms with thin red curtains (only on sunny days!). One famous patient was "Mad" King George III of Great Britain and Ireland. Perhaps he was driven mad, or even madder, because he suffered from porphyria which is associated with extreme photosensitivity. From the very early 20th Century, surgical tuberculosis was treated by sending patients to "sanitaria", special hospitals which were situated where the air was clearest and sunlight plentiful such as in the Swiss mountains. Perhaps there were not so many of these in the UK!

The use of the medicinal and beneficial properties of natural sunlight was classically termed heliotherapy (from the Greek Helios, the Sun God), but when artificial light sources were developed at the turn of the last century such as Finsen's arc lamp, the first artificial light source to replace the sun, the term phototherapy was gradually adopted. In modern times, from the 1950s through to the present, blue light phototherapy has been routinely given for the treatment of jaundiced newborns.

The first stumbling attempts to develop LEDs also took place in the 1950s: Holonyak, the 'Father of the LED' announced the first practical red light LED in 1962: finally there *was* something new under the sun. However, as you will hear, it took over another three decades before an LED was finally made available which was appropriate as a phototherapeutic light source.

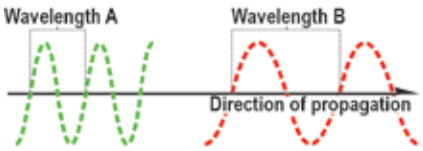

Fig 1. Schematic showing two wavelengths, and how wavelength is measured.

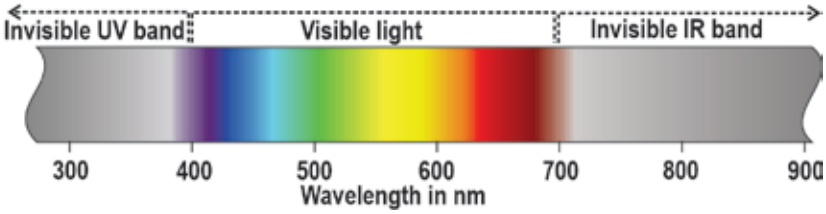

Fig 2. Illustration showing part of the broad light spectrum from invisible ultraviolet (UV), through visible light, to the invisible near-infrared (IR) wavebands with the corresponding wavelengths. Note that only a small portion of the UV and IR bands is shown.

Wavelength

As noted already, light propagates in straight lines, but it does so in the form of a stream of photons or quanta, tiny packets of energy without weight, which travel in a sinusoidal waveform (see the illustration in Fig 1).

Measuring one complete cycle gives us the wavelength of the light, which is expressed in nanometres (nm), one billionth of a metre (1 nm = 1 × 10-9 m). The wavelength of a beam of light will tell us if the light is visible or invisible to the human eye, and if it is visible, the wavelength will determine the colour we see the light as.

The illustration in Fig 2 shows the spectrum of light from part of the invisible ultraviolet (UV) through the familiar colours of the rainbow of visible light from violet to deep red, and into part of the invisible near-infrared (IR) waveband.

For therapeutic indications, wavelength is critical, because it determines not only the specific target in the tissue but also the intrinsic depth of penetration into that tissue.

Light-target interactions

Light energy interacts with targets, such as the skin, in many ways, with reflection, transmission/penetration, scatter and absorption liable to occur.

Light can be reflected off a target, like a mirror, or in the case of the skin, the outer layer of the epidermis, the stratum corneum (a in the Fig 3).

Light can be transmitted through or penetrate into the target, like light through clear glass. In the case of the skin, light can penetrate down into the skin through the epidermis to different depths in the dermis and beyond, depending on the wavelength (b in Fig 3). In general, longer wavelengths will penetrate deeper than shorter ones.

If the target is inhomogeneous, like translucent glass, the light will penetrate, but it is scattered around by the particles making up the glass so cannot be perfectly transmitted.

Our skin is composed of many different substances and particles with different optical properties, so light scatters well: light scatter in skin occurs forwards, laterally and even backwards (c in Fig 3). The longer the wavelength, the more scattering occurs.

Finally, light can be absorbed in the target, so that all the energy in the incident photons is transferred to the target (d in Fig 3).

All of these reactions occur simultaneously when tissue is targeted with light, but the most important reaction in the use of light in medicine is absorption, because without absorption there can be no reaction.

Longer wavelengths of light penetrate deeper than shorter ones.

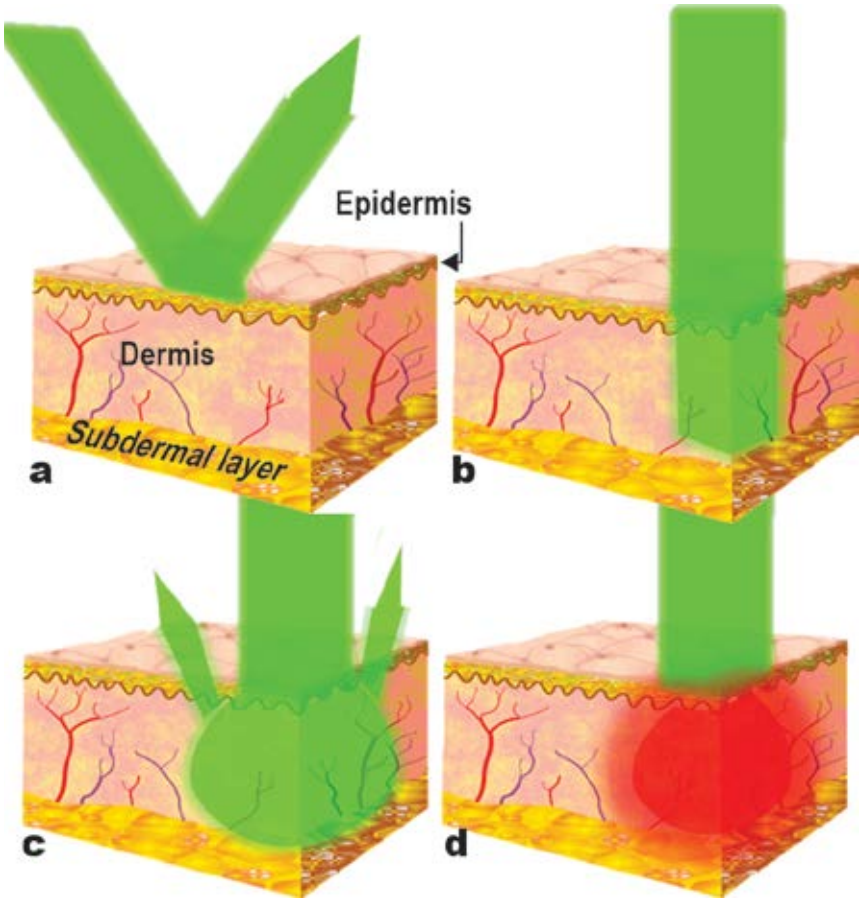

Fig 3. Light-tissue interactions illustrated

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Here (Fig 4) is an example of the author's finger being irradiated with green (left panel) and red (right panel) laser pointers. The green light cannot penetrate deeply into the finger with minimal scatter even though the pointer is towards the edge of the fingertip and not the centre, because green light has blood and melanin as its main targets so all of the light is absorbed in these elements and thus penetration is extremely limited.

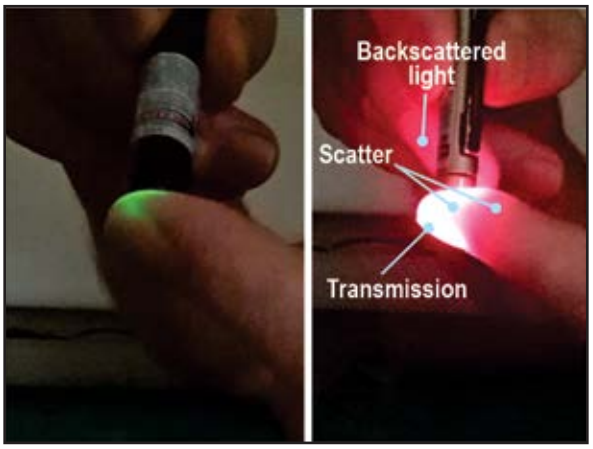

Fig 4. Poor penetration through a finger with green light compared with excellent penetration and scatter with red light from laser pointers.

On the contrary, the red light penetrates through the finger, exiting through the fingernail and transilluminating the entire fingertip. This simple example illustrates very well penetration, transmission and scatter, including back-scatter. Critics of light therapy often discount its efficacy by claiming that light does not penetrate beyond the first few millimetres of tissue: as you can see from the example using a very low-powered (<3 mW) laser pointer, red light penetrates very deeply into tissue, but near-infrared light penetrates even better. This is the reason why wavelength is a crucial consideration for phototherapy with LEDs.

Genesis of Low Level Laser Therapy (LLLT)

The term "low level laser therapy" with the acronym LLLT was first coined by Calderhead, and published in 1988 in the first book on the subject, "*Low Level Laser Therapy, a Practical Introduction*" by Toshio Ohshiro and R Glen Calderhead (John Wiley & Sons, Chichester, UK). After playing with many wavelengths, the authors had found that low incident levels of light energy at the wavelength of 830 nm in the near-infrared waveband had outstanding properties in pain attenuation, and subsequently, wound healing.

Ohshiro, together with Matsushita Electric (National Panasonic), designed and developed a laser-diode based phototherapy system emitting 60 mW in continuous wave at 830 nm that is still being used extensively throughout Japan and South-East Asia today.

Since then a large body of published evidence has accumulated on the safety and efficacy of 830 nm LLLT for a large range of indications including, but not limited to the following: enhanced and accelerated wound healing of acute or chronic, traumatic or surgical wounds including non-healing ulcers; pain attenuation in acute and chronic pain of all aetiologies including musculoskeletal and neurogenic pain; treatment of arthroses, neuralgias and causalgias; treatment of bacterial and viral infections; and interesting work on LLLT for post-stroke and severe cranial trauma.

There are still the nay-sayers and flat-earthers who refuse to accept the scientific validity of LLLT ("*I don't understand it, therefore it doesn't work*"), but if these people search on *PubMed*, which only indexes accepted and published peer-reviewed papers, the search term "LLLT" will produce over 6,000 hits! A very, very few of these papers may have reported negative results, but the overwhelming majority are extremely positive, as are all of the meta-analyses that have appeared on LLLT, such as those from Harvard Medical School and others. Even the negative results are valuable, however, (provided the study protocols are correct) because they can show us what doesn't work.

How does LLLT work?

Before proceeding any further, perhaps an explanation of how LLLT works would be a good thing! There are entire chapters, or even entire books, examining this question.

To keep it as simple as possible, LLLT involves an athermal and atraumatic energy exchange between the incident photons at low irradiancies (power densities) and the cells or targets that absorb them. You will remember that each photon has its own discrete energy package. On photon absorption by a cell, that energy is added to the cellular energy pool, thereby raising the activity of the cell beyond its normal level. Several things can happen to photoactivated cells.

- If cells or tissues are damaged or somehow compromised, they will be repaired, either by themselves or with a little help from their friends. Traumatic or surgical wounds are an example of damaged cells, and skin cells in photoaged skin are compromised through both intrinsic and extrinsic factors, especially UV-related oxidative stress.
- If the cells are functional, i.e., if they have a job to do, they will work more efficiently and faster. An example would be fibroblasts to make new collagen and elastin, replenish the ground substance and maintain the homeostasis of the extracellular matrix.
- If there are not enough cells to do the job properly then they will either proliferate, or more cells will be recruited in to do the job. An example would be photodegranulation of mast cells in a wound or treated area to call in more macrophages and neutrophils through chemotaxis (cell motility dependent on chemical signalling), accelerate the inflammatory stage and lay down powerful trophic and antioxidant factors.

These events can happen singly or together, with the result achieving a valid clinical effect but without heat or damage, as long as the level of excited activity is kept below the damage threshold. Above that, photothermal activity occurs and the cell is damaged, but still alive. Even more light energy absorbed in the cell will take the reaction above the survival threshold, and create enough heat to cook the cell or blow it to pieces.

The accompanying illustration (Fig 5) shows the difference between athermal and atraumatic LLLT and photothermally-mediated reactions as

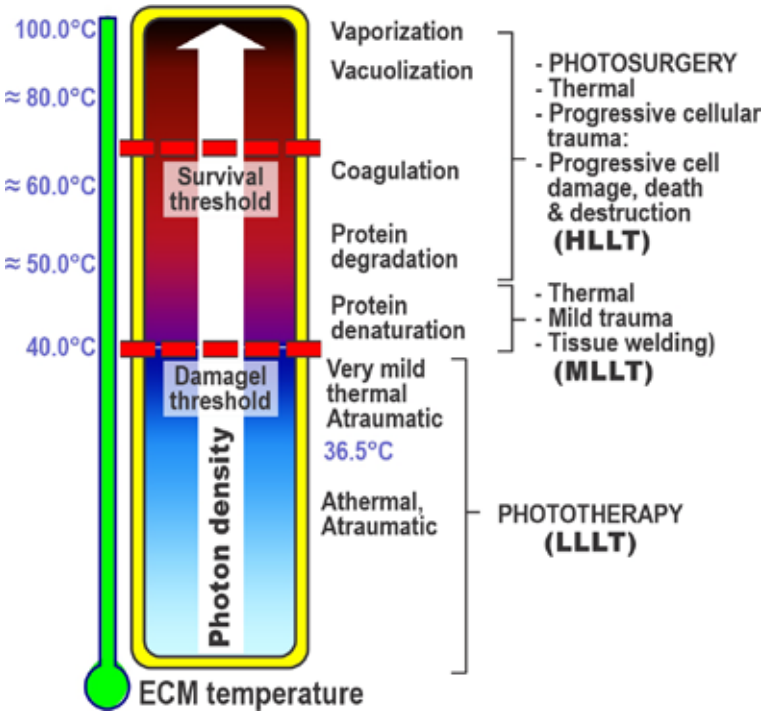

Fig 5. Diagrammatic representation of a cell showing its damage and survival thresholds. True LLLT occurs in the area below the damage threshold.

in photosurgery, vs phototherapy.

Almost always, more than one LLLT treatment will be required. This is especially true for the more chronic wounds or pain, where the affected tissues are badly to severely compromised. The standard protocol for wound healing evolved as a treatment as soon as possible after the (traumatic or surgical) wound, 24 hr, 72 hr post wound and then twice weekly for 1 – 3 weeks depending on the severity of the wound. The weekly treatments should be two days apart. This is to allow the photoactivated cells to start to work efficiently before 'hitting' them again.

Photorejuvenation requires two treatments a week (2 days apart) for four weeks, and then follow up over the next 8 weeks together with a good daily moisturising and sunscreen programme. For acute pain, it is possible to treat three days in a row and then go to the twice-weekly protocol. Whatever is being treated, the patient must be educated to be … patient. LLLT is not a magic wand, but it has been proven to work and works very well.

The author's recommended optimum wavelength is 830 nm in the near-infrared for the reasons which will be explained hereafter, but 633 nm will also work reasonably well.

Enter the Light-Emitting Diode, and Low Level LIGHT Therapy

Everyone knows what light-emitting diodes (LEDs) are… they are arranged in clusters as super-bright traffic signals, as tail-light clusters in cars, twinkling cheerily on Christmas trees or as highly visible indicator lights on pieces of electronic equipment. LED technology has been around for several decades: It was mentioned earlier that the first practical LED was showcased in 1962, but that it took some 36 years before an LED was available which was clinically appropriate. In fact, it was only in the past two decades that LEDs have come into their own as light sources capable of having a viable clinical effect in the field of phototherapy (as distinct to photosurgery). Before this 2-decade watershed, LEDs were bright, cheap and cheerful, but they had low and unstable output powers, a wide angle of divergence and, particularly, very broadband spectral output. One could find an infrared LED with a wide waveband of around 100 nm (e.g., 800~900 nm), but not an 830 nm wavelength LED.

This changed in 1998 with the

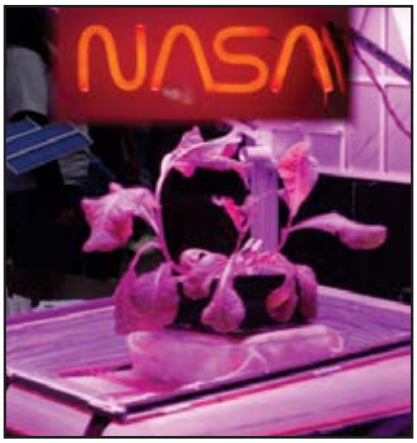

Fig 6. Demonstration of LEDs being used in a hydroponic unit to assess growing plants in space.

development of the so-called "NASA LED" by Prof Harry Whelan and his team in the NASA Space Medicine Laboratory based in Houston, Texas (Fig 6). This new generation LED was many orders of magnitude more powerful than even the most powerful of the previous generation, had a narrower angle of divergence with stable and consistent output powers, but most importantly it was quasimonochromatic, i.e., *almost* all one wavelength like a laser is, delivering more than 98% of the emitted photons at the rated wavelength: this meant that we could now have an LED that was most certainly clinically useful and capable of targeting wavelength-specific cells, with almost laser-like precision. Whelan's group's first LEDs were designed to stimulate plant growth in the International Space Station using hydroponic beds to feed astronauts, but wavelengths suitable for phototherapy in human subjects came along very soon. The first clinical application was reported in 1999 by Whelan and colleagues who showed that near-IR LEDs at 830 nm could heal wounds in an animal model in a much shorter time compared to control wounds. Now there was something even newer under the sun.

The first generation of dedicated LED-based phototherapeutic systems appeared in 2000 with a 633 nm (visible red) system specifically designed for photodynamic therapy (PDT) for non-melanoma skin cancers (NMSCs), such as squamous cell carcinomas, Bowen's disease and actinic keratoses. In PDT, a photosensitiser such as aminolaevulinic acid (5-ALA) is applied topically to the target area and allowed to sink into the skin and incubate, where

Images provided courtesy of Dr R. Glen Calderhead

it preferentially localises in mitotic tissue such as cancers or precancerous lesions and porphyrin formation is induced through the natural reaction with the body's haeme cycle. The target tissue is then irradiated with light of a specific wavelength, usually red around 633 nm because of its deeper penetrating powers. The 633 nm wavelength is at one of the minor peaks in the porphyrin action spectrum, and the light activates the porphyrins created in the skin by the 5-ALA (protoporphyrin IX and coproporphyrin III) during the incubation period. The photoactivated porphyrins then react with triplet oxygen (O_3) which is plentiful in the body and break it down into normal oxygen and singlet oxygen ($^1O_2$). The latter is a powerful free-radical which acts specifically on the target cells to kill them through oxidative stress-related apoptosis, and the target lesion is destroyed with minimal damage to surrounding normal skin cells. Note that PDT is not classed as LLLT, because although it is athermal it is not atraumatic, creating deliberate damage.

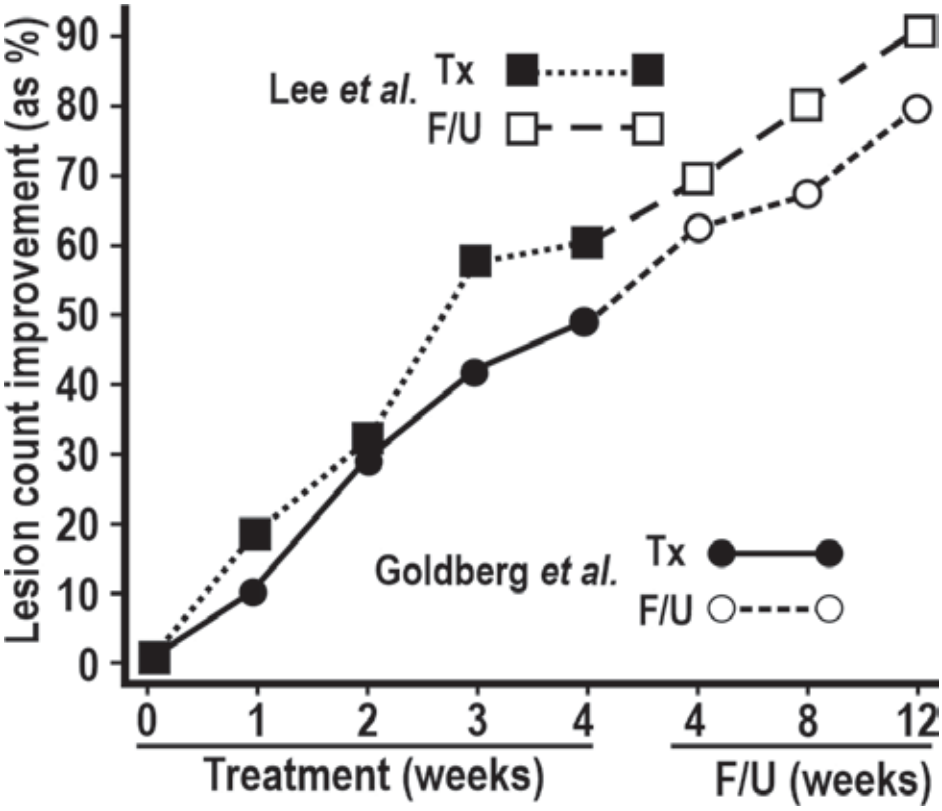

Fig 7. Clearance rate of inflammatory acne lesions for the Goldberg and Lee groups following LED-only phototherapy. Note the significant continued improvement beyond the 4-week treatment period.

Earlier kinds of PDT light sources delivered a very small beam of red light which irradiated only the target tumour or lesion. The new LED-based PDT system had planar arrays of LEDs which could irradiate all of the tissue around the lesion, including the lesion itself, in a hands-free manner. The results were consistent and excellent, but one added advantage was that patients who had facial lesions treated (which was most of them) not only had excellent cure of their lesions, but also reported that their overall skin condition had noticeably improved.

The manufacturers caught on to this and very quickly designed a larger and more powerful 633 nm LED system which was dedicated to skin rejuvenation. This was the true beginning of the use of LED photorejuvenation for the ageing face based on excellent science, and the results were very good.

A blue head was also developed with 415 nm LEDs, which was used with the 633 nm head consecutively for light-only treatment of acne. One treatment each of first blue and then red LED therapy was given per week, 2 days apart, over a 4-week period, followed by an 8-12 week evaluation follow-up. The results were surprisingly good, as shown in two published papers in the peer-reviewed literature, one from a US group and one from a South Korean group (*Goldberg DG et al, 2004, J Cos Laser Ther; Lee SY et al, 2005; Laser Surg Med*). At the end of the 4 weeks, an average clearance of between 50% and 60% of inflamed lesions was seen, but what surprised and delighted both the researchers and patients was a steady continuous improvement in clearance to the end of the 12-week follow-up assessment, as illustrated here (Fig 7). The graph suggests that the results from the Lee group showed a faster improvement than those of the Goldberg group, but although both studies had approximately the same number of subjects, those in the Lee group had significantly more severe acne based on the Burton acne grading used in the studies.

These findings might suggest that the more severe the acne is, the faster the improvement might occur with LED phototherapy. Taking the results of these studies together with others that followed, it was shown that around 85% clearance of inflammatory acne lesions could be achieved in an average of 87% of patients by the end of the follow-up period with this light-only approach. It must be said that LED phototherapy does not work for every acne patient, but then neither does isotretinoin, furthermore, there are no horrible side effects with LED phototherapy and almost every acne patient sees at least some improvement. The results have been consistent and robust, with very few break-outs seen in the 12-week post-treatment period. When break-outs do occur, top-up sessions can be easily given using the same alternating protocol, but with a shorter overall treatment course from 1 week for minor break-outs and upwards, depending on the severity of the breakout.

It is important to note that, when these studies were done, the 830 nm head was not available.

In current phototherapy protocols for acne, the 633 nm treatment has been replaced with the 830 nm wavelength, and the results have proved even better.

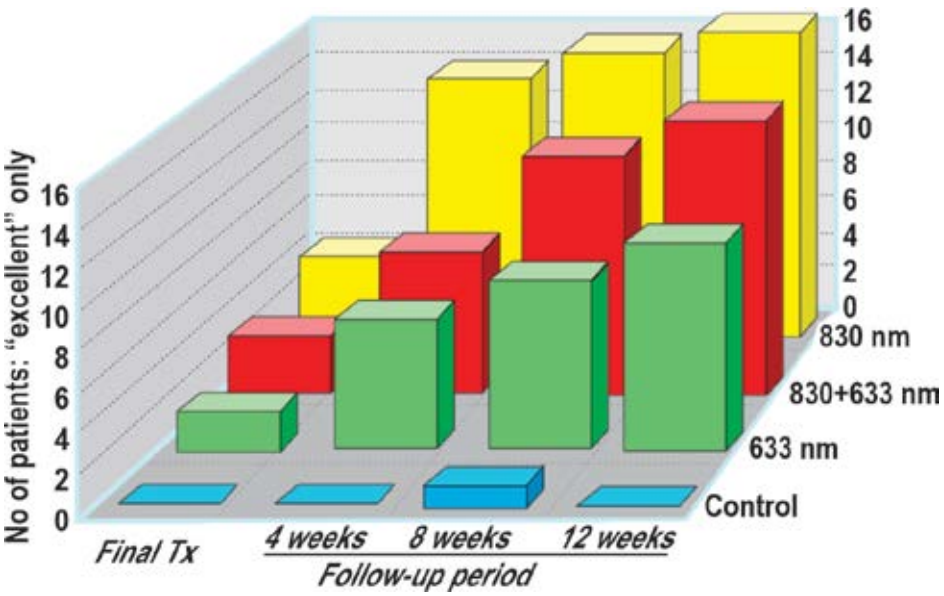

Fig 8. Results from the Lee LED photorejuvenation study during the 12-week follow-up period for patients scoring "excellent' satisfaction. Despite no further treatment of any kind, continued improvement was seen, most evident in the 830 nm group

The rise of 830 nm LED-based LLLT

In the very early 2000s there was no 830 nm head from any system on the market, but one LED phototherapy system manufacturer was persuaded by Dr R Glen Calderhead (who was by then their Medical Director) to make one, which appeared on the market in late 2004, based on Calderhead's decades-long experience with successful laser diode (LD)-based LLLT at 830 nm. Calderhead believed that 830 nm LED-LLLT could offer a major advantage over LD-LLLT. The latter is manually delivered in a punctal manner, over a very small area per point with several irradiated points. In addition, it cannot be delivered in contact mode on open wounds of any kind. LED-based systems, on the other hand, deliver their energy in a noncontact, hands-free manner over a large area of tissue including open wounds, thus offering advantages in both the treatment effect and lessening of the operator-related fatigue.

The 830 nm head quickly proved superior to the 633 nm head, or even the combination of the 830 nm with the 633 nm head. By 2005 the reports on the efficacy of LEDs as an LLLT source were building up, and so Prof Kendric C Smith, one of the USA's leading photobiologists, wrote in the journal *Photomedicine and Laser Surgery* in 2005 that low level laser therapy should become low level **LIGHT** therapy (same acronym of LLLT), as the LED approach was well-proven to be safe and effective. Thus we see the term LED-LLLT in use today, alongside other terms such as photobiomodulation (PBM). Photobiomodulation is the official MEsH (Medical Subject Headings) term from the American National Library of Medicine. The author, however, prefers to use his term LLLT as descriptive of the viable clinical effect achieved in tissue following PBM at the target cell level.

A pivotal LED-LLLT paper was published in 2007 in the *Journal of Photochemistry and Photobiology B* on LED skin rejuvenation by Celine SY Lee and colleagues (*Lee SY et al, 2007, J Photochem Photobiol B*). This paper makes essential reading for anyone who doubts that LED-LLLT works to produce new collagen and elastin and shows that skin rejuvenation is based on wound healing.

In four separate groups of patients she compared 830 nm LEDs on their own, 830 nm followed consecutively with 633 nm LEDs, and 633 nm LEDs on their own, compared with a sham-irradiated control arm. In fact, the paper really evaluated the wound healing processes underpinning rejuvenation, and showed that with 830 nm > 830 + 633 nm > 633 nm there was better collagen and elastin deposition demonstrated through histology; better rejuvenation of fibroblasts and improved type I collagen fibre diameter deposition as shown ultrastructurally with transmission electron microscopy; superior elasticity of the skin as measured objectively by a cutometer; and significantly better patient satisfaction at the 'excellent' level for the 830 nm head compared with the 633 on its own the 830-633 nm combination and the sham-irradiated controls. Of special note was that both the measured elasticity and patient satisfaction had certainly improved by the end of the 4-week treatment period, but surprisingly continued to improve quite dramatically without any further topical treatment like creams or sera over the following 12 weeks (Fig 8). The study clearly proved that LED-LLLT had started the wound-healing process, culminating in improved remodelling and better tissue rejuvenation, but without heat or damage.

LED masks

A word needs to be said here about the proliferation of a large number of LED-based mask-type applicators on the market for home use in facial rejuvenation, of which no doubt the reader is aware. If the wavelength of the LEDs in the mask is appropriate, e.g., near-infrared or visible red, and the bandwidth of the LEDs is narrow enough, then there will definitely be a beneficial effect (*for suggestions regarding other appropriate wavelengths, please take note of the comments in the Conclusions section below*).

Although a good mask will offer some benefit, they will not have the same degree of efficacy or maintained effect as a full rejuvenation treatment regimen with one of the clinical systems. Additionally, for LEDs to achieve their maximum effect, there needs to be some distance between them and the target to allow the phenomenon

Images provided courtesy of Dr R. Glen Calderhead

of photon interference to occur, and this is not the case with the mask-type applicators. Photon interference is an interesting quantum phenomenon unique to noncoherent LEDs whereby a higher near field irradiance can be found at a distance from the LEDs compared to that measured right at the LEDs themselves, and this mandates the ideal treatment distance recommended by manufacturers of the clinical systems which is usually 15-20 cm.

However, in all fairness, it has to be said that mask-type systems are very convenient and can be used for a few minutes daily while relaxing at home. The ideal indication for LED masks could well be as a maintenance programme following a full LED rejuvenation protocol with one of the clinical systems.

When choosing a mask-type LED system, be sure that the manufacturer has given all the specifications, especially the safety profile of the LEDs being used in the mask. One mask was withdrawn from the market by the U.S. FDA because it was inducing "visual disturbance" after long-term use. *Caveat emptor!*

LED-LLLT today

To return to the clinical systems, the next stage in the LED-LLLT story saw a new generation LED-based system launched in 2011 which had all the benefits and solid science of the previous system mentioned above and its imitators, but took over where those devices had left off. System technology has been advanced one stage further with new-generation, more efficient LEDs, much better and user-friendly design, larger treatment heads and some unique technologies which have enhanced photon energy, thereby improving clinical efficacy, and offering a unique wavelength combination which maximised the effect of LED-LLLT in both the epidermis and the dermis.

This new generation of systems can now be found in extensive clinical use worldwide in a range of establishments, from top-line medispas through aesthetic and cosmetic clinics, sports surgery centres, surgical and trauma centres, general and specialist hospitals and plastic surgery centres including breast augmentation. One especially enterprising application has been in the establishment of 'walk-in' salons in major department stores in London and elsewhere in the UK offering a swift cleansing, a very comfortable 830 nm LED-LLLT facial photorejuvenation session and post-therapy facial care. Take a look at **www.thelight-salon.com**. This group has recently exported its concept to the USA.

LED-LLLT, particularly in the near-infrared around 830 nm, has now racked up an impressive number of published basic science and clinical papers: although not a complete list, the following have been covered in the peer-reviewed literature with more being added regularly:

- Significant indications as adjunctive treatment following aesthetic or cosmetic procedures, such as surgery, fractional laser, IPL treatments, thread implantations and so on, to decrease downtime through faster resolution of oedema, erythema and discomfort.
- Wound healing of various aetiologies demonstrating enhanced and accelerated healing compared with controls: this also includes healing of compromised wounds such as diabetic foot vasculogenic and decubitus ulcers.
- Effective pain attenuation in pain of all aetiologies: acute or chronic, musculoskeletal or neurogenic, neuralgias and arthroses.
- Repair and regeneration of bone, including slow-union fractures and osseointegration of implants and prostheses.
- Successful use in severe cerebral trauma and post-stroke cases together with repair and regeneration of damaged nerves.
- Sports medicine indications for sprains, strains and contusions with an athlete return-to-play (RTP) in a controlled study of one-half the historically-anticipated time for RTP.
- Significant prophylaxis against hypertrophic scar formation post-surgery.
- Improved proliferation and extended lifespan of human adipose-derived stem cells both in vitro and following in vivo implantation.
- The powerful systemic effect of LED-LLLT whereby distant wounds to the irradiated area are healed faster than unirradiated controls.
- Vascular insufficiency improved in cases of Raynaud's disease associated with scleroderma, including prophylaxis against further amputation, and in Buerger disease (thromboangiitis obliterans).
- Control of both bacterial and viral infection.
- Control and healing of a variety of dermatoses and other inflammatory skin conditions such as eczema and psoriasis.
- Successful treatment of post-mastectomy lymphoedema.
- Treatment of radionecrosis post radiation therapy for breast cancer.
- Control and alleviation of pain and discomfort of post-chemotherapy oral mucositis.

So, you want to buy an LED-LLLT system?

LED-LLLT definitely works, of that there can be no doubt, and it is here to stay. However, not all LED systems are created equal! When considering an LED system for their practice, the clinician must ask him/herself the following questions:

What is the wavelength, and what is the bandwidth?

Note that the latter should be plus-or-minus a few nanometres. Anything more than ±10 nm is not acceptable for targeting wavelength-specific targets. The established wavelengths are as follows:

- **830 nm** for the vast majority of indications involving any aspect of wound healing, pain attenuation, and skin rejuvenation. Hair regrowth and baldness prevention have been recently added to the list. Variations either way on this near-infrared wavelength are acceptable, but it has been

shown to be the ideal wavelength, and moreover has the greatest penetration through bone. 830 nm is also used sequentially with 415 nm for the treatment of inflammatory acne.

- **633 nm (red)** is ideal as an activator for 5-ALA PDT. It has also some good press for hair restoration. Indeed, 633 nm will also do some of the things that 830 nm can do, but not all, and not as well.

- **415 nm (blue)** is for acne (not ≤410 nm or ≥420 nm because of the steep action spectrum curve of porphyrins endogenous to *Propionibacterium acnes*, which are the only target of the blue light). This wavelength should not be used on its own because it can cause skin darkening, but should be combined with 830 nm as discussed above.

- **590 nm (yellow)** is an interesting wavelength for concentrating on the epidermis, but note that it will not penetrate into the dermis to below the superpapillary layer so offers very little towards dermal renewal. However, because of its high absorption in blood it is also useful for some very superficial vasculogenic conditions, like rosacea. It works well in combination with 830 nm.

- **530 nm (green)** might have some benefit for epidermal pigmented lesions, but it is not proven. Like yellow, note that green will not penetrate much beyond the epidermis and is therefore ineffective for rejuvenation purposes.

By the way, beware of those systems that claim they are "*...driven by NASA technology*": all current LEDs worth their salt are of NASA LED lineage!

Beware also of systems that combine wavelengths simultaneously without some good scientific argument for doing so. Not all colour combinations are effective, and some are known even to retard cellular activity. For example, red and yellow LEDs are often used in combination to give 'orange' light. Although our eyes can see the light as orange, what the skin cells will 'see' are red and yellow photons, and they have different characteristics regarding penetration and chromophore (target). Unless some very good explanation is given for combining colours, stick to one single wavelength. Many home use and so-called clinical systems exist on the market with pretty flashing lights of many alternating colours, and can even play little tunes ... ignore them. You might as well stand in front of your Christmas tree!

What is the irradiance?

Irradiance (also known as power density) gives an idea of the effective photon intensity and is stated in mW/cm². Irradiance is the prime determinant of tissue reaction. Don't confuse the irradiance with the output power in mW. Fairly low mW output can have a high irradiance and vice versa, depending on how the LED energy is gathered and delivered. Reported irradiances vary from 20 mW/cm² upwards, although some may be considerably lower in what is called ultra- or micro-LLLT. If the irradiance is too high into the W/cm² range, however, tissue heating will occur with potential photothermal effects, and this is not true LLLT.

What is the recommended dose?

The dose or fluence is measured in joules per square centimetre (J/cm²) and is the product of the irradiance in W/cm² and the treatment time in seconds. Reported doses range from 2 J/cm² upwards. The main LED-LLLT systems on the market with published papers recommend 60 J/cm² at 830 nm.

What regulatory clearances does the system have?

This means clearances by the regulatory body for medical systems in the country in which the system is being used, such as the FDA in the USA. For the UK the CE mark is currently good, but internal medical physics departments at hospitals, safety officers in clinics or local health authorities may have their own requirements.

What published papers are there?

Be very wary if there are no published papers for the system concerned, apart from those published on the very few systems which have actually made it into the peer-reviewed literature. In fact, these papers are often used by less than scrupulous LED system manufacturers to 'prove' that their system works "because it is the same" as the one used in the referenced paper.

Conclusion

As well as having good science behind it, LED-LLLT has solid intrinsic benefits. It is safe and effective. It is very easy to apply, and can be delivered by a trained therapist or assistant. It is non-laser, noninvasive and nonionising. It is pain-free and side-effect free and can be used to treat pain and side effects. Last but not least, it is very well tolerated by patients of all ages, from infants to centenarians.

With the right LED-LLLT system, you are poised to join the wound healing revolution, and get even better results with happy patients!

To answer the question posed by the title, appropriately applied LED-LLLT offers real hope for both the clinician and their patients, without the hype.


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