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Review

Intricacies of Dose in Laser Phototherapy for Tissue Repair and Pain Relief

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Abstract

Inaccurate measurement and incorrect reporting of dosages are major shortcomings of phototherapy articles. As many as 30% of published reports in the field either lack relevant information needed to determine a dosage or report dosages that are altogether inaccurate. The high prevalence of dosage-related mistakes in published reports suggests that dosage determination errors are common among clinicians and other end-users. This special article is designed to advance understanding of the relevant parameters used in phototherapy for tissue repair and pain relief, particularly among clinicians and others who may not be completely familiar with the technology. I define and discuss five key parameters that influence dosage, including 1) radiant power, 2) radiant energy, 3) power density, 4) energy density, and 5) wavelength, and use hypothetical cases to demonstrate how factors such as beam spot size, size of lesion, mode of treatment (contact, noncontact, or scanning), frequency of treatment, dose per treatment, and cumulative dose affect dosages and treatment outcomes. The potential effects of patient-related factors, such as etiology, pathology, tissue optical density, depth of target tissue, and skin pigmentation are discussed concurrently and strategies are suggested to improve dosage determination.

Introduction

Inaccurate measurement and incorrect reporting of dosages rank high among the shortcomings of phototherapy papers submitted for publication in professional journals. A recent review indicates that as many as 30% of published phototherapy reports lack details of the relevant information needed to determine dosage or report dosages that are altogether inaccurate.[1] The prevalence of dosage-related mistakes suggests that dosage determination errors are common among clinicians and other end-users. That phototherapy equipment is, at times, labeled with inaccurate parameters further complicates the situation. Yet successful treatment outcomes hinge directly on correct dosimetry and informed selection of treatment parameters. Just as a certain dose of medicine can relieve pain, a higher dose can be toxic, or a lower dose can be ineffective, so too can doses of light be beneficial, detrimental, or ineffectual.

The well-informed clinician can, within reason, control dosages, even though certain parameters are preset by equipment manufacturers. However, knowledge of the potential effects of various parameters (wavelength, pulse frequency, power, power density, energy, and energy density), their relationships to one another, and an understanding of certain patient-related characteristics and beam behavior, are essential to determining the right amount of energy needed to treat a particular condition. The purpose of this paper is to advance understanding of the relevant parameters used in phototherapy for tissue repair and pain relief. The specific aims are to 1) define and explain the relationships between key parameters, 2) use examples and hypothetical cases to demonstrate the potential effects of relevant parameters, and 3) offer information that enables researchers, clinicians, and other end-users to improve measurement and reporting of dosages.

Basic Treatment Parameters

The parameters that influence dosage include 1) radiant power, 2) radiant energy, 3) power density, 4) energy density, and 5) wavelength. As a foundation for further discussion of these parameters and their potential effects on dose, I will begin by defining them in the following segments.

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Table 1. Common Terms and Units of Measurement Used In Phototherapy

Term	*Symbol*	*Equation*	*Metric or SI unit of measurement*
Radiant energy	Q	$Q = \Phi t$ or $\Phi \times t$	joules (J)
Radiant power	Φ	$\Phi = Q/t$ or $Q \div t$	watts (W)
Spot size[a]	a	$Q = \Pi r^2$ or $L \times W$	cm^2
Power density or irradiance	E_R	$E = \Phi/A$	W/cm
Energy density or fluence	H	$H = Q/A$ or Et	J/cm^2

[a]Πr^2 is used to calculate the area circular spot sizes; $L \times W$ is used when area is rectangular or square.
SI, Système International d'Unités.

Radiant power

Power may be defined as the rate at which energy is expended. It is generally measured in watts (W); but in phototherapy, because of the relatively low amounts of power needed to achieve therapeutic benefits, it is often measured in milliwatts (mW) (Table 1).

One milliwatt is one thousandth of a watt. By definition, power can be determined mathematically by calculating energy per unit time, i.e., by dividing the energy measured in joules (J) by time measured in seconds (sec):

$$\text{Power (W)} = \frac{\text{Energy (J)}}{\text{Time (sec)}} \quad [1]$$

Since power is represented by phi (Φ), and time and energy are represented by the letters t and Q, respectively, the above formula may be rewritten:

$$\Phi\ \text{(W)} = \frac{\text{Q (J)}}{t\ \text{(sec)}} \quad [2]$$

where Φ = radiant power measured in watts, Q = radiant energy measured in joules, and t = time measured in seconds.

If phototherapy device X delivers 15 J of energy in 30 sec, then the power of the device can be calculated:

$$\Phi = \frac{15\ \text{J}}{30\ \text{sec}} = 0.5\ \text{W (or 500 mW)} \quad [3]$$

All things being equal, the greater the power of a given therapeutic device, the shorter the necessary treatment time to achieve a particular target dose (Fig. 1). However, in practice all other parameters are never the same from one patient care situation to another, or from one therapeutic device to the next; hence, a discussion of the variables that can potentially alter this relationship will be presented shortly.

Radiant energy

Radiant energy is a measure of the energy of visible and invisible electromagnetic radiation and is measured in joules (J); the Système International d'Unités (SI) unit named after James Prescott Joule (1818–1889), who first revealed the relationship between heat energy and mechanical work. Radiant energy is calculated by multiplying radiant power with time as shown in the following mathematical relationship:

$$\text{Energy (J)} = \text{Power (W)} \times \text{Times (sec)} \quad [4]$$

Since the scientific symbol for energy is Q, and power and time are symbolized by Φ and t, respectively, the above formula may be rewritten:

$$Q = \Phi t \quad [5]$$

Where Q = radiant energy measured in joules, Φ = radiant power measured in watts, and t = time measured in seconds.

To further explain the point, if the average power produced by phototherapy device X is 500 mW and treatment is timed for 30 sec, then the total energy delivered to the patient may be computed:

$$\Phi = 0.5\ \text{W (or 500 mW)}, t = 30\ \text{sec}$$
$$Q = \Phi t \quad [6]$$
$$Q = 0.5\ \text{W} \times 30\ \text{sec} = 15\ \text{J}$$

Total energy is one of the most critical parameters that influences treatment outcomes. Although the term radiant energy is informally used interchangeably with the electromagnetic waves themselves, it should be reserved exclusively for the inherent energy of the waves. Moreover, it should be noted that radiant energy is not the same as luminous energy. Luminous energy is the perceived energy of

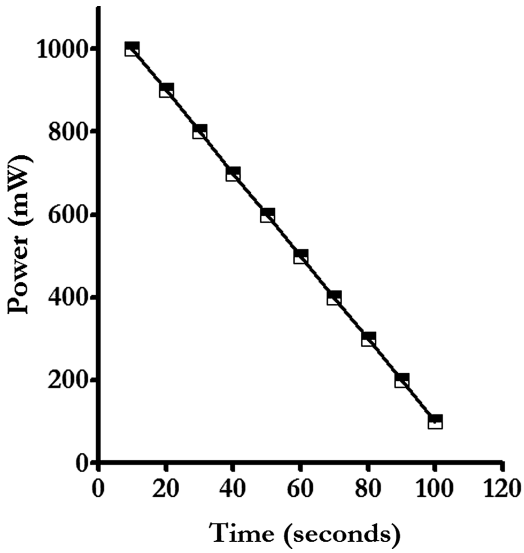

FIG. 1. Graph illustrating the relationship between power and time. All things being equal, the higher the power of a given device, the shorter the treatment time. However, other factors may alter this relationship.

light and is dependent on the eye's sensitivity to light, while radiant energy is the actual measured amount of energy inherent in the particles of light, i.e., the photons themselves.

Beam spot size

Beam spot size (BSS) defines the area covered by the beam either at the tip of the applicator or at any given distance beyond that point. At the tip of the applicator, spot size is essentially the same as the effective radiating area (ERA) of the applicator; hence, it can be readily assumed that both are interchangeable when the applicator is placed in direct contact with the patient. However, when the applicator is distant from the patient, the beam may spread depending on its divergence angle and spatial profile (Fig. 2). If the divergence angle is minimal, divergence is often negligible over the relatively short distances of just 1 or 2 cm encountered in experimental and clinical treatment situations. In such situations BSS may be assumed to be equivalent to the ERA of the applicator.

Light beams produced by light emitting diodes (LEDs) tend to diverge significantly. Unless their emitted beams are optically modified to mimic a laser, their spot sizes are often larger than their ERA even within short distances, making it necessary to measure the actual spot size when the applicator is not in direct contact with the subject. As the spot size becomes larger over distance, the intensity of the beam is reduced, because the same quantity of photons emitted by the light source is spread to cover increasingly larger areas. Dispersion of the beam may be evenly diffused or spotty depending on its source and profile.

Power density (or irradiance)

Power density may be defined as the ratio of power to the surface area of the beam. Also known as irradiance, power density is basically power per unit area of the spot size cast by the beam. As previously noted, when the applicator is in direct contact with the patient, the spot size is the same as the ERA of the device. In theory, it also corresponds to the area of tissue being irradiated; however, this is never the case in practice because of beam dispersion in tissue. Power density is measured in watts per square centimeter (W/cm^2) and is calculated:

$$\text{Power density } (W/cm^2) = \frac{\text{Power } (W)}{\text{Area } (cm^2)} \quad [7]$$

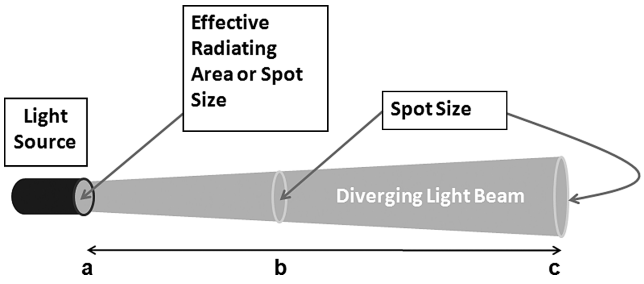

FIG. 2. Illustration showing the relationship between beam divergence and beam spot size. The spot size at the tip of the applicator or light source (a) is essentially the same as the effective radiating area (ERA) of the applicator. The spot sizes at distances (b) and (c) from the source are shown, increasing progressively as the beam diverges.

The mathematical symbol for irradiance is E_e and that of area is a; therefore, the above equation may be rewritten as follows:

$$E_e\ (W/cm^2) = \frac{\Phi\ (W)}{a\ (cm^2)} \quad [8]$$

Where E_e = power density (or irradiance), Φ = radiant power measured in watts, and a = area or spot measured in square centimeters.

As a follow-up to our previous example, if the ERA of the applicator or spot size of phototherapy device X is 5.0 cm^2, its power density can be determined:

$$\Phi = 0.5\ W,\ a = 5.0\ cm^2$$
$$E_e = \frac{\Phi}{a} = \frac{0.5\ W}{5.0\ cm^2} = 0.1\ W/cm^2\ (\text{or } 100\ mw/cm^2) \quad [9]$$

The importance of power density

Of all the physical parameters relevant to dosimetry, power density is perhaps the most poorly understood. Yet, it is the most critical factor to consider in an experiment or treatment because of its significant influence on dose, and its potential to exert a positive or negative influence on the target tissue as exemplified by the following example. If phototherapy device Y has 1000 mW power and two interchangeable applicators, one with 5.0 cm^2 ERA and the other with 0.1 cm^2 ERA, following the method used in Equation 9 above, the power density can be determined for each applicator as shown in Table 2.

As shown in the table, changing the applicator of the same machine to one with a smaller ERA increased the power density 50-fold; turning the applicator from a 200 W/cm^2 therapeutic device into a 10,000 W/cm^2 surgical tool that can cut tissue. This change has nothing to do with the power of the machine, which remains 1000 mW. Note that if another interchangeable pad measuring 600 cm^2 (or 20 cm by 30 cm) was used with this device, the power density would be significantly diminished to 16.67 mW/cm^2 (i.e., 1000 $mW/600\ cm^2$).

Energy density (or fluence)

Energy density, also known as fluence, may be defined as the amount of energy delivered per unit area. In other words, it is energy divided by area; it is measured in joules per square centimeter and represented by H. Since we have shown that energy (J) = power (W) × time (sec) and energy density = energy/area (a), it follows that:

$$\text{Energy density } (H) = \frac{\text{Power } (\Phi) \times \text{Time } (t)}{\text{Area } (a)} \quad [10]$$

Power divided by area is power density; therefore, energy density = power density × time, or $H = E_e \times t$, where H = energy density or fluence measured in joules per square centimeter, E_e = power density (or irradiance) measured in watts per square centimeter, and t = time measured in seconds.

In our previous calculation, we determined that the power density of phototherapy device X is 100 mW/cm^2. If treatment

Table 2. The Potential Effect of Effective Radiating Area or Beam Spot Size on Power Density

Power density with 5.0 cm^2 applicator	*Power density with 0.1 cm^2 applicator*
$E = \Phi/a$	$E = \Phi/a$
Since $\Phi = 1000$ and $a = 5\,cm^2$	Since $\Phi = 1000$ and $a = 0.01\,cm^2$
$E = 1000\,mW/5\,cm^2$	$E = 1000\,mW/0.01\,cm^2$
Therefore, $E = 200\,mW/cm^2$ (or $0.2\,W/cm^2$)	Therefore, $E = 10{,}000\,mW/cm^2$ (or $10.0\,W/cm^2$)

Note: These calculations are based on using the same phototherapy equipment. The only change is the aperture size of the applicator, i.e., the effective radiating area.

time is 30 sec, the energy density or dose delivered per spot size can be determined:

$$E_e = 100\ mW/cm^2,\ t = 30\ sec$$
$$H = E_e \times t = 100\ mW/cm^2 \times 30\ sec \quad [11]$$
$$= 3000\ mJ/cm^2\ (or\ 3.0\ J/cm^2)$$

The significance of energy density

Energy density or fluence is typically reported as dose in practice. Since dose is a critical factor that determines whether treatment would be beneficial, detrimental, or ineffectual, its significance cannot be overemphasized.

We previously stated that the greater the power of a given therapeutic device, the shorter the necessary treatment time to achieve a particular dose, ceteris paribus. From the foregoing discussion, it is clear that differences in power density, either between machines or between applicators of the same machine, can alter this relationship between power and treatment time. For example, assuming that a dose of $4\,J/cm^2$ was needed to treat a particular case involving a 5-cm^2 area, it would take 20 sec to perform the treatment if the 5-cm^2 applicator of therapeutic device Y was used. However, a longer treatment time, 240 sec (4.0 min) would be needed to attain the same dose if the 600-cm^2 pad was used. Of course the pad would treat a larger surface area, but the fact remains that changing the applicator of a given therapeutic device alters the relationship between power and treatment time.

Wavelength

Light "particles" twirl and gyrate as they are propagated in space, creating undulating waves. As illustrated in Fig. 3, the distance between two peaks of the wave is defined as a wavelength. The shorter the wavelength, the higher the frequency of vibration of the light particle. Each repeated or repeatable segment of the wave that corresponds to the same identical point is considered a cycle or period (Fig. 3). It is not so obvious, from looking at a light beam, that the photons emanating from the source are in vibratory motion; however, this is true for all forms of light, including light produced by phototherapy devices. If one device has an 880-nm wavelength as opposed to a 660-nm wavelength of another device, the former has a longer wavelength relative to the latter—the adjoining waves of the former device have longer peak to peak distances relative to the latter device.

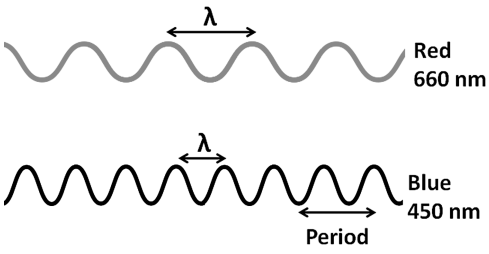

FIG. 3. Illustration showing wavelength and the wave nature of light; λ denotes wavelength. Note that the red 660-nm light has a longer peak to peak distance (wavelength) than the blue 450-nm light.

As a general rule, the longer the wavelength of a phototherapy device, the deeper the depth of penetration of its beam into tissue.[2–6] Red and infrared lights are commonly used for therapeutic purposes; therefore, it seems appropriate to compare the two. Because infrared light has a wavelength approximately above 700 nm and red light is typically right below 700 nm in wavelength, infrared light penetrates tissue more deeply than red light. For example, 880-nm infrared light will penetrate tissue more effectively than 660-nm red light. However, this does not mean that the 880-nm light is not absorbed in superficial tissue; it simply implies that in spite of its absorption in superficial tissue, the waves continue onward into deeper levels of tissue. For this reason longer wavelengths are usually recommended for treating deeper lesions than light sources with shorter wavelengths. Conversely, the shorter wavelengths are considered advantageous in treating superficial target tissues since the photons are absorbed mostly in those tissues.

Among red and infrared light sources, subtle differences in wavelengths may produce differing light penetration effects. For example, 780-nm infrared light will penetrate tissue less than 950-nm infrared light, and 635-nm red light will penetrate less than 670-nm red light. In other words, just because two light sources are red or infrared does not mean that they have the same depth of penetration in tissue. The common misconception that a more deeply penetrating wavelength is therapeutically more efficacious than a less penetrating wavelength is simply wrong. The first "law" of photochemistry states that "Light must be absorbed in order to produce an effect." Therefore, without light absorption, mere penetration to deeper levels of tissue would not yield the desired therapy.

Equipment manufacturers tend to keep up with phototherapy research and are more savvy in today's highly competitive marketplace than they seemed to be in the past. During the 1970s, 1980s, and 1990s, most phototherapy devices had single wavelength sources of light, usually red or infrared; few combined both. Today, a majority of phototherapy devices have a combination of two or more wavelengths of light—usually red and infrared—and some are even polychromatic, with a broad spectrum of wavelengths.

Treating patients with appropriate wavelengths of polychromatic light or a combination of red and infrared wavelengths offers the following advantages: 1) the ability to effectively treat deep and superficial lesions simultaneously, and 2) the ability to cover a broader spectrum of the therapeutic window of wavelengths for tissue repair and pain relief; which, based on the literature, appears to lie within the 600–1000 nm range.[7,8] Nonetheless, in research situations where the effect of an individual wavelength of light is desired, having a device with a combination of wavelengths can be a disadvantage.

Factors That Influence Dose

BSS and size of lesion

In many circumstances, the surface area of the target tissue being treated does not correspond to the ERA of the applicator. Many times the spot size or ERA is smaller than the area being treated. In such situations, sequential treatment of the target area is recommended to ensure that every unit area receives a similar dosage of light energy as shown in Fig. 4a. In many situations, it is neither sufficient nor acceptable to treat a few randomly selected spots on the target lesion without attempting to treat the entire lesion (Fig. 4). Randomly selected treatment of a few spots may cause inappropriate dosing of the target tissue because some areas would be fully irradiated, some partially, and others minimally or not at all. Similarly, undue overlapping of treatment is not recommended, because some areas of the target tissue would be treated twice and effectively overdosed.

Sequential irradiation may not result in precise dosing of every square centimeter of tissue since the shape of the applicator does not always correspond to the shape of the lesion. Moreover, as light penetrates the tissue, it scatters and diffuses throughout, causing the irradiation of areas adjoining the target tissue. Such collateral irradiation is unavoidable and difficult to control for during treatment. In spite of these shortcomings, sequential irradiation remains the preferred mode of treatment.

If the target area is smaller than the ERA of the applicator, an applicator with an equal-sized or smaller ERA is recommended to concentrate the energy on the target tissue and avoid needless irradiation of other tissues. However, in certain treatment situations, such as ulcer treatment, irradiation of adjoining normal tissues at the edge of the ulcer may beneficially promote tissue repair and edema reduction.

Contact, noncontact, and scanning modes of treatment

Treatment may be done with the applicator either in direct contact with the patient or at a distance away from the skin surface. The former is referred to as contact mode of treatment while the latter is the noncontact mode of treatment. Noncontact treatment may involve the use of an applicator that irradiates the target tissue in a sweeping or scanning fashion. Whenever possible, the contact mode of treatment is preferred for the simple reason that the loss of energy is minimal—virtually every photon emanating from the applicator enters the patient's skin or tissue. This is not the case with the noncontact mode of treatment, in which some of the photons are reflected or refracted from the surface of the skin resulting in loss of energy and diminishing the intended amount of treatment energy.

The tendency to treat open lesions using the noncontact mode of treatment is understandable because of the concern that the applicator may become contaminated and cause cross-contamination of patients. However, this should be avoided as much as possible.

Total dose, frequency of treatment, and dose per treatment session

In each situation, it is as important to use the appropriate dose per treatment session as it is to apply the right number of cumulative doses. The frequency of treatment may also affect the outcome of therapy and even then it is not necessarily sufficient to assume that once the right dose, frequency of treatment, or total cumulative dose are used, the desired outcome will be achieved. The following hypothetical scenario is presented to clarify the point.

Let's assume that it has been established that with our treatment device X, a 70-cm^2 area around the ankle must be irradiated at 5 J/cm three times per week in order to heal an ankle sprain. Given the 5-cm^2 applicator of the device, it will be necessary to apply treatment sequentially to ensure even photostimulation of each square centimeter of the 70-cm^2 area. This means that 14 sequential 5-cm^2 spots will have to be irradiated to cover the entire target area and that the cumulative amount of energy delivered per treatment session will be 350 J (i.e., 5 J/cm^2×70 cm^2). Assuming it takes 2 weeks (six treatments) to resolve the lesion, it follows that the 2100 J of energy (350 J×6 treatments) received by the patient was needed to achieve the desired result. Given the 100 mW/cm^2 irradiance of the device, 50 sec would be needed to treat each

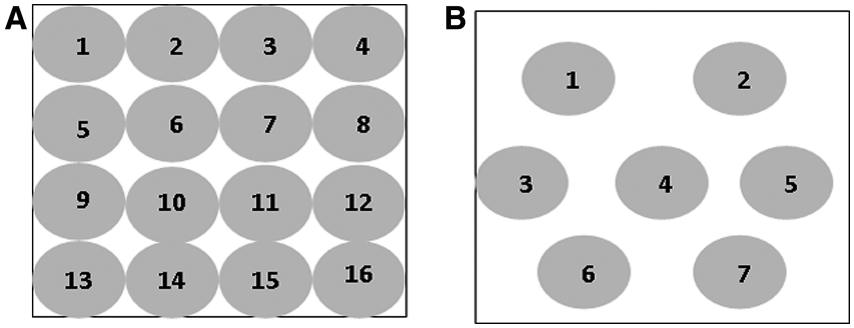

FIG. 4. Illustration showing (**A**) sequential treatment versus (**B**) selective or random treatment of a target area. Sequential treatment is recommended as selective treatment always results in erroneous dose calculation.

5-cm^2 spot size. Using the same assumptions, each treatment session must run for 700 sec or 11.67 min, since each of 14 spot sizes would require 50 sec.

The above example seems logical and clear. However, each parameter used to achieve this hypothetical research outcome must be adequately accounted for when translating the findings to particular clinical situations. Deviations in any of the parameters must be adequately accounted for, otherwise a different outcome will result. Depending on the configuration of one's treatment device, adjustments may be necessary to reproduce as closely as possible the treatment scenario described above. For example, if one's device has a lower irradiance, say 50 W/cm^2, each spot size would have to be treated for 100 sec to obtain the 5 J/cm^2 energy density. This means that each treatment session will be longer—1400 sec (23.34 min). Similarly, phototherapy equipment with higher irradiance will result in shorter treatment sessions. An important point here is that energy density (i.e., fluence or dose) is as important as the total amount of energy delivered per treatment session, which in turn is as important as the cumulative amount of energy applied over the entire course of treatment.

Given the plethora of devices available today, the spot size or ERA must be taken into consideration too. Using a device with a larger ERA or spot size but the same irradiance may result in a shorter treatment session because the larger the spot size, the fewer the number of sequential spot sizes needed to irradiate the target 70-cm^2 area. Indeed, if the applicator's ERA is large enough to cover the entire 70-cm^2 area, treatment could be done in one quick step without irradiating one spot size after another. Furthermore, it would be wrong to assume that giving 2100 J total energy to the patient at any dose or frequency of treatment would yield the same result. For example, delivering the entire amount of energy in just one treatment instead of six could be detrimental and destructive to the tissue. The goal should be to find the right combination of parameters to yield the desired results without solely focusing on the fastest way to perform treatment.

The exact size of the target tissue or lesion is an important consideration when translating research results to a unique clinical situation. If the target treatment area of a specific patient is 35 cm^2 and not 70 cm^2, in order to maintain the same dose level, a smaller amount of total energy would be needed. The converse would be correct if the target area is larger than 70 cm^2. These considerations illustrate the interplay between irradiance, target treatment area, and spot size or ERA; yet, other factors including those relating to the patient must be considered as discussed in the following section, if one is to achieve a positive result.

Patient-Related Factors

Each patient is a highly complex individual, differing in personal traits, behavior, physiology, and—at times—anatomy, when compared to another. Patients with the same diagnosis and history may respond differently to treatment. Besides individual differences, other factors may compel the clinician to modify the hypothetical research result presented above. Such factors include the presenting pathology, etiology, type of lesion (acute versus chronic condition), depth of the target tissue, skin pigmentation, and the overall condition of the patient, including patient's sensitivity to light. A brief discussion of how some of these factors can influence dose is presented below.

Pathology and etiology

Patients present with a wide range of pathological conditions and the etiology of each case may differ significantly from one patient to another. Additionally, from one clinical visit to the next the pathological condition of each case may change significantly, necessitating further modification of treatment. Such complexities make it almost impossible for a given dose to yield the same result at all times. For example, a swollen ulcer with exudates may require a different dose from a nonswollen dry ulcer, because fluid may alter the optical density of the tissue. Similarly, the effective dose for osteoarthritis may differ depending on the factor that provoked the initial destruction of cartilage—trauma, overweight, overuse, disuse, heredity, etc. Even within the same patient, an identical effective dose may not be applicable to every joint because of obvious anatomical and morphological differences, including joint size. Similarly, a chronically recurring inflammation may require a different set of treatment parameters than one without recurrence.

These points are highlighted to sensitize the clinician to common pathological and etiological variables that can influence treatment outcome even in the presence of hard data supporting a particular treatment approach. Providing a set of guidelines for each clinical scenario is daunting. Although it is desirable to have such guidelines, the field is still in its infancy and has yet to achieve such a level of knowledge. Most books offer useful suggestions and guidelines based on available literature and clinical experiences. However, they should be considered starting points for clinical decision making, because, consistent with the standards of practice in other fields, they are not unequivocally backed by hard clinical research data. For instance, there is a growing consensus that chronic lesions require a lower frequency of treatment at relatively higher dosages than acute cases, which are perceived to respond better to frequent treatments at relatively lower dosages. Much as it stands to reason that acute lesions require a different set of parameters than chronic lesions of the same pathology and etiology, there is a dearth of hard data supporting this notion; but, there are clinicians that swear by it. Truthful or not, a preponderance of hard data is needed to buttress such assertions, given the prevailing emphasis on evidence-based practice.

Optical density and nature of the target tissue

Optical density (OD) is a measure of transmittance of each wavelength of light through a medium. The higher the OD, the lower the transmittance; meaning that more light is absorbed within the medium and/or reflected by it. Thus, tissues with high ODs tend to absorb light energy more than those with low optical densities, and this property does not necessarily correlate with the physical density of the tissue. For example, bone, which is physically dense and strong, does not necessarily have a higher OD than skeletal muscle, as can be demonstrated by shining red light through bone and muscle separately. Since tissues with high OD absorb more light, relatively high dosages may not be necessary to achieve beneficial treatment effects. Similarly, a low OD

suggests that relatively higher dosages may be required to achieve the desired results, assuming that the same amount of energy is needed to achieve the desired result in both tissues. Certainly, there are no hard and fast rules about this, since, under certain conditions, an optically dense tissue may require high doses while a relatively translucent tissue may not. Moreover, the OD of a particular tissue may differ from one pathological condition to another. For example, an inflamed bone may evince a different optical property compared to one that is not inflamed.

Depth of the target tissue

As noted in the section on wavelength, wavelength exerts a significant influence on the depth of penetration of light. Within the therapeutic range of wavelengths, longer wavelengths are recommended for deep lesions, while shorter wavelengths are considered more appropriate for superficial target tissues. However, if one is limited to one wavelength of light—relatively long or short—clinically beneficial effects may still be achieved by manipulating the light source. For example, the brightness of a source with a relatively short wavelength can be enhanced at lower depths of tissue by increasing its power density. Moreover, increasing the duration of treatment increases the likelihood that a cumulatively larger quantity of photons or light energy will propagate to deeper tissue levels.

Skin pigmentation

Basically, the more pigmented or darker the skin, the less the amount of light penetrating the skin.[9–11] This is consistent with the practical observation that highly pigmented skin—particularly skin with high melanin—tends to suffer less damage from sunlight exposure than less pigmented skin. The clinical implication is that higher doses may be needed to deliver the same quantity of photons to the target tissue below the skin of persons with dark skin compared to those with light skin. Additionally, longer wavelengths may be more effective in treating deep lesion in individuals with darker skins.[9,11]

Open versus closed lesion

From the foregoing discussion, it should be clear that because light is absorbed by skin—whether light or dark—target tissues below the skin will receive fewer photons compared to those not covered by skin, i.e., open lesions. As with similar situations discussed previously, it may be necessary to adjust treatment parameters in order to compensate for the reduced amount of energy reaching target tissues below the level of the skin. Given the dearth of studies in this area, one must rely on clinical experience as a guide.

Concluding Remarks

In conclusion, a good therapeutic device is often only as good as the clinical skills of the end user, and good clinicians are similarly only as good as their tools allow. It takes the combination of excellent clinical tools and outstanding clinical skills to achieve desired clinical results. The purpose of this article would be achieved if it helps dispel common treatment misconceptions and fosters accuracy of dosimetry in phototherapy treatments for tissue repair and pain relief. The guidelines and standards, proposed by the World Association for Laser Therapy, for designing and conducting clinical studies and systematic reviews of the literature offer additional information.[12,13]

Disclosure Statement

No competing financial interests exist.

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