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Stimulation of Low-level Laser Light Transmission from the Skin Surface to The Tibia Using The Monte Carlo Method

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Abstract

The patient experiences trouble walking and surviving as a result of tibia fractures or tibial osteoporosis. The tibia, a crucial bone in the lower extremities that requires the longest recovery time, as well as the relatively low level of activity in the legs, are both factors. In the patient's day-to-day existence, this has a substantial effect. Regenerating tissue, reducing pain, and reducing inflammation are all effects of low-level laser light. In this work, the effects of lasers of four different wavelengths—633 nm, 780 nm, 800 nm, and 940 nm—were examined using the Monte Carlo approach. We put the curve fitting technique into practice using the parameters we learned from the outcomes of the many Monte Carlo simulations. With an RSME of 2.62% and 1.32%, respectively, the findings demonstrated the link between energy and beam radius with regard to depth. We anticipate that the study will provide a quick analysis of how laser beams affect different regions in order to improve treatment settings.

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1 Introduction

Light's application in contemporary medicine began in the nineteenth century, with significant advancements. advance in understanding both the physical nature of light and light-matter interactions [1]. Photons interact with biological materials in tissue via a variety of mechanisms, which can be classed as dispersion or absorption [2]. Scattering has the potential to alter the transmission path, as well as the polarity and spectrum of the dispersed light. Scattering light states may be examined and plotted. diagnostic maps [3].

A tibial fracture or osteoporosis makes walking and life difficult for the sufferer. The tibia is an essential bone in the lower limbs; it is also the one that takes the longest to heal and has very restricted flexibility [4]. As a result, it has a significant impact on patients' everyday life. For many years, researchers have been investigating the use of low-power semiconductor lasers in bone regeneration therapy [5]. Low-power lasers have the ability to regenerate tissue, relieve pain, and reduce inflammation.

The first lasers were utilized in medical applications not long after their discovery (the ruby laser in 1960 and the helium-neon [HeNe] laser in 1961 [6]. Endre Mester of Hungary discovered the capacity of the He-Ne laser to accelerate wound healing and boost hair development in mice in 1967, and shortly after began utilizing the laser to treat people with non-healing skin wounds [7]. Since then, the use of low-power lasers (as opposed to high-power lasers, which kill tissue via photothermal effects) has become increasingly common in clinical settings to heal illnesses and prevent tissue damage [8][9]. Death, pain relief, decrease of inflammation, and regeneration Low-level laser treatment has been shown to be useful in treating a variety of organ systems, illnesses, and injuries [10].

2 Method

2.1 Monte Carlo Method

The Monte Carlo simulation is a fundamental and adaptable modeling technique. Light transport in tissue is a model-based approach for modelling physical processes. The Monte Carlo approach tracks the history of photons as they are scattered and absorbed in the radiation transport issue. The Monte Carlo simulation is seen in Figure 1 "Photons" are delivered into the tissue at a place given by the x, y, and z coordinates associated with the trajectory predicted by the directed cosine in generic Monte Carlo simulations. The random distance traveled before the photon contacts with the tissue is determined by selecting a random number [0, 1] and the medium's local attenuation coefficient. The number of photons is lowered by one at the conclusion of each photon step. A scattering function (or "phase") function that depicts the angular dependency of single scattering by the individual tissue directing the residual amount of non-absorption. When a new route is selected, the photon travels a random distance once more.

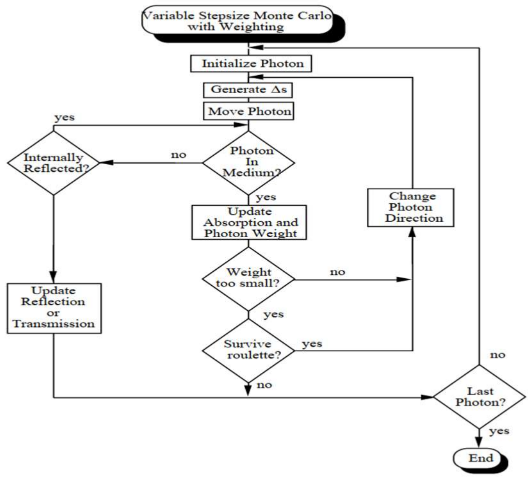


Figure 1. The flow chart of a Monte Carlo program

Figure 1 shows a flowchart of the steps of a Monte Carlo program. The photon travels a fraction of an inch at the start of the program, where it can be dispersed, absorbed, transmitted, or reflected inside or outside of the tissue. If the photon is absorbed, the absorbed spot is recorded. When the two-layer border is reached, the software checks to determine whether there are any internal reflections or photons exiting the tissue. If the photon is internally reflected, the photon location is modified and the program proceeds; otherwise, the photon exits and records the data. A little part of the (1-aw) photon packet will be absorbed step by step by continuing photons. This section is recorded, and the photon weights are modified as a result. If the photon weight exceeds the minimum, a program is run to determine if the photon has ended or continues to propagate. If the photon does not exist, a new photon packet is initiated. The procedure will be run until the desired amount of photons are sent.

2.2 Experiments

In this study, we use Optical parameters of layers at a wavelength of 633 nm, 780, 800, 940 nm, respectively in Table 1.

Table 1. Optical parameters of layers at a wavelength of 633, 780, 800, 940 nm.

Wavelength [nm]	Layer	n	Thickness	μ_a $[cm^{-1}]$	μ_s $[cm^{-1}]$	g
633	Bandage powder	1.52	0.7	0.1	0.99	0.68
	Skin	1.37	0.13	0.334	272.9	0.81
	Fat	1.42	0.23	0.128	125.5	0.91
	Anterior tibial muscle	1.4	0.36	1.32	89.6	0.97
	Tibial	1.43	1.6	0.8	271	0.85
780	Bandage powder	1.52	0.7	0.1	0.99	0.68
	Skin	1.37	0.13	0.142	197.3	0.81
	Fat	1.42	0.23	0.0846	114.67	0.91
	Anterior tibial muscle	1.4	0.36	0.331	71.2	0.97
	Tibial	1.43	1.6	0.57	133.15	0.85
800	Bandage powder	1.52	0.7	0.1	0.99	0.68

	Skin	1.37	0.13	0.1	187	0.81
	Fat	1.42	0.23	0.11	95	0.91
	Anterior tibial muscle	1.4	0.36	0.273	68.7	0.97
	Tibial	1.43	1.6	0.9	170	0.85
940	Bandage powder	1.52	0.7	0.1	0.99	0.68
	Skin	1.37	0.13	0.1905	156.7	0.81
	Fat	1.42	0.23	0.168	108.6	0.91
	Anterior tibial muscle	1.4	0.36	0.401	58.1	0.97
	Tibial	1.43	1.6	1	151	0.85

3 Results and Discuss

Figure 2 represents the absorption distribution when transmitted with wavelength: 633, 780, 800, and 940, respectively. Overall, at a wavelength of 633 nm there is the lowest depth penetration (~2cm) and the wavelength of 780 nm has the highest depth penetration (~2.3 cm).

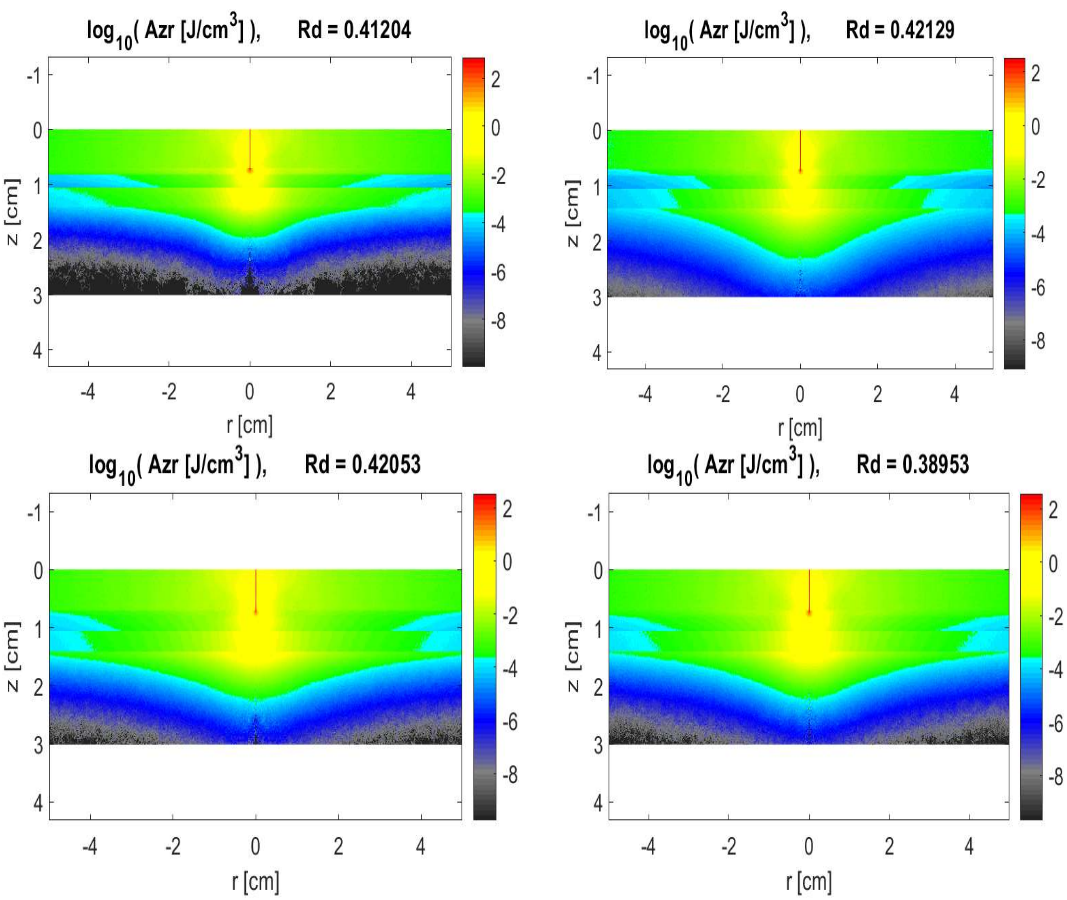


Figure 2. The energy density of the wavelengths according to the depth and radius of the beam. (A): Wavelength 633nm; (B): Wavelength 780nm; (C): Wavelength 800nm; (D): Wavelength 940nm.

Under experimental conditions, the illumination power is 20J and uses 2 million photons. Results from the graph show that at a wavelength of 780 nm, it reaches the biological surface, facilitating the process of biological stimulation to take place in Figure 3.

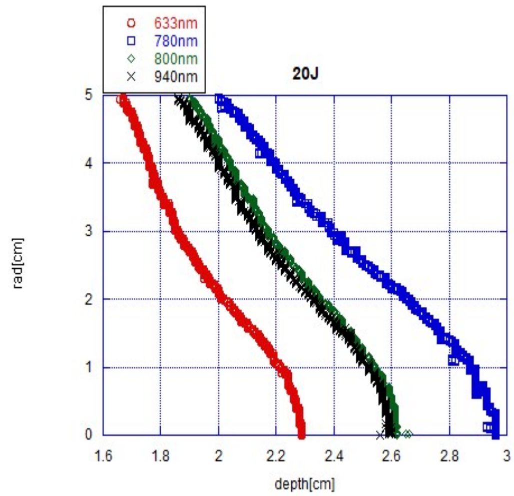


Figure 3. The penetration depth of the wavelengths according to the energy levels with 20J.

In addition, we perform the equation of the depth function by energy and the beam radius function by energy. Using depth relationship data, beam radius by energy at wavelength 780 nm obtained from MCML and CONV algorithms in combination with curve fitting.

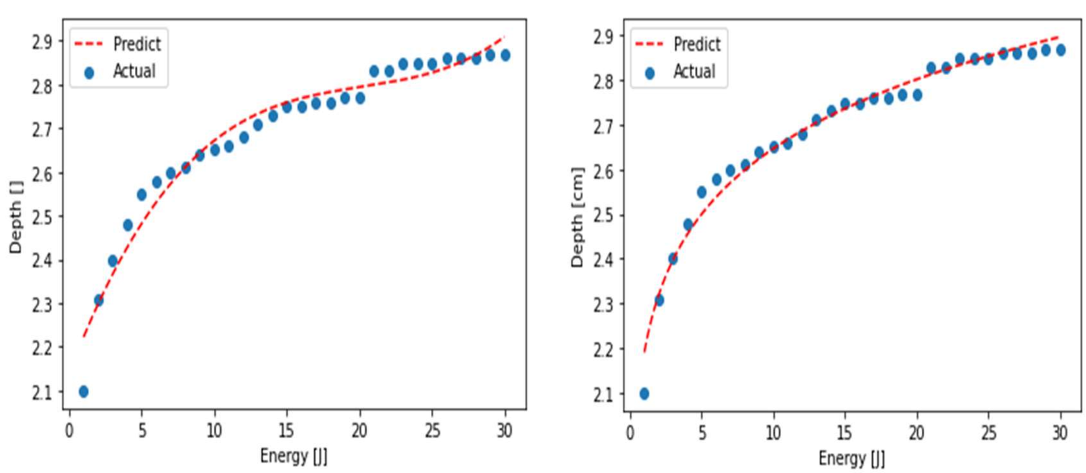
In the case of the depth function by energy, the result is In Figure 4A, we obtain an energy depth equation that looks like the equation

$$D = 0.08714 \times E - 0.00406 \times E^2 + 2.13912 \qquad (1)$$

with a Root Mean Square Error (RMSE) value of 3.72%. And Figure 4B, we obtained a depth equation by energy that looks like equation

$$D = 2.19022 \times E^{0.08213} \qquad (2)$$

with an RMSE value of 2.62%.



A B

Figure 4. The graph shows the actual and predicted values of the energy function over depth.

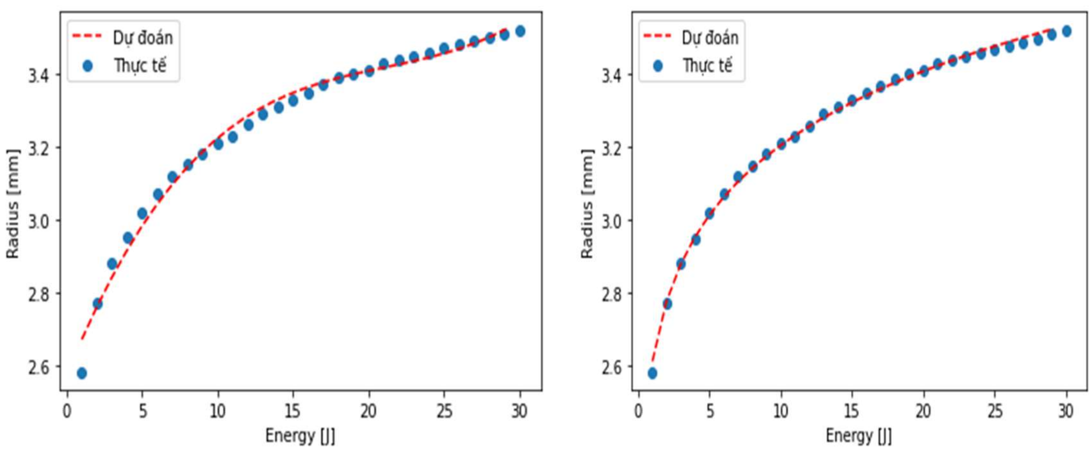
In the case of the function of beam radius by energy, the result is Figure. In Figure 5A, we obtain a beam radius equation by energy that looks like equation:

$$R = 0.10237 \times E - 0.00442 \times E^2 + 0.00007 \times E^3 + 2.57202 \quad (3),$$

with a Root-Mean Square Error (RMSE) value of 2.63%. And Figure 6B, we obtain the beam radius equation by energy that looks like the equation:

$$R = 2.61008 \times E^{0.08917} \quad (4)$$

with an RMSE value of 1.32%.



A B

Figure 5. The graph shows the actual and the predicted value of the beam radius function against depth.

4 Conclusion

Tibia fractures or osteoporosis of the tibia cause difficulty in walking and living for the patient. The tibia is an important bone of the lower extremities, which takes the longest time to recover, and the activity of the legs is also relatively limited. This has a significant impact on the daily life of the patient. Low level laser light has the effect of tissue regeneration, pain relief, and inflammation reduction. In this study, we used the Monte Carlo method to survey the impact of lasers on the tibia area with 4 wavelengths: 633 nm, 780 nm, 800 mn, and 940 nm. We implement the curve fitting method using the parameters obtained from the Monte Carlo simulation results at different wavelengths. The results showed the relationship between energy and the beam radius by depth with a RSME of 2.62% and 1.32%, respectively. We hope that the study will support the rapid survey of the impact of laser beams on other areas that help optimize the parameters in treatment.

Acknowledgment

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