BioPhotonic Systems, LLC
PTE-4b
Photobiomodulation Source

User's Guide

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Introduction

The use of light to enhance healing goes back many hundreds of years as humans have noticed the healing power of the sun. In recent time research has been conducted to try to understand the mechanisms of the healing processes.

While it is true that light of many wavelengths useful in healing, only those in a limited wavelength range have the ability to penetrate into our tissue beyond a few microns. Light in the ultraviolet region is useful in generating vitamin D in the skin and radiation in the mid and long wave regions is useful in providing therapeutic heat locally. However both of these processes involve light absorption at the surface of the skin.

There is a region in the spectrum between the red and near infrared region where the light is not absorbed at the surface but penetrates into the flesh. This region starts at about 600 nm where the hemoglobin molecule, which absorbs shorter wavelengths stops absorbing and extends to about 1000 nm or 1 micron where water absorption starts to limit radiation penetration. Figure 1 shows the absorption coefficient flesh from about 400 nm to 2000 nm. The area close to 0 in value extends from about 620 nm to about 1125 nm. This is the window for phototherapy light to penetrate deep in to the body's tissue.

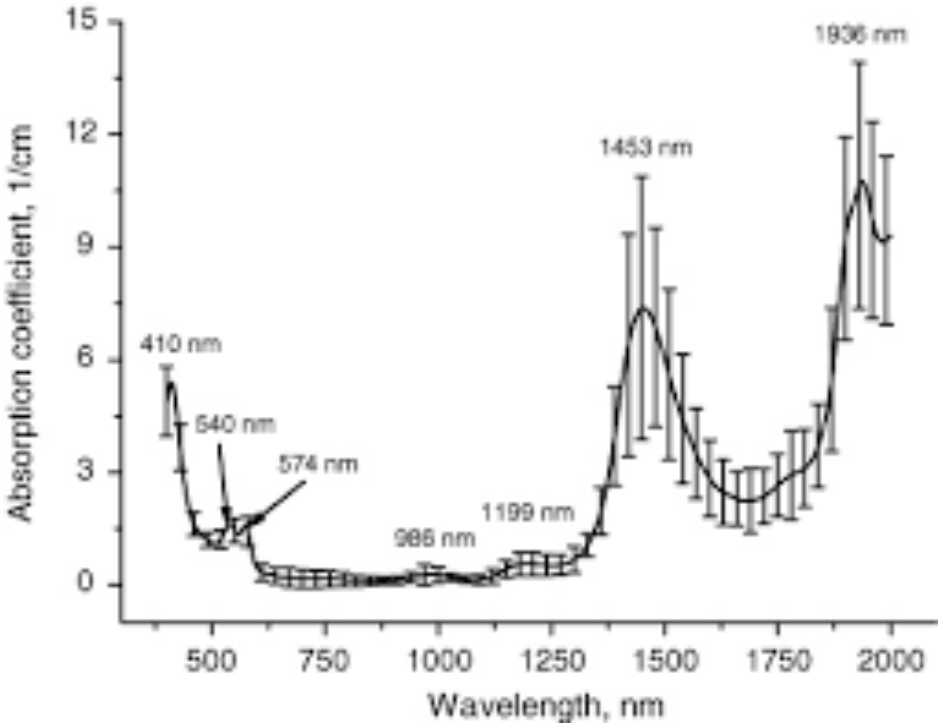

Figure 1. Absorption coefficient for human tissue from 400 nm to 2000 nm.

In this region the light can penetrate up to several centimeters into the body. It is also useful note that hard tissue such as tendons and bones, which do not transmit light directly, are translucent. As such they scatter the photons in the light but do not attenuate it. The effect is the same as placing a flashlight behind a fine china plate. Its translucence allow the presence of the flash light to be detected by the presence of a glow in the plate.

In terms of light based therapy, this means that radiation in this spectral window can reach the interior of bones and joints.

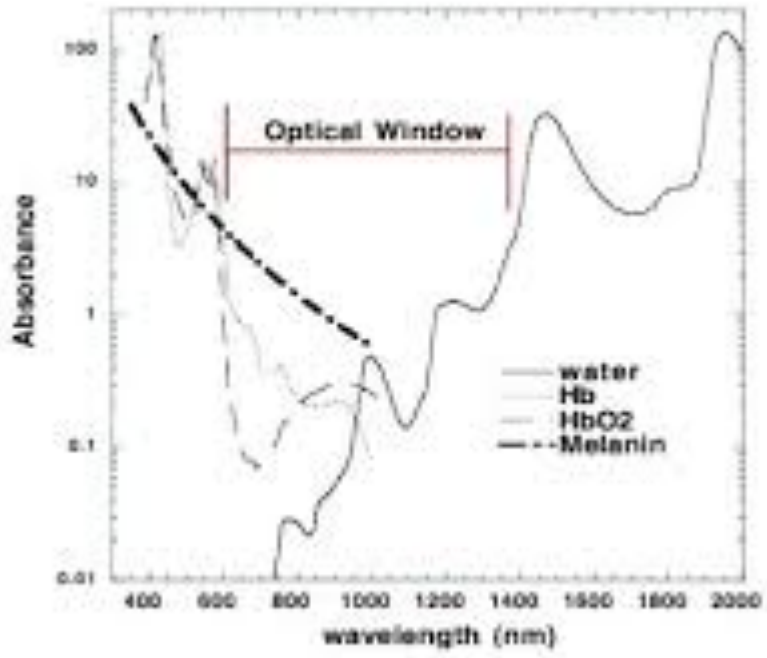

Figure 2. Log absorbance of human tissue components from 400 nm to 2000 nm.

The mechanism of the absorption is shown more clearly in figure 2 where the absorbance of tissue is shown as a function of the absorbing molecule. We see that hemoglobin (indicated by Hb) has a sharp drop near 600 nm while water absorption starts to dominate past 1000 nm. The skin pigment melanin is shown also indicating that pigmented skin can reduce the penetration of the light in photo therapy. Again the window for transmission is clearly present between 650 nm to 1100 nm.

Photobiomodulation

In the medical world “photo therapy” is usually associated with therapies in which light is used to activate a drug therapy. One example is in the treatment of cancer in which photoactive drugs are introduced intravenously where they migrate to and accumulate within cancer cells. Light activates the drugs and they kill the tumor.

Physicians and scientists have adopted the term "photobiomodulation" or PBM for short to refer to the type of photo therapy resulting from lower doses of light. This term is meant to emphasize the modulating effect of the light and the fact that the light does not directly induce transitional effects. Rather it serves to "modulate" the cell's natural balance.

A good example is the effect on inflammation in which a low dose of light can reduce inflammation but successively larger doses can lead to increased inflammation. One result of this is the biphasic nature of photobiomodulation. Biphasic indications occur with many drugs in which case a small dose helps the symptoms but a large dose affects the patient negatively.

So it is careful to approach the amount of light delivered cautiously and start with low levels, working up until the maximum effect is encountered.

Therapeutic Indications

Many studies have been conducted on the use of light for photobiomodulation. A good reference is Hamblin, et. al (2018). A useful summary of the effects on aging population is also contained in Ibe et. Al. (2015)

Briefly the effects of photobiomodulation that have been observed include:

1. Inflammation reduction.
2. Pain remediation
3. Acceleration of healing processes
4. Blood rejuvenation
5. Cosmetic improvements

In addition, there are indications of many other uses as varied as sports medicine to weight loss.

Biological Mechanisms

The exact nature of the biological mechanisms is a subject of intense research. Around 2005 Russian scientists in the Laboratory of Laser Biomedicine at the Institute of Laser and Information Technologies in the Russian Academy of Sciences near Moscow performed some interesting experiments. Under the direction of Dr. Tiina Karu a series of tests were conducted on HeLa cells in petri dishes (Karu, 2005). In these experiments the cells were irradiated with a variety of wavelengths and the effects on biological processes in the cells were observed. Two effects that were studied were 1) the adhesion strength of the cells to the substrate and 2) the rate of RNA and DNA transcription (cell division).

In these experiments, so called "action spectrum" were obtained to show how effective specific wavelengths were in initiating the effect. Results from the tests

indicated that in the window between 600 to 1000 nm there were four distinct peaks in the action spectra. These are shown in figure 3.

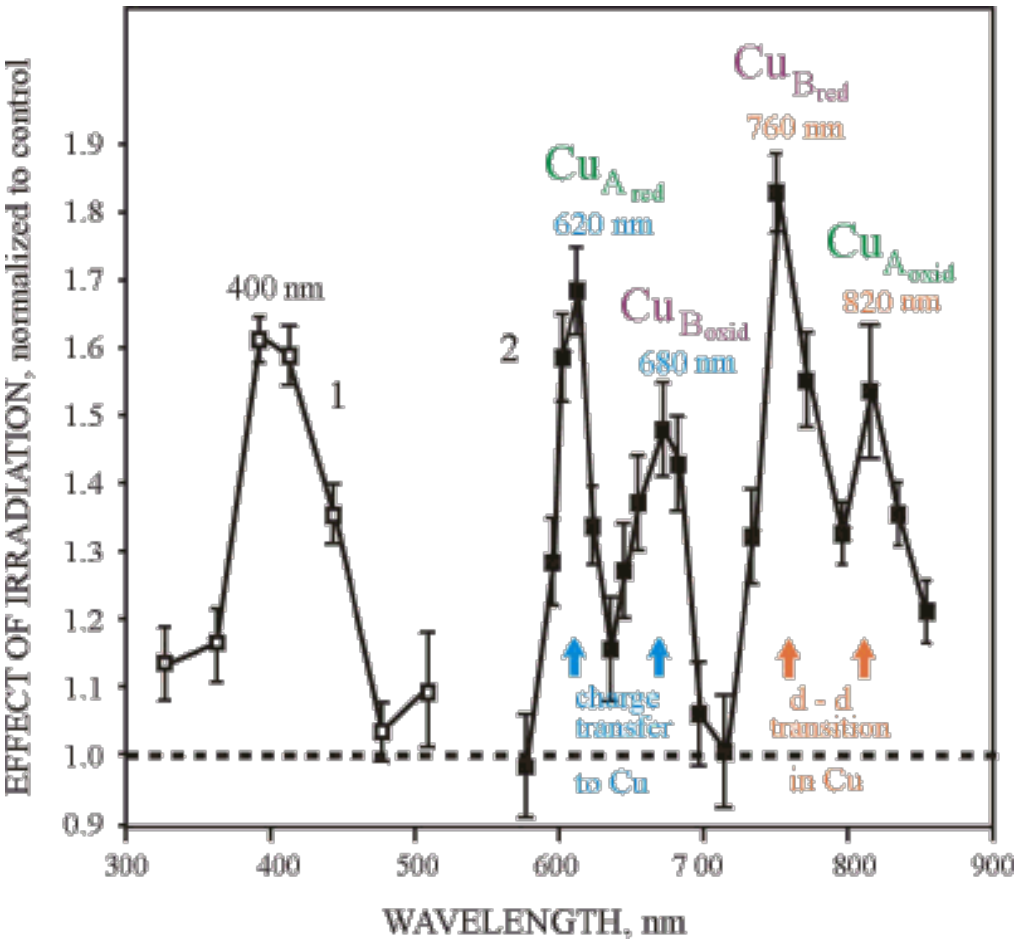

Figure 3. Action spectra for photon interaction with HeLa cells (from Karu 2005)

Explanation for these peaks has evolved (Karu, 2008) to center around one of the four main molecules in the mitochondria that are used to produce adenosine triphosphate or ATP, the so-called "fuel" for all cellular functionality. This molecule is cytochrome c oxidase (CCA) and has been well studied. It contains copper atoms with absorption features that correlate with the action spectra. These atoms are in either oxidized or reduced states within the CCA depending on the state of transition. The bands are indicated in figure 3 above.

Previous Medical Research

The medical research literature contains many references to studies conducted in vivo and in vitro on PBM effects. Hamblin et al, referenced above, contains a good summary. In the early years the emphasis was on the use of lasers to provide the radiation. As a result, most of the research was conducted at the few discrete wavelengths available. Laser beams are very concentrated or "bright' in optical

terms. It is easy to concentrate the beams to cause thermal damage to tissue and indeed there is a whole branch of medicine concerned with use of high power lasers for tissue cutting and tattoo removal.

Using lasers in PBM of necessity required spreading the beam out to reduce the localized energy flux. In addition, laser light is polarized and coherent in general. While there has been much made of these properties for PBM applications, it is highly unlikely that any effects result from them.

High power LEDs have only been available for a few years and they represent an opportunity for PBM sources. They are available in a wide variety of wavelengths and powers. Unlike lasers their radiation pattern is spread out and they are considerably lower in optical brightness (etendu) than lasers so their potential to damage tissue is reduced.

Typical laser powers for PBM are measured in milliwatts with a 10 mw laser being a potent source. LEDs on the other hand have individual powers of several watts or up to 1000 times the photon flux of a laser source. The beams do not have to be diffused to spread them out. LEDs are also considerably less expensive than lasers in general, thus making PBM sources potentially available to more patients.

Characterization of the PTE-4b Source

The PTE-4b was designed to produce photons in the four major bands identified in the studies carried out by Dr. Karu. High power LEDs were selected from two companies and combined in a rugged enclosure. The characteristics of the four LEDs are shown in table 1 below.

Table 1. Optical and Electrical Characteristics of LEDs in the PTE-4b source.

Center Wavelength (nm)	617 nm	660 nm	760 nm	830 nm	Total
FWHM (nm)	16.0	25.0	26	40.0	
Operating Current (mA)	700.0	700.0	700.0	700.0	700.0
Operating Voltage (V)	4.7	4.8	4.0	3.4	16.9
Electrical Power (W)	3.3	3.4	2.8	2.4	11.8
Exit Aperture Diameter (mm)	50.0	50.0	50.0	50.0	50.0
Aperture area (cm^2)	20.0	20.0	20.0	20.0	20.0
Total Optical Power (W)	1.7	1.7	0.7	0.4	4.5
Optical Power Density (mW/cm^2)	84.8	87.1	35.7	22.8	230.4

Figure 4 below shows the output power spectrum of the PTE-4b source compared with the action spectra shown in light blue. As can be seen there is good alignment between the peaks of both spectra.

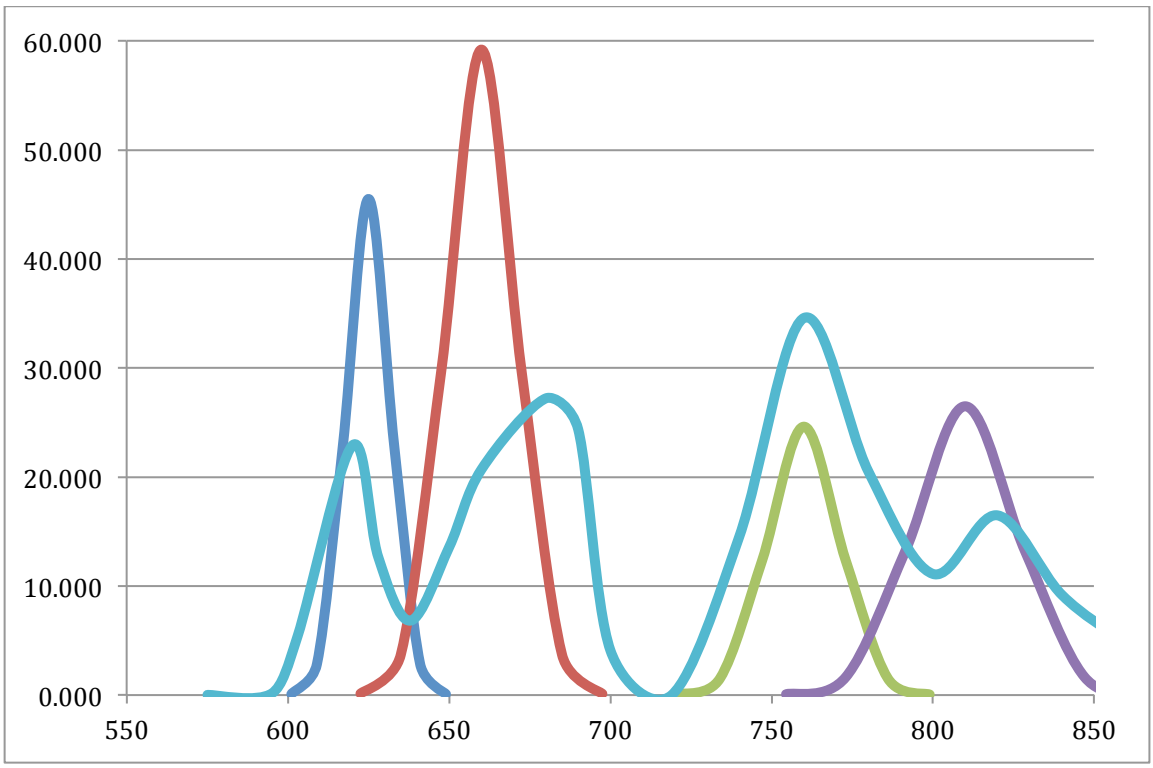

Figure 4. Output Spectra for the PTE-4b. (Action spectra – light blue, 617 nm LED - blue, 660 nm LED – red, 760 nm LED – green, 830 nm LED – purple)

Unfortunately the LEDs in the NIR produce lower outputs than the amber and red LEDs. The distribution of optical power among the four wavelengths is shown in figure 5 below.

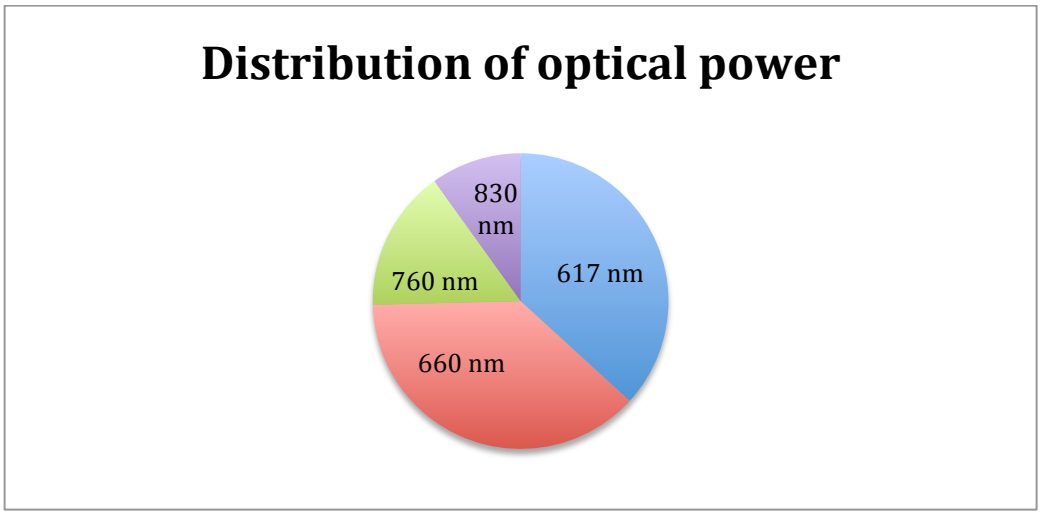

Figure 5. Optical power distribution in the PTE-4b.

The irradiance or optical power per unit area produced by the PTE-4b decreases with distance from the light. Results for the PTE-4B are shown in figure 6 below. Immediately next to the glass window the output is about .23 w/cm^2. At 5 cm away the irradiance is down to about .03 w/cm^2.

Typical dosages for PBM vary with condition but usually fall in the range of 10 – 100 J/ cm^2. To compute the delivered energy to the treated area we merely multiply the irradiance by the exposure time in seconds. For example if the light were placed immediately on the surface to be treated for 8 minutes, the dosage would be:

480 seconds x .23 w/cm^2 = 110 J/ cm^2

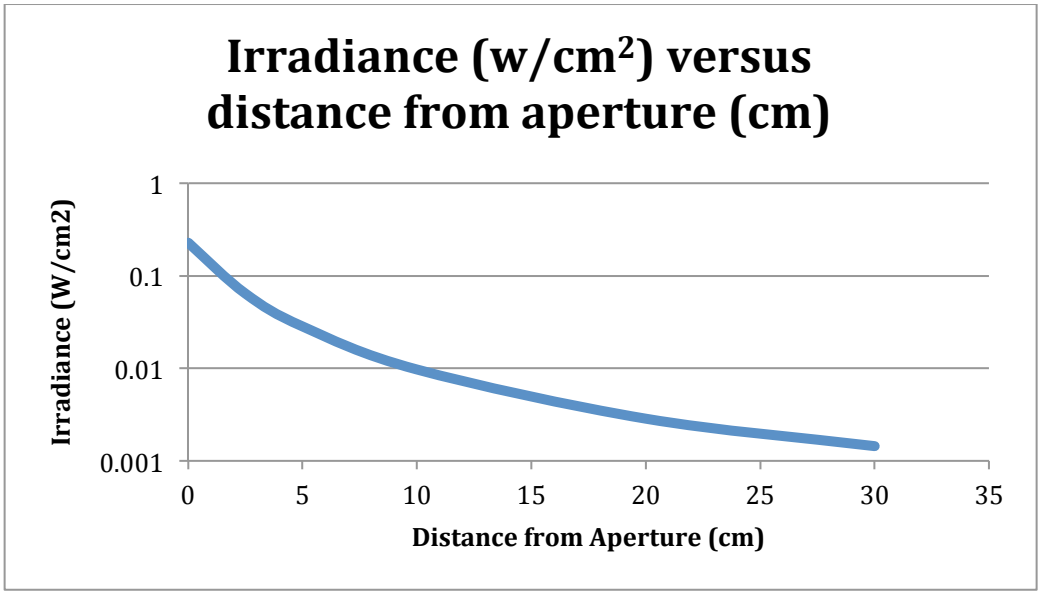

Figure 6. PTE-4b irradiance as a function of distance from the aperture

Biphasic Dosage properties of PBM

As mentioned earlier, PBM in biphasic in nature. Fortunately, little harm can come from excess energy from a source, but the desired effect may not be realized or a reversal of the desired effect may be generated.

Huang et al, (2009), provide a good summary of this effect as well as speculation on the probably biochemical pathways of PBM that cause this effect.

A complicating effect is that the biphasic response is dependent not only on total energy delivered but additionally by the rate at which it is delivered.

The PTE-4b is a relatively low level source. It is designed to be used for applications from 1 to 20 minutes without negative effects.

In any event, it is wise to start with short times and increase over time until an optimum effect is observed.

References

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