On the Necessity of Class IV

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The biological effect stimulated by laser therapy is related to the number of photons that reach the affected area, *not* the number of photons incident on the surface. Penetration is a complicated quantity that depends on wavelength of the radiation, power density of the beam delivered, and the absorbing/scattering properties of the particular tissue-type being treated. Far too often, laser companies make claims of treatment capabilities based on the amount of energy (number of Joules) their laser can produce. This is a completely meaningless quantity on its own. For example, a single fluorescent bulb will produce about 4 million Joules in a normal 12-hour work day, and you would be exposed to far more just by stepping outside for a couple hours. It is important to overcome this dangerous shortage of information in both deciding between lasers and developing treatment planning strategies. Starting from output power, we can step through the calculation that leads us to the meaningful quantity of dose.

From Power to Power Density

One quantity any laser company will be able to report is power output. This is the amount of energy per unit time emitted in the laser's beam, usually reported in Watts, or for Class III or below, milliWatts (thousandths of a Watt). Even worse, some laser companies report this value as the power they are able to "produce", determined by applied voltage and the current through the actual laser manifold. This is all that is necessary when classifying, for example, a table-top pumping laser used strictly for research in materials science or quantum optics. In lasers for which it is necessary to steer the beam by way of fiber optics, much of the power "produced" is lost in the coupling of even the most efficient fiber optic setups. A simple power meter placed along the beam-line can confirm that many lasers do not *deliver* all the power they can "produce".

Beyond mere power output, the treatment area is of paramount importance to understanding the number of photons delivered to the affected area. For comparison, a long tube 100 Watt fluorescent bulb like those in any office building is bright enough to light up an entire room, and it does, in fact, spread 100 Joules of light per second across the entire breadth of a room. If instead, that bulb were only as big as your fist (like a normal incandescent bulb), those 100 Watts would be much "brighter". Better still, if all of that light was collimated into a beam (as in a laser) the "brightness" would be extreme. The power output simply defines the number of total photons emitted, but it is exactly the concentration (density) of the photons that dictates the number of photons delivered to a target area. That target area, for the most part however, is not on the surface of the skin and so it is important to understand how treating a highly-scattering medium like human tissue will affect the dose delivered to non-superficial targets.

From Surface Power Density to Power Density Delivered

Power density is the only necessary intensity parameter for *in vitro* experimentation because there is no attenuation due to a monolayer of cells. From power density measurements, calculating the energy density (i.e. dose) is straightforward: power density in units of Watts/cm^2 multiplied by treatment time in seconds yields dose in units of $\text{Joules}/\text{cm}^2$. This is the energy deposited per area of irradiated tissue. *In vivo*, however, this parameter does not tell the whole story. Tissue is a highly scattering medium and there is non-trivial attenuation at depths in the human body. The power density simply refers to the intensity (number of photons) at the output of the laser. This intensity decays exponentially with depth in tissue, and the decay constant (related to the penetration depth) is determined by the wavelength of the laser and the optical properties of the tissue.

Furthermore, radiation will scatter laterally (radially, since the beam is cylindrical) and so there will be dose deposited beyond the spot size of the laser. It is important to remember that only a finite number of photons is emitted from the laser, so this spreading of the beam will also lead to a further decrease of photons along the central beam axis. Combating this spread is the flip-side of the scattering coin. Even the most coherent lasers are not completely collimated; that is, they slightly diverge, but scattering of the divergent parts of the beam will add more photons to the collimated path.

Again, these are complicated phenomena that have to be modelled and measured to give an accurate description of the dose deposition of any laser beam to be used *in vivo*. Comparing lasers to each other must therefore include more than just power density analysis. Figure 1 is an example of such analysis. From these profiles and a detailed analysis of the optical properties of the different types of tissue, we can calculate the necessary treatment distances and times for therapeutic regimens.

From Power Density to Dose

Now it is possible to understand the number of Joules to be delivered to a target area. Again it is not the total number of Joules delivered at a certain depth that is important since we can see that the beam is spread over an area and we are not treating infinitely small regions. Instead, the important parameter is the energy density; that is, energy per unit area, more commonly called dose with units of J/cm^2. From the depth dose profile, a distinct version of which is necessary for each wavelength, frequency, and power setting as well as for every type of material through which the laser beam will penetrate (skin, bone, soft tissue, fat, etc.), you can map out the intensity and determine

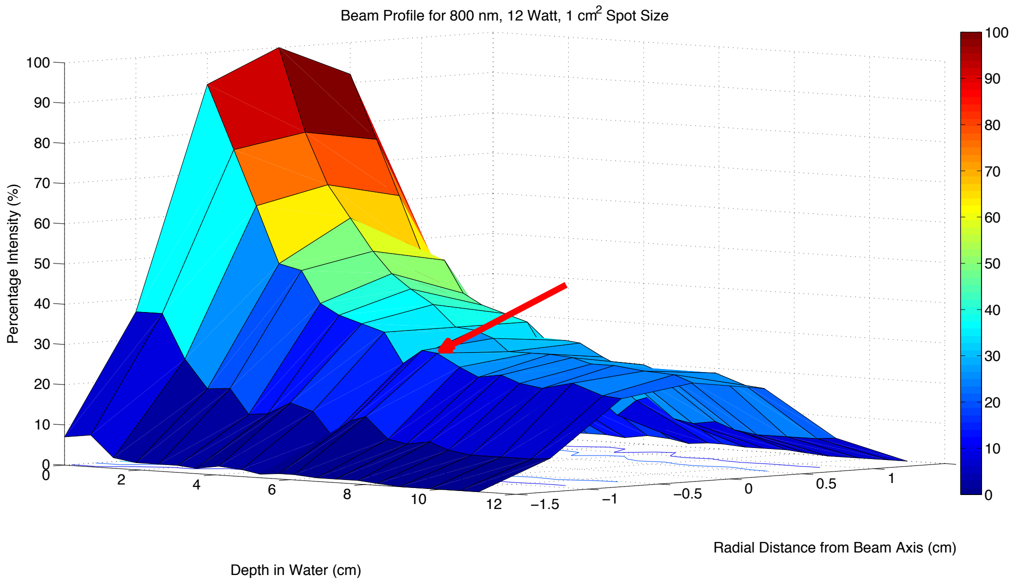

Figure 1: Example of an actual *measured* 3-D dosimetric beam profile of the K-Laser K-1200 in a water phantom. For instance, a point (red arrow) that is 6.1 cm deep in water and 0.5 cm from the central beam axis will be exposed to radiation whose intensity is 29% of the full intensity at the surface of the skin. This type of information is crucial to determining the dose delivered to tissue at a distance inside the body.

the power density across a desired area. From the power density at a given depth, we can then revert to the same simple formula used *in vitro*: power density in units of Watts/cm^2 multiplied by treatment time in seconds yields dose in units of $\text{Joules}/\text{cm}^2$.

Sample Calculation

If you wish to deliver 1000 Joules to a lower lumbar ailment at a depth of 3 inches (~8 cm), for example, you cannot simply take a 500 milliWatt Class III laser and treat for 2000 seconds (500 milliWatt = 0.5 Joule/sec x 2000 sec = 1000 Joule) because you would only actually be delivering 276 Joules to the affected area (0.5 Watt at surface x 27.6% intensity at 8 cm [from Figure 1 along the central beam axis] x 2000 seconds). In fact, you would have to irradiate for 7246 seconds (over 2 hours!!) to build up enough dose. If instead you used a 12 Watt laser, you could achieve 1000 Joules at 8 cm in 302 seconds (only about 5 minutes). Depending on the beam size of the laser and the scattering properties of the tissue involved, the energy density (dose) can be determined, but according to this first-order analysis, about 5-10% of the beam is scattered away from the 1 cm^2 surface beam and so these treatment times would have be to corrected to 105-110% of their values to acheive 1000 J/cm^2.

Take Home Message

There is much more to consider when comparing lasers or predicting success of treatments than either a simple power output or surface energy value. The central thesis to this entire discussion, though, is the necessity of starting off with high power density since all contributing factors lead to severe attenuation of the beam. If only superficial dermatology concerns you, than less intricate and less expensive Class II or III lasers may be suitable for you. But for any subcutaneous, and especially deep muscle or joint ailments, if you wish to achieve any analgesic or biostimulatory effects, these lower power lasers simply cannot deliver sufficient dose at depths in the body in reasonable treatment times.