## Five Parameters You Must Understand to Master Control of Your Laser/Light-Based Devices


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Special Topic

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## Abstract

In this article, the authors review basic fundamental principles of light characteristics and their interaction with the target tissue. It is imperative for the practitioner to understand these concepts to deliver appropriate, efficacious, and safe phototherapeutic treatment for their patients. Once a diagnosis is made and a laser is chosen as a treatment tool, a basic knowledge and understanding of the physics and properties of light/tissue interaction is essential to allow practitioners to provide their patients with optimal results.

## Keywords

laser, light, basics, parameters, wavelengths

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A thorough understanding of the parameters involved in choosing a laser/light treatment as a therapeutic option is essential for safe and effective treatment. Much like the order of operations in algebra, these core principles have a parallel effect. If they are not mastered and applied properly, you will never have control of the treatment and be at the complete mercy of the device and manufacturer protocols, which are often only "safe."

Five parameters should be considered each time a laser or light-based device is used: wavelength, power, spot size, pulse width, and cooling. If a laser device allowed control of each of these parameters independent of the other, you would be able to adjust the treatment more precisely to match your patient. Devices that allow the practitioner the freedom to individualize these 5 settings create the ideal environment for maximum efficiency at minimal risk.

## WAVELENGTH

Wavelength is determined by our target chromophore. Each wavelength will have a unique absorption characteristic in one of our endogenous chromophores: melanin, hemoglobin, oxyhemoglobin, and water. Two basic principles are involved in light tissue interaction: absorption and scatter. Absorption is critical in the targeted treatment effect. The higher the absorption and less scatter, the less energy will be required to heat the target to the desired temperature and to achieve the resultant effect. Also, the higher the absorption, the more superficial the penetration. Generally, in the ultraviolet (UV) to the near infrared (IR) spectrum, the shorter wavelengths (200-600 nm) have more superficial penetration due to their absorption pattern, and longer absorption wavelengths (650-1200 nm) have deeper penetration in the tissue. The least penetrating wavelengths are in the far UV (excimer) and far IR ($CO_2$) spectrum due to their high affinity to water[1-8] (Figure 1). Common erbium and carbon dioxide resurfacing devices utilize these far IR wavelengths (2940, 10 600 nm) to achieve epidermal/dermal removal.

Target chromophores have differing locations in tissue. The first and most abundant of these is water, which is homogeneous throughout tissue. Water is commonly targeted directly or indirectly for tissue stimulation and ablative therapies such as microresurfacing. Carbon dioxide and erbium lasers are the 2 most commonly instituted

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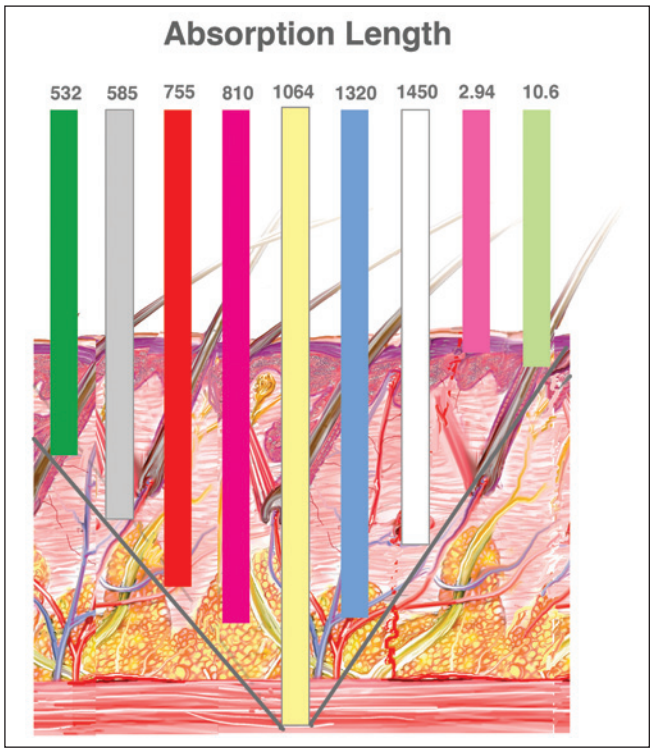


**Figure 1.** Illustration depicting the depth of penetration of the various common wavelengths of devices in the near infrared spectrum.

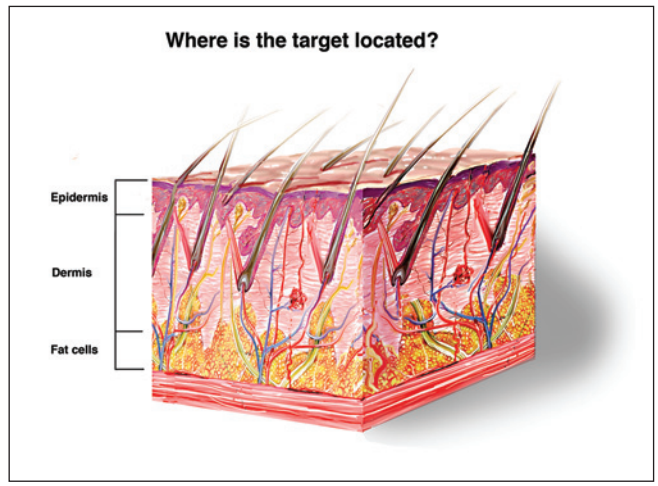


**Figure 2.** Graphical representation of the depth of the various targets within the skin: pigmented lesions (dermis/epidermis junction and above), vascular, and hair follicles.

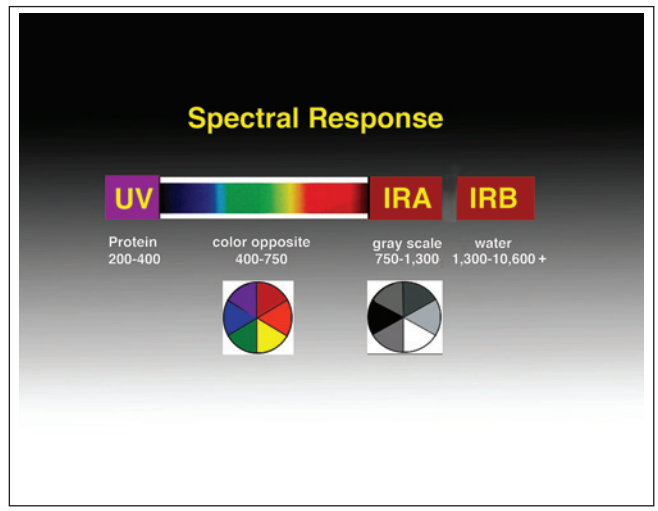


**Figure 3.** Wavelengths within the visible spectrum respond best to their corresponding color opposite. Wavelengths in the near infrared spectrum respond to the darkest shade of gray present.

resurfacing modalities. Newer fractionated resurfacing techniques create microislands of damage surrounded by spared collagen and dermal adnexae, resulting in a theoretical advantage in downtime from less total tissue treatment surface area and an increased rate of collagenesis within the affected areas. Melanin is most prevalent in the epidermis, produced by melanocytes at or near the dermal/epidermal (DE) junction. These cells are also located in the deep dermis and subcutaneous tissues, as well as on the surface of hair follicles, which is the target for depilation and hair removal procedures.

Blood is another chromophore targeted for treatment with many laser and light devices, with the actual target being the translucent vessel walls, which are located at or deep to the DE junction within the papillary or reticular dermis[2] (Figure 2). Wavelengths within the visible spectrum respond best to their color opposite, as shown in Figure 3. Wavelengths in the near IR spectrum respond to the darkest shade of gray present. Much like the difference in the heating of a car in sunlight, the blue car is hotter at the end of the day than the yellow car of the same make and model. This principle also holds true for lasers and tissue targets. White epidermis contains a significantly lower amount of melanin than black skin and therefore less target based on the chromophore (pigment) density. At the longer wavelengths (1200 nm), the epidermal transmission/absorption of the energy depends on the water content as opposed to pigment.[1,2,5,6,8-13]

## POWER AND SPOT SIZE

Power and spot size are individual parameters that, when combined, provide power density (Figure 4). The combination of these 2 characteristics will tell us how much energy and heat are delivered to the desired target. Much like a magnifying lens, a given number of photons are directed to a concentrated area, which creates a specific temperature rise at the target as the energy creates its thermal effect to the target tissue. By controlling density, devices are able to increase their power output. For example, if the biggest spot size available for a given device is 12 mm and maximum energy output is 50 J/cm$^2$, but the treatment we wish to deliver requires more energy/cm$^2$, an available option is to decrease the spot size to create a

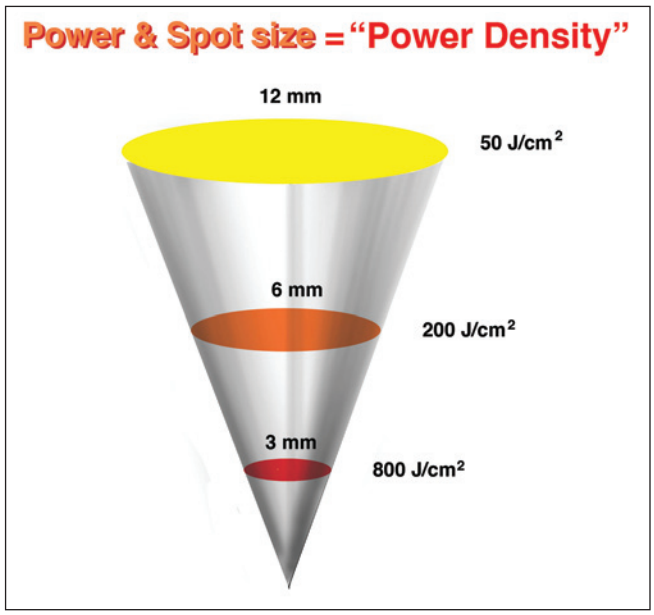


**Figure 4.** Much like a magnifying lens, a given number of photons are directed to a concentrated area, which creates a specific temperature rise to our target as the energy creates its thermal effect to the target tissue. By controlling density, devices are able to increase their power output.

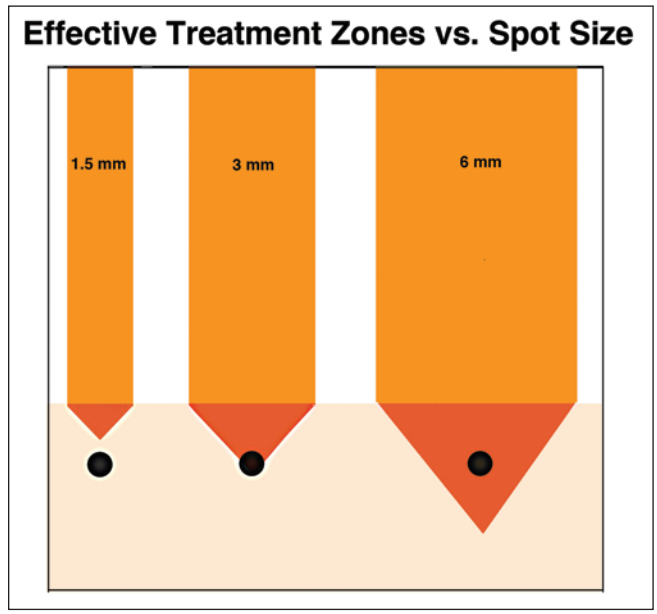


**Figure 5.** Illustration of the treatment response when altering spot size and density.

higher power density for treatment. This is a very simple way to explain how power density can be controlled to increase energy delivery for a given target.

As valuable as this is and as easy as this sounds, remember that when you change spot size, you have other effects that must be taken into account. When the spot size is decreased, so is the depth of penetration due to more rapid scatter of the photons under the tissue surface, creating a more superficial treatment effect.[1,14,15] When the beam radius is less than the penetration depth, the energy intensity rapidly decreases due to the beam scatter.[1,5,14,15] Figure 5 shows the treatment response when altering spot size and density; an arbitrary 6-mm spot size beam (light green) hits the tissue surface and creates an inverse pyramid (darker green) where approximately 63% of the photon concentration is located. If we can surround our target with this 63% concentration, we will be able to use the least amount of energy at the surface to successfully treat the target. The lower the energy, the lower the complication risk. You will also note that as the spot size decreases, the 63% area also decreases proportionally. This has a tremendous effect on heating of the target when, for example, the target (represented in the figure) falls outside the effective treatment zone. A general rule is that when you decrease the spot size by half, you will need to deliver double the energy to create an effect at the same treatment depth because of the scatter and decreased intensity of the incident beam.[1,14,15]

For example, in a clinically translatable scenario, when targeting a 6-mm spot, you might need 90 J/cm$^2$ to close the vessel, but when you target a 3-mm spot, 180 J/cm$^2$ would be needed to have the same effect. Further, if you target a 1.5-mm spot, 360 J/cm$^2$ would be needed and have the same effect as 90 J/cm$^2$ on a 6-mm spot. Naturally, 90 J/cm$^2$ would be the safest and most effective setting but not always the most practical. While larger spot sizes do allow the wavelength's effective treatment zone be at maximum efficiency, if the more superficial treatment is desired, you could simply reduce the spot size, which will increase the scatter in tissue, thus decreasing the effective treatment zone depth.

It is theorized that decreasing the spot size causes more scatter among the photons, decreasing the efficacy of the treatment; with larger spot sizes, the scatter is reduced, allowing more photons to be delivered to the desired target in a wavelength-dependent matter.[1,3,5-8] This can also be beneficial when treating areas with competing chromophores that might lie beneath the primary target. Smaller spot size will help avoid the underlying target and reduce the complication rate. However, as previously discussed, the improved delivery of the photons to the larger area will create more thermal effect to the tissue and may lead to increased pain with treatment. The ultimate governor of treatment depth is wavelength, regardless of energy or spot size. Wavelength-dependent scatter differs within the epidermis and dermis and, generally speaking, coincides in a direct linear relationship with wavelengths from 355 to 1200 nm and then inversely for wavelengths greater than ~1200 nm with increased affinity to water. Unfortunately, accurate direct measurements of fluence and absorption scatter profiles at a given depth for a given wavelength are lacking.[8,11-13]

## PULSE WIDTH

Pulse width is the delivery time or exposure time of the selected energy delivered to the target tissue. Different

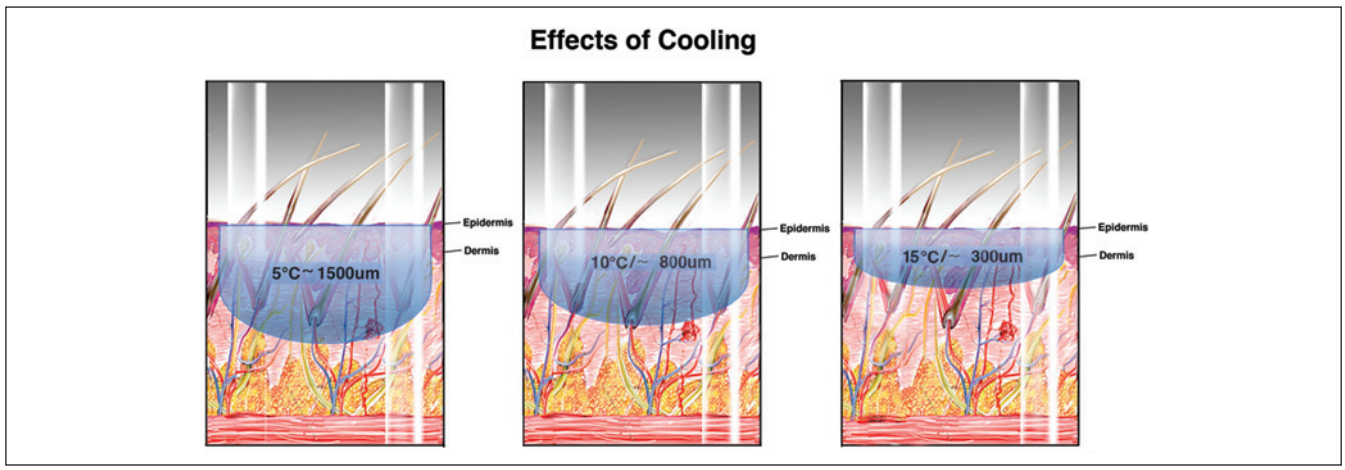


**Figure 6.** The degree of cooling delivered to the underlying tissue has a profound effect on skin protection. Levels of cooling with 5°C, 10°C, and 25°C are shown.

target volumes require different energy exposure times. For example, smaller volumes of water take less time to reach their boiling point when compared with larger volumes. The principal component that is essential in understanding pulse width is thermal relaxation time (TRT).[1,5,8,16-18] Thermal relaxation time is defined as the unit time for a target to release more than half of the temperature rise in the target tissue.[8,13,19] To clarify, when placing energy into the target tissue, the energy is transferred as heat. The target tissue will give off the heat or cool down at a constant interval of time, so to achieve a desired heating effect in the tissue target, the energy must be contained in the target without "losing" the heat into the surrounding tissue. Therefore, the delivery time must be faster than the target TRT or cooling time. This theory, described by Anderson et al, is better known as selective photothermolyis.[1,5,8,16-18] Extending the pulse width or delivery time of energy will create the desired effect on a larger target. If attempting to treat a larger volume target at a short pulse width, your treatment will be inadequate because of the larger target volume. Again, using the boiling water analogy, a pint will boil much faster than a gallon of water, and if you allow the same time interval to reach the boiling point for the gallon of water, you'll only achieve warm instead of boiling water (desired effect). The ideal pulse width or energy exposure time to the target is half of the TRT.[5,10,16-18,21-23]

## COOLING

Photothermic/laser therapy aims to maximize and direct thermal damage to target chromophores (superficial vessels, hair shaft, or dermal water) while minimizing injury to the superficial epidermis. Clinicians have struggled in determining how to amply protect the superficial layers of the skin without compromising the efficacy of the laser treatment. Conventional ablative therapy consists of removing the superficial epidermis and papillary dermis, with the hope of sparing the reticular dermis and deeper tissues.[8,11-13,19] In some scenarios, epidermal disruption has been found to cause unnecessary morbidity by increasing the risk of infection, erythema, scarring, and hypopigmentation of the treated area.

Selective cooling of the superficial skin layers during some treatments reduces undesired thermal injury to the epidermis. Contact cooling of the skin is achieved by heat conduction into an adjacent precooled solid body, kept at a constant temperature (–10°C to + 4°C) by a cooling system.[24-27] Ross et al[27] discussed the principles behind the laser therapy and cooling strategy, while emphasizing the distribution of heating principles with depth and absorption. The heating effect of tissue will decrease as treatment depth is increased because of the absorptive capacity of the shallower tissue and scattering of the thermal energy. As active cooling is performed synchronously with the laser, therapy heat transfer will be directed downward, focusing the treatment zone while protecting the superficial tissue[24-28] (Figure 6).

Sapphire plate contact cooling and cryogen spray cooling are 2 of the better-studied cooling modalities in practice. The contact cooling system works by recirculating chilled water, often at 4°C, around a transparent medium that is kept in direct contact with the target for less than 2 seconds, after which time it is manually removed. The second modality, selective epidermal cooling or dynamic cooling, uses the Freon substitute (cryogen) as the conductive medium and is delivered in spurts of spray directed over a treated area of a fixed diameter. The droplet temperature is variable but is usually set clinically between 45°C and 55°C.[8,19,26-28]

As the target tissue layer is treated with the hyperthermic/laser therapy, certain bimolecular and cellular alterations will occur. Melanin, which is contained in the epidermis and highly concentrated at the DE junction, absorbs the photon energy, causing the temperature rise in the tissue layer. Above a certain threshold value, the epidermal temperature will continue to rise, causing nonspecific thermal injury. The appropriate protective superficial cooling temperatures

needed for a given wavelength or energy of laser therapy have not been well established.[19]

## CONCLUSIONS

In this brief overview, we have summarized and simplified the basic principles of laser/light devices utilized in phototherapeutic treatment. This elementary synopsis generalizes the common device parameters with the intention of providing practitioners with a more complete understanding of the critical components for treatment. This information is invaluable in furthering understanding of light/tissue interaction, arming practitioners with the necessary tools to provide the safest and most efficacious treatment to their patients.

### Disclosures

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