Sakarya University Journal of Science, 22(4): 1095-1100, 2018.

SAKARYA UNIVERSITY
JOURNAL OF SCIENCE

e-ISSN: 2147-835X
http://www.saujs.sakarya.edu.tr

Received	Revised	Accepted	DOI
04.08.2017	03.07.2018	14.11.2017	10.16984/saufenbilder.332802

Measurement of the Penetration Depth in Biological Tissue for Different Optical Powers

Halil Arslan*[1], Yaşar Barış Doluğan[2], Ayşe Nur Ay[3]

ABSTRACT

In photodynamic therapy, the knowledge of the penetration depth for the light is needed in order to ensure that the adequate optical energy is received by the tumorous tissue. In this study, the optical penetration depth of 635 nm laser light in chicken breast tissue has been measured by using 8 tissue samples with different thicknesses between 2.5 mm and 9.0 mm. Transmitted light intensities through the tissue samples have been measured for 11 different optical power values in the range of 130 mW – 660 mW. Measurement results for each power value have been analyzed according to the Beer-Lambert law. With the help of statistical analyzes, it has been determined that the optical penetration depth in biological tissue does not depend on the optical power.

Keywords: PDT, Penetration depth, Beer-Lambert law

1. INTRODUCTION

As the medical applications of laser have increased, understanding of the propagation of laser light in biological tissue becomes essential for effective diagnosis and therapy. For example, in photodynamic therapy (PDT), such knowledge is crucial to ensure that the adequate optical energy is received by the tumorous tissue.

PDT requires the use of tumor-localizing photosensitizing agent together with the light of a wavelength specific to activation characteristics of the photosensitizer [1]. After the photosensitizer molecules absorb the light, they transfer the energy directly to molecular oxygen to form singlet oxygen. Thanks to its high reactivity and short half-life, the singlet oxygen causes the death of tumor cells near by [2]. In addition to the photosensitizer concentration, determination of the optical dose received by the target tissue accurately is very important for a successful treatment without damaging the healthy tissue [3,4]. The optical properties of the target tissue must be accurately characterized in order to determine the distribution of the light within that tissue [5]. The optical penetration depth is one of the commonly studied parameters since it is an indicator of light transmittance through tissues [6]. There exist many studies in the literature indicating the experimental results for the penetration depth of the light of different wavelengths in various tissue types (see, for example, [7-10]).

Propagation of the light in a biological tissue is known to be complicated because of the multiple scattering effects. When the light enters the tissue, it is either scattered or absorbed depending on the wavelength and the tissue type. However, several

[1] Faculty of Technology, Electrical- Electronics Engineering Department, Sakarya University, Turkey, harslan@sakarya.edu.tr
[2] Institute of Natural Sciences, Biomedical Engineering Program, Sakarya University, Turkey
[3] Faculty of Technology, Mechatronics Engineering Department, Sakarya University, Turkey

techniqes have been used to analyze the interaction of light with tissue. For example, Monte Carlo method is used to simulate photon transport in tissues since 1983, when it was first introduced by into the field of light tissue interactions [11]. Recently, this method has been utilized to determine the penetration depth in muscle tissue for two different wavelengths [12].

In addition, Beer-Lambert law, which explains the exponentially attenuation of the light as it passes through the tissue, is also used to compute the optical penetration depth. According to the law, transmittance (T), which is the ratio of the transmitted light (I) to the incident light (I_0), is given by the equation;

$$T = \frac{I}{I_0} = e^{-\mu d} \quad (1)$$

where μ is the attenuation coefficient and d is the thickness of the tissue sample. The depth at which the transmittance inside the tissue equals to "$1/e$" is defined as penetration depth (δ). Therefore, the transmittance can be written in terms of the penetration depth as;

$$T = e^{-d/\delta} \quad (2)$$

After the detection of the light intensities transmitted through the slab of tissue with various thicknesses, Beer-Lambert law can be used by fitting an exponential curve to the results [13].

In this study, the optical penetration depth in chicken breast tissue has been measured by using 635 nm PDT laser system. The experiments have been repeated for 11 different optical power values from 130 mW to 660 mW and the results have been statistically tested.

2. MATERIAL AND METHODS

2.1. Experimental Setup

The experimental setup used in this study for measuring the optical penetration depth is shown in Figure 1.

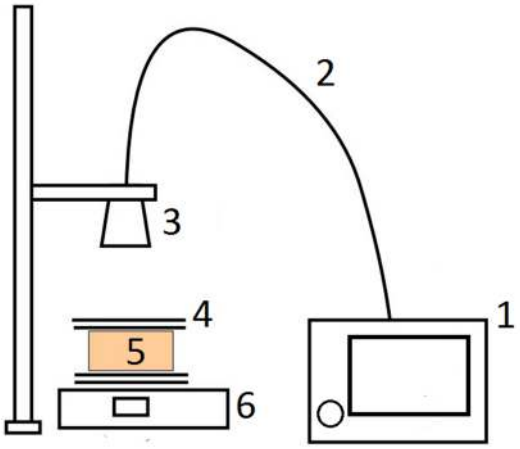

Figure 1. Experimental setup for measuring the optical penetration depth in biological tissue. **1**: PDT laser device **2**: Fiber optic cable **3**: Collimator **4**: Microscope slide **5**: Tissue sample **6**: Array powermeter.

PDT laser device used in this study is known as LAXCELL T3000 PDT laser system, which is purchased from a Korean company, Bio-Optics Co. Although the system offers three different radiation modes (continuous, burst, burst-pulse), it was run only in continuous mode during the experiments. The system produces an effective and stable optical wavelength of 635 nm with a maximum optical power of 1.5 W [14]. Wavelength measurement results of the laser system has been plotted in Figure 2.

The laser system has been connected to a collimator by using an optical fiber. The collimator has been used to obtain a parallel beam of 635 nm light.

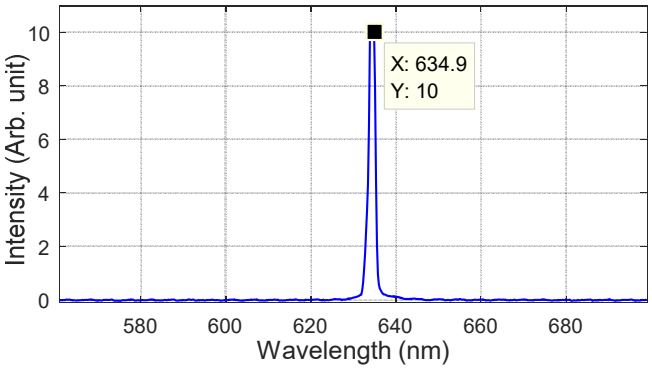

Figure 2. Wavelength spectrum of PDT laser device

Chicken breast tissue samples have been used in the experiment. For this purpose, raw chicken breast tissues have been kept in room temperature for 20 minutes, and then fatty and skin parts have been removed. 8 different tissue samples with

different thicknesses in the range between 2.5 mm and 9 mm have been prepared and then each sample has been placed between two microscope slides.

For the measurement of the optical power, an array powermeter with an active area of 1 cm^2 has been used in the experiment. During the measurements, the experimental setup has been isolated so that no external light source could affect to the measurement results. By using the powermeter, optical power of the transmitted light through the tissue samples have been measured together with the one through empty slides. The same procedure has been repeated for 11 different optical power values from 130 mW to 660 mW. Transmittance values have been obtained by dividing the powers of the transmitted lights through the tissue samples to that for empty slides.

2.2. Statistical Tests

In this study, measurement results have been analyzed by using two different statistical tests, which are ANOVA and correlation tests. All the statistical analyses of this study have been completed by using Microsoft Office Excel 2013 program.

Firstly, the statistical test called One-Way ANOVA has been performed in order to obtain the effect of optical power to the transmittance of the light through the tissue samples. In an ANOVA test, null and alternative hypothesis should be set. The alternative hypothesis assumes that there is a significant difference between the groups whereas, the null hypothesis assumes that there is no significant difference among the groups. After setting the hypothesis, F-ratio and probability of the F must be calculated. Later on, the critical p value of the F-ratio should be compared with the established alpha. Generally, the p value associated with the F must be smaller than the value of 0.05 in order to reject the null hypothesis and accept the alternative hypothesis [15].

In addition to ANOVA, the correlation between the optical power and penetration depth has been determined statistically. The correlation test shows whether there is a relationship or a connection between two or more group of data sets [16]. In this study, the test has been performed in order to determine if there is a correlation between the optical power and the penetration depth.

3. RESULTS AND DISCUSSION

Measurement results for the transmittances of 635 nm laser through different thicknesses of chicken breast tissue samples for the optical powers from 130 mW to 660 mW obtained in this study are given in Table 1.

Table 1. Transmittances for different thicknesses (d) of tissue samples and optical powers (O.P.)

O.P.\d	2.5 mm	3.0 mm	3.5 mm	4.0 mm	5.0 mm	6.5 mm	7.5 mm	9.0 mm
130 mW	0.38	0.34	0.26	0.23	0.2	0.18	0.15	0.12
160 mW	0.36	0.32	0.3	0.25	0.2	0.18	0.16	0.13
190 mW	0.36	0.32	0.28	0.24	0.21	0.18	0.16	0.13
260 mW	0.36	0.31	0.27	0.23	0.2	0.17	0.15	0.12
320 mW	0.36	0.31	0.28	0.25	0.21	0.16	0.15	0.12
350 mW	0.38	0.31	0.28	0.24	0.21	0.18	0.16	0.12
380 mW	0.38	0.36	0.3	0.25	0.24	0.18	0.16	0.13
450 mW	0.36	0.32	0.28	0.23	0.2	0.17	0.15	0.12
520 mW	0.37	0.31	0.26	0.23	0.18	0.17	0.15	0.12
590 mW	0.36	0.33	0.3	0.26	0.22	0.21	0.17	0.14
660 mW	0.36	0.33	0.29	0.26	0.23	0.17	0.15	0.13

As it is shown in the table, transmittances of the light through a specific thickness of tissue sample for different power values are close to each other. However, one-way ANOVA tests have been used in order to compare the mean transmittances between 11 different optical power values. Later on, the correlation between the penetration depth and the optical powers have been checked. The criterion for statistical significance for all of the analyses has been set to a value of P = 0.05 [17].

The ANOVA test results for the transmittance values are given in Table 2. The first column of the table represents the optical power values. In the test, P-value is a key issue to obtain the difference between the groups. In order to determine whether there is significant different between two data sets, the p value should be less than 0.05. However, as it can be seen from the table, p value of this test has been found to be greater than 0.05. This means that there is no significant difference between the

data sets regarding to the optical powers [18]. Since the F value changes regarding to the p value, one can also determine the results by checking F and F_crit values. In this ANOVA test, the F value is less than F_crit which also refers that the transmittance of the light through the tissue sample does not depend on the optical power.

Table 2. ANOVA test result

Opt. Power	*Count*	*Sum*	*Mean*	*Var.*	
130 mW	8	1.86	0.23	0.0082	
160 mW	8	1.90	0.24	0.0069	
190 mW	8	1.88	0.24	0.0065	
260 mW	8	1.81	0.23	0.0068	
320 mW	8	1.84	0.23	0.0071	
350 mW	8	1.88	0.24	0.0073	
380 mW	8	2.00	0.25	0.0084	
450 mW	8	1.83	0.23	0.0072	
520 mW	8	1.79	0.22	0.0073	
590 mW	8	1.99	0.25	0.0060	
660 mW	8	1.92	0.24	0.0072	
ANOVA					
Sour. of Var.	***SS***	***MS***	***F***	***P-value***	***F_crit***
Between G.	0.0057	0.0006	0.0800	0.9999	1.9560
Within G.	0.5531	0.0072			

In addition to tranmittances, penetration depths have also been analysed. For this purpose, transmittances given in Table 1 have been plotted separately for each optical power value as a function of tissue thickness. Each graph has been fitted to the function of $e^{-x/\delta}$ in order to get the penetration depth (δ). As an example, the plot of transmittance vs. tissue thickness for 660 mW is given in Figure 3 together with the fit curve (solid line), which yields 5.83±0.30 mm penetration depth.

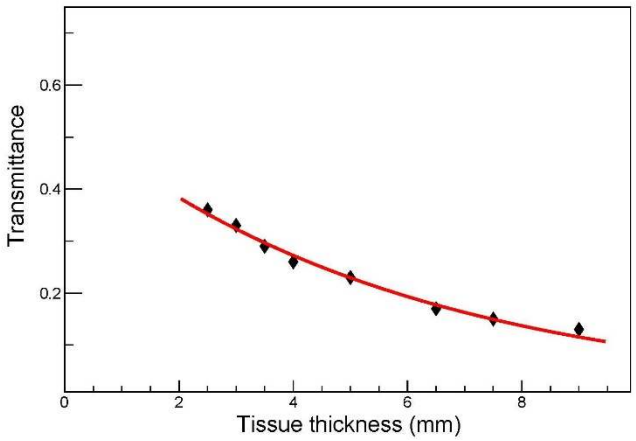

Figure 3. Transmittance as a function of tissue thickness for the optical power of 660 mW

After the penetration depth for each optical power value has been calculated, the results have been analyzed by performing the correlation test. The result of the correlation calculation is given in Table 3 together with penetration depth values for the optical powers of the interest.

Table 3. Correlation between the optical power and penetration depth

Opt. Power (mW)	**Pen. Depth (mm)**		**Correlation**	
130	5.29±0.77		***Power***	***Pen. Depth***
160	5.94±0.55	*Power*	1	
190	6.09±0.58	*Pen. Depth*	0.28	1
260	5.64±0.59			
320	5.57±0.37			
350	5.70±0.64			
380	5.64±0.52			
450	5.53±0.56			
520	5.36±0.77			
590	6.82±0.58			
660	5.83±0.30			

As it can be seen from the table above, penetration depth values obtained for different optical powers are closed to each other. If there is a strong

relationship between two groups of data, the correlation value of the test would be grater than 0.7. The correlation value of the test performed in this study has been found to be 0.28, which means there is no correlation between the penetration depth and the optical power.

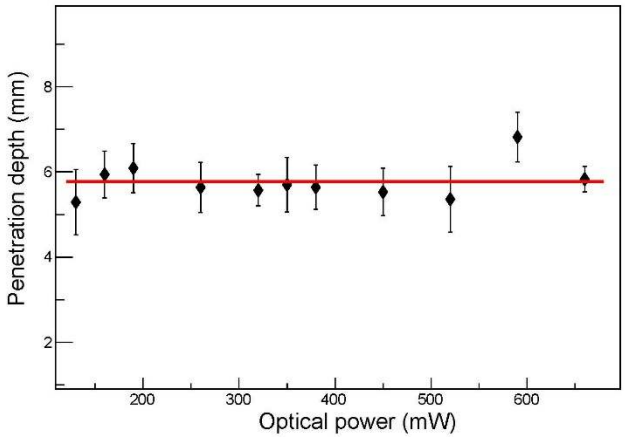

Figure 4. Penetration depth as a function of optical power

In Figure 4, the penetration depth is illustrated as a function of optical power. Solid line represents the mean penetration depth value that is found to be 5.77±0.57 mm. This value is consistent with the results of the experimental studies performed by different groups [8, 19]. All of the penetration depth values are closed to this value except the one for the optical power of 590 mW. This disagreement may be caused from some systematical errors during the measurement. Depending on the results of statistical tests, it can be said that changing the optical power does not affect the penetration depth of the light in target tissue. Based on this finding, which is agree with the literature [20], the following deduction related with the clinical application can be made; in PDT, delivering the light to deeper sides of the tumor can not be achieved by just increasing the optical power.

4. CONCLUSION

In this study, the optical penetration depth in chicken breast tissue has been measured by using 635 nm PDT laser system. Transmittances through the tissue samples with different thicknesses have been determined and the same procedure has been repeated for 11 different optical power values from 130 mW to 660 mW. Penetration depths have been determined by analyzing the results according to Beer-Lambert law. The results of the transmittances and the penetration depths have been statistically tested. According to the ANOVA test, it has been found that the transmittances of the light through the tissue samples of specific thicknesses have similar values for different optical powers. The results of the correlation test have been found to be consistent with the ANOVA. According to the test, penetration depth has no correlarion with the optical power. Therefore, increasing the optical power is not an effective way in order to deliver the light to deeper sides of the tumorous tissue in PDT. As a result, the mean optical penetration depth for chicken breast tissue at 635 nm has been calculated as 5.77±0.57 mm, which is agree with the previous experiments.

ACKNOWLEDGMENTS

This study is supported by Sakarya University Scientific Research Projects Coordination Unit. Project Number: 2017-09-00-013.

REFERENCES

[1] T.J. Dougherty, C.J. Gomer, B.W. Henderson et al., “Photodynamic Therapy”, *J Natl Cancer Inst*., 90(12), pp. 889–905, 1998.

[2] A.P. Castano, T.N. Demidova, and M.R. Hamblin, “Mechanisms in photodynamic therapy: part one—-photosensitizers, photochemistry and cellular localization”, *Photodiagnosis Photodyn Ther.*, 1(4), pp. 279–293, 2004.

[3] L. Grossweiner, “Light dosimetry model for photodynamic therapy treatment planning”, *Lasers Surg Med*., 11(2), pp. 165-173, 1991.

[4] T.C. Zhu and J.C. Finlay, “The role of photodynamic therapy (PDT) physics”, *Med Phys*., 35(7), pp. 3127–3136, 2008.

[5] Z. Huang, H. Xu, A.D. Meyers et al. “Photodynamic therapy for treatment of solid tumors – potential and technical challenges”, *Technology in Cancer Research & Treatment*, 7(4), pp. 309–320, 2008.

[6] M.R. Arnfield, J.D. Chapman, J. Tulip, M.C. Fenning and M.S. McPhee, "Optical properties of experimental prostate tumors in vivo", *Photochem. Photobiol.,* 57(2), pp. 306-311, 1993.

[7] S. Stolik, J.A. Delgado, A. Pe´rez and L. Anasagasti, "Measurement of the penetration depths of red and near infrared light in human ex vivo tissues", *J. Photochem. Photobiol. B, Biol.,* 57, pp. 90-93, 2000.

[8] Y.B. Dolugan, H. Arslan, M.Z. Yıldız, A.E. Ozdemir, A.F. Kamanlı and A.N. Ay, "Measurement of the optical penetration depth in chicken breast tissue" in *Proceedings of the 5th International Conference on Advanced Technology & Sciences*, 2017, pp. 222–222.

[9] H. Kolarova, D. Ditrichova and J. Wagner, "Penetration of the Laser Light Into the Skin In Vitro", *Lasers in Surgery and Medicine*, 24, pp. 231–235, 1999.

[10] D.C. Shackley, C. Whitehurst, J.V. Moore, N.J.R. George, C.D. Betts And N.W. Clarke, "Light penetration in bladder tissue: implications for the intravesical photodynamic therapy of bladder tumours", *BJU International*, 86, pp. 638-643, 2000.

[11] B.C. Wilson and G. Adam, "A Monte Carlo model for the absorption and flux distributions of light in tissue", *Med Phys.*, 10(6), 824–830, 1983.

[12] H. Arslan, "Simulation Study for the Penetration Depth of Red and Near Infrared Light in Muscle Tissue" in *Proceedings of the 4th International Symposium on Innovative Technologies in Engineering and Science*, 2016, pp. 329–333.

[13] A. Abdo, A. Ersen, and M. Sahin, "Near-infrared light penetration profile in the rodent brain", *Journal of Biomedical Optics*, 18(7), 075001, 2013.

[14] H.S. Lim, "Reduction of thermal damage in photodynamic therapy by laser irradiation techniques", *Journal of Biomedical Optics*, 17(12), 128001, 2012.

[15] Statistics Solutions. (2013). ANOVA Retrieved from: http://www.statisticssolutions.com/academic-solutions/resources/directory-of-statistical-analyses/anova/

[16] G. Cetinel, L. Cerkezi, "Wavelet Based Medical Image Watermarking Scheme for Patient Information Authenticity", *International Journal of Aplied Mathematics, Electronics and Computers,* 2016.

[17] P. A. Katyayan, M. K. Katyayan, "Effect of smoking status and nicotine dependence on pain intensity and outcome of treatment in Indian patients with temporomandibular disorders: A longitudinal cohort study", *The Journal of Indian Prosthodontic Society,* 2017.

[18] A. Ay, M. Z. Yildiz, B. Boru, "Real-time feature extraction of ECG signals using NI LabVIEW", Sakarya University Journal of Science,10.16984/saufenbilder.287418, 2017.

[19] G. Marquez et al., "Anisotropy in the absorption and scattering spectra of chicken breast tissue", *Applied Optics*, 37(4), 798-804, 1998.

[20] H.P. Berlien, G.J. Müller, "Applied Laser Medicine", Springer Science & Business Media, pp. 384, 2012.