ISSN 1413-3555
Rev Bras Fisioter, São Carlos, v. 12, n. 1, p. 70-4, jan./fev. 2008

Analysis of low-level laser therapy doses in Brazilian equipment

Análise da dose do laser de baixa potência em equipamentos nacionais

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Abstract

Introduction: Low-level laser therapy is becoming more popular and there is a growing interest in its effects, as reflected in the increased number of articles published about the subject. Many therapists and researchers have used a laser dose definition based on energy density (ΔE). However, the variety of laser equipments may lead to differences in the therapeutic results found, since the parameters supplied by these equipments vary according to the manufacturer. Objective: To analyze the final energy transmitted to the tissue when applying the same ΔE using equipment of different Brazilian brands. Material and methods: Seven brands of Brazilian equipment with different mean power (Pm) were evaluated by means of simulations. ΔE of 1J/cm^2 was applied using each brand of equipment, in order to evaluate possible differences in the final energy. Results: The same ΔE applied using different brands of Brazilian equipment supplied final energy that ranged from 10 to 90mJ. This variation in the energy was mainly due to differences in Pm. These values ranged between 5.4 and 75mW. Conclusions: This variability in the final energy that is transmitted to the tissue indicates that ΔE may not be the best parameter for describing the dose to be used. In addition to ΔE, the final energy needs also to be stated, in order to establish the dose for obtaining the best therapeutic results.

Key words: low-level laser therapy; dose; parameters.

Resumo

Contextualização: A laserterapia de baixa potência vem sendo cada vez mais utilizada, e o crescente interesse por seus efeitos relaciona-se com a grande quantidade de publicações científicas. Muitos terapeutas e pesquisadores têm-se baseado na definição da dose do laser pela densidade energética (ΔE); porém, a grande variedade de equipamentos de laser pode levar a diferença nos resultados terapêuticos encontrados, por fornecerem parâmetros que variam de acordo com o fabricante. Objetivo: Analisar a energia final transmitida ao tecido ao aplicar-se a mesma ΔE em equipamentos de diferentes marcas nacionais. Materiais e métodos: Foram avaliados sete equipamentos nacionais, com potência média (Pm) diferentes, e foram realizadas simulações aplicando ΔE de 1J/cm^2 em cada aparelho, para avaliar possíveis diferenças na energia final. Resultados: A mesma ΔE aplicada em diferentes aparelhos nacionais forneceu energia final que variou entre 10 e 90mJ. Esta variação na energia deveu-se principalmente a diferenças na Pm, sendo encontrados valores entre 5,4 e 75mW. Conclusão: Esta variabilidade na energia final, que é transmitida ao tecido, indica que a ΔE parece não ser o parâmetro que melhor descreve a dose a ser utilizada. É preciso mencionar não só a ΔE, mas também a energia final, para que se possa estabelecer a dose para obtenção do melhor resultado terapêutico.

Palavras-chave: laser de baixa potência; dose; parâmetros.

Recebido: 27/11/2006 – Revisado: 23/07/2007 – Aceito: 8/11/2007

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Introduction

Low-level laser therapy has been investigated and used in clinical practice for approximately 20 years. The initial studies were done in Europe by Mester[1,2] at the beginning of the 1970s. There has been growing interest in the effects of laser energy, as shown by the significant quantity of scientific publications, with controlled experiments on both animals and humans[3,4].

However, researchers and therapists have questioned the clinical benefits of laser energy because of divergences in the encountered results, due to the lack of methodological standardization of the studies[1,2]. While some researchers have defended the idea that laser energy has therapeutic effects, others have contested such properties, thus highlighting the need for cautious interpretation of results when clinically reproduced.

In this sense, when characterizing a laser application, all its parameters need to be described in detail, such as wavelength, energy emitted to the tissue, energy density, beam area, duration of application, peak power, mean power (in the case of pulsed applications) and power density[1,5,6]. This complete description of the parameters has the function of helping the professional who is applying the laser therapy to clinically reproduce the findings from experimental trials.

One of the most important aspects of laser applications, and where the greatest divergences are found, is the dose, which is defined as the quantity of radiation emitted to the tissue. The ideal dose to be used is based on research in the literature describing successful laboratory practices, and is estimated according to the tissue to be irradiated, and adjusted according to the energy absorbed by each tissue, the duration of irradiation and the size of the affected area[7].

Contributing towards this difficulty in dose standardization, is that the various models of laser equipment provide parameters that may vary according to the manufacturer. Considering that the parameter most described in the literature is the energy density (ΔE), the same value used in different models of equipment may lead to variations in total energy absorbed by the tissue, which may give rise to a variety of effects and may even be harmful to the tissue to which it was applied[7-12].

In view of this, the present study had the objective of analyzing whether there are any differences in final energy transmitted to the tissue when applying the same ΔE using different equipment options available in Brazil.

Materials and methods

First, data relating to the infrared laser apparatus, with wavelengths of 904 or 905 nm, were gathered from the instruction manuals provided by the companies. Since some of the information was not found in the manuals, contacts were also made by telephone and/or the internet. The models and brands of the equipment were numbered as follows (Table 1): 1. Laser Plus Microcontrolled Communicator 904-25W (KW Equip. Eletr.); 2. Laser Plus Microcontrolled Communicator 904-75W (KW Equip. Eletr.); 3. Laserpulse (Ibramed); 4. Laser Endophoton LLT-IR (KLD Biosistemas); 5. Lasermed 4090 – 60W (Carci); 6. Lasermed 4090 – 20W (Carci); 7. Laser 904 (HTM Eletronica).

Seven companies with nine models of laser therapy equipment were originally selected. However, the equipment of "Kroman" and "Bioset" brands were excluded because of difficulties in obtaining complete information regarding their parameters.

The parameters investigated were: Peak power (***Pp***), pulse duration (***Tpd***), frequency (***f***), mean power provided by the manufacturer (***PmM***) and beam area. Using these data, the real mean power (***PmR***) and the irradiancy or power density (ΔP) were obtained. ***PmR*** was compared with ***PmM***. For these calculations, the following equations were used[1,13]:

$$Pm_R\ (W) = Pp\ (W) \times Tpd\ (s) \times f\ (Hz)$$
$$\Delta P\ (W/cm^2) = Pm_R\ (W)\ /\ \text{beam area}\ (cm^2)$$

Table 1. Technical characteristics of the equipment studied and their respective parameters: peak power (*Pp*), pulse duration (*Tpd*); frequency; manufacturers and real mean power (*PmM* and *PmR*); beam area; power density (irradiance) (ΔP), energy density (ΔE), application time to reach 1 J/cm² and final energy emitted. The final energy emitted was calculated using the *PmR*.

Equipment	Pp (W)	Tpd (ns)	Frequency (Hz)	PmM (mW)	PmR (mW)	Beam area (cm²)	ΔP (mW/cm²)	ΔE (J/cm²)	Time (s)	Energy (mJ)
1	25	200	5000	15.0	25.0	0.04	625.0	1	1.6	40
2	75	200	5000	40.0	75.0	0.04	1875.0	1	0.5	37.5
3	15	180	2000	5.0	5.4	0.07	77.1	1	13.0	70.0
4	50	100	10000	50.0	50.0	0.01	5000.0	1	0.2	10.0
5	60	160	2000	20.0	19.2	0.09	213.3	1	4.7	90.0
6	20	160	2000	7.0	6.4	0.07	91.4	1	10.9	70.0
7	50	200	2000	20.0	20.0	0.07	285.7	1	3.5	70.0

After calculating the above values, a simulation was done using an energy density (*ΔE*) of 1 J/cm^2 in all the equipment models. With the data obtained, the following equations[7] were used to show whether the energy emitted to the tissue (*E*) through the point of application would be equal in equipment with different *Pm*:

$$\Delta E\ (J/cm^2) = \Delta P\ (W/cm^2) \times t\ (s)$$
$$E\ (J) = Pm_R\ (W) \times t\ (s)$$

Results and discussion

In addition to the data obtained from the manufacturers, the calculations for each model of equipment are presented in Table 1. It was seen that the parameters obtained and calculated varied greatly according to the different types of equipment. Differences were found in the following parameters: peak power (15-60 W), pulse duration (100-200 ns) and frequency (2,000 to 10,000 Hz), which caused variations in the *PmR* calculations for each model of equipment (5.4 – 75 mW).

Comparing *PmR* with *PmM*, it was observed that in two of the seven models of equipment there was disagreement in the obtained values (equipment "1" and "2"), which could indicate a deficiency in the information generated by the manufacturers of the respective models. It is emphasized that, in this study, *PmR* was considered to represent the most reliable aspect of the data for each model of equipment.

The beam area obtained was slightly different between the investigated equipment models. When added to the great variations found in the calculated *PmR*, this gave rise to a large difference in the *ΔP* calculation (77.1 - 5000 mW/cm^2). Thus, the duration of the application needed to reach the selected energy density (1 J/cm^2) was directly influenced, since the equipment with lower *ΔP* needed longer application times per point.

When applying the same *ΔE* to the analyzed equipment, the variations in the duration of application and *PmR* led us to obtain different energy quantities for each type of equipment, with a range from 10 to 90 mJ for each application point.

Although the *Pm* of equipment "4" was relatively high (50 mW), the short duration of application needed to reach 1 J/cm^2 (0.2 s) contributed towards the low final energy that was obtained (10 mJ). Likewise, equipment "3", with a low *Pm* (5.4 mW) and a long application time (13 s), provided a relatively high final energy level (70 mJ). This would lead us to conclude that the energy is influenced mainly by the duration of the application. However, equipment "5" demonstrated the highest energy level (90 mJ), although it did not provide a prolonged application time (4.7 s), thus showing the need to specify all of the parameters used, and not only one parameter to characterize the selected dose.

Due to the great variety of tissue types exposed to laser treatments that have been described in the literature, some experimental findings have been correlated with the results of this present study. Most studies on laser application for cicatrizing skin wounds show positive effects, as observed through the proliferation of fibroblasts and endothelial cells, and increased deposition of collagen and keratin[4,12-15]. However, there is great variation in relation to the *ΔE* used, and the values found ranged from 1 to 21.4 J/cm^2 [12,15]. It is worth remembering that the calculated final energy levels in these studies were 1 and 1.5 J, respectively. Thus, different *ΔEs* were observed to produce similar final energy levels and physiological results. Correlating the previous data with that from the present study, it was observed that applying an *ΔE* of 21.4 J/cm^2 with equipment "4" and "5" would produce final energy levels of between 0.2 J and 1.9 J, respectively. This difference in the final dose may not be numerically significant, but it may have a therapeutic influence, if it is considered that there is a therapeutic window for anti-inflammatory, analgesic and cicatrizing effects for each tissue.

In evaluating cell growth and collagen synthesis in fibroblast cultures, Pereira et al.[16] concluded that an *ΔE* of 3 or 4 J/cm^2 produced better results than did 5 J/cm^2. In analyzing these data, it can be seen that the final energy levels obtained in their study were 2.9 J, 3.9 J and 4.8 J, respectively. Bjordal et al.[7] stated that doses over 4 J for each point might inhibit fibroblast activity. These studies show that high energy doses do not seem to provide the best effects for tissue repair.

Also with regard to the effects of doses with specific therapeutic aims, Matera et al.[4] stated that the *ΔE* recommended in laser therapy to promote increased numbers of fibroblasts and collagen fibers, and increased vascularization and reepithelialization, should be between 1 and 5 J/cm^2. In their study, they concluded that 2 J/cm^2 demonstrated better results than 4 J/cm^2.

In the same way, Pugliese et al.[17] observed the influences of the GaAlAs laser on the biomodulation of elastic fibers and collagen in skin wounds in rats, concluding that 4 J/cm^2 was superior to 8 J/cm^2. However, neither their study nor that of Matera et al.[4] stated the parameters needed to arrive at the final energy, although Matera pointed out the importance of giving details about the dose.

Contradicting the findings that pointed towards a probable therapeutic window for lasers with *ΔE* below 5 J/cm^2, Hopkins et al.[13] evaluated changes in experimental human wounds using an 820-nm laser at 8 J/cm^2. From two skin abrasions produced on the same limb, there was success in improving the stimulated wound and also in relation to the non-irradiated wound, in comparison with another group that did not receive laser irradiation. This leads us to believe that laser energy probably has a systemic effect. It is worth remembering that the final energy used in their study was 1.8 J for each point of application.

To reach this final energy of 1.8 J in the laser equipment that we analyzed, five minutes and thirty seconds would be needed for each application point using equipment “3”, with a *Pm* of 5.4 mW, and four minutes and 40 seconds would be needed using equipment “6”, which demonstrated a *Pm* of 6.4 mW. We put forward the idea that it may be important to use the Brazilian equipment with greater *Pm*, in order to decrease the duration of each laser therapy application, thus facilitating the clinical applicability.

It could be seen that *ΔE* alone did not seem to be the ideal parameter to be followed for studies to be reproduced clinically. The scientific evidence is contradictory, principally because of the lack of details on the dose used, thus making it difficult to identify the final energy transmitted to the tissue. The diversity of the subjects exposed to irradiation, i.e., humans or experimentation animals, also contributes towards obtaining different results.

In analyzing some studies on the effects of laser energy for cicatrizing tendons, these also were found to show great variety in their choice of parameters. In a study on the use of the GaAs laser for tendon cicatrization in rats, Tavares et al.[18] stated that the *ΔE* responsible for the cicatrizing effect must be around 3 to 6 J/cm^2. For this reason, they used 4 J/cm^2, and this generated satisfactory results. It is worth emphasizing that their study does not mention other parameters, such as the duration of application and the beam area, and that their *Pm* does not correspond to the calculated *Pm* based on the parameters used.

Other studies[19,20] also used *ΔE* within this range, i.e., 3.6 and 5 J/cm^2, obtained positive results from cicatrization with different energy levels: 5.4 J and 1.5 J, respectively. Demir et al.[21] chose an *ΔE* of 1 J/cm^2 for tendon repair in rats, which was outside of the range proposed by Tavares et al.[18], thereby obtained success with a final energy level of 0.36 J. By correlating this result with our study, and by using equipment “4” with the same *ΔE* (1 J/cm^2) for the same period of time (60s) that was applied by Demir et al.[21], we would obtain a final energy level of 3 J. Likewise, if we wanted to reach a final energy of 0.36 J using 1 J/cm^2 with the same equipment, only 0.3s of application would be required. Therefore, it is presumed that the use of the same *ΔE* level in equipment with different *Pm* offers divergent physiological results, which could be explained by the large differences in the final energy levels transmitted to the tissue.

The applicability of laser energy to nerve tissues seems to be one of the most controversial areas of phototherapy[22]. In the study by Chen et al.[23], inhibition of nerve regeneration in rats occurred with energy densities between 2 and 15 J/cm^2 and energy levels, approximately, between 1.6 and 6.5 J. In disagreement with these findings, Miloro et al.[24] showed positive results with 6 J/cm^2 and 6.3 J of emitted energy in a synthetic tube. It may be presumed that there were differences in the obtained results because the samples were not identical. However, Bagis et al.[25] also studied the effect of laser energy on the nerve tissue of rats and did not obtain significant results, using *ΔEs* between 0.31 and 19 J/cm^2 and energy levels between 0.09 and 5.3 J. To reach these final energy values, the authors used a prolonged application time (900s) for their equipment with a low *Pm* (0.02-0.08 mW). As can be seen, there is a need for more clinical trials with better descriptions of the characteristics of the laser and the biological effects of phototherapy on nerve regeneration[22].

These and other studies reinforce the doubts that exist when establishing the laser dose through the total energy: do the best therapeutic effects obtained through laser irradiation on the tissue occur when a high power is emitted for a short time or a lower power is emitted for a more prolonged time?

In addition to the parameters needed for establishing an ideal dose for low-level laser applications, some other questions still need to be answered. One of these is in relation to the use of laser energy on infected tissue. Infection has always been considered to be an absolute contraindication for the application of phototherapy because the effects of laser energy on the growth of bacteria still remain obscure.

In an *in vitro* study[26], application of red laser induced the death of the photosensitive organisms *Staphylococcus aureus* and *Pseudomonas aeruginosa* using doses of 0.1, 0.2 and 0.4 J/cm^2 with an HeNe laser and 2.5, 5 and 10 J/cm^2 with an InGaAl laser. Several parameters that were used are mentioned in the study, making it possible to calculate the final energy levels: 0.028, 0.057 and 0.114 J with the HeNe laser and 0.15, 0.3 and 0.6 J with the InGaAl laser.

However, Navratil et al.[27] reported that GaAs laser applications might stimulate bacterial growth with *ΔE* of 0.33 J/cm^2, similar to what was used in the preceding study. Nonetheless, they did not report the final energy transmitted. For laser energy to have a bactericidal effect, their data concur with our hypothesis that *ΔE* cannot be the only way to establish the dose.

The analysis of these various studies leads us to highlight the need for equipment in Brazil that not only provides the calculation of the *ΔE* dose, but also informs the final energy levels emitted to the tissue. In this way, the parameters used could be better described, which would facilitate the clinical reproduction of successful trials.

Conclusion

It was concluded that the use of the same *ΔE* in equipment with different *Pm* values may provide variable final energy levels, thus indicating that *ΔE* does not seem to be the parameter that best describes the dose to be used. It is necessary to mention not only the *ΔE* but also the final energy level, so that the dose for obtaining the best therapeutic results can be established.

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