

Evaluation of Thermal Damage Thresholds and Coagulation Behavior of 809 nm Diode Laser in Liver Tissue

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Abstract—Liver is a unique organ which has ability to regenerate itself. However, the liver tumors represent the most prevalent pathologies in this organ. Current surgical techniques for liver treatment suffer from drawbacks have been observed as insufficient application precision, uncontrolled ablation volumes, and post-application bleeding. Laser technology has emerged as a promising alternative due to its effectiveness. However, a significant limitation of lasers has resulted thermal damage which was caused by tissue temperature elevation. Laser light induces multi-layered thermal effects in targeted tissues, including ablation, carbonization, and coagulation, where progresses from inner to outer layers. Selecting an appropriate laser type is crucial based on its penetration depth and the depth of the tumor. Among laser techniques, Laser Interstitial Thermal Therapy (LITT) is widely recognized for its efficacy in liver tumor ablation and leveraging modified laser applicators. This study aims to evaluate the impact of irradiation duration on the liver tissue to establish optimal parameters for 809 nm wavelength diode laser. Initially, irradiation durations leading to coagulation or carbonization were measured, and corresponding energy values were calculated. Subsequently, temperature variations within the tissue were recorded. Findings indicated that the average thresholds for coagulation and carbonization were observed at irradiation times ranging from 0.33 to 1 second at power levels of 0.5 to 1 W, and from 0.34 to 1.31 seconds at 1 to 3 W for the 809 nm laser.

Keywords— liver; tumor; laser ablation; coagulation; carbonization

I. INTRODUCTION

A healthy liver has ability to regenerate itself as different from other organs [1]. Especially in hepatectomy operations, even if 90% of the liver is removed, the organ can return to its previous state after 3 months and fulfills all its functions without any problems. However, long-term bad habits such as alcohol, obesity, smoking and diseases such as hepatitis A, B and C types cause irreversible scars in the liver

malignant tumor such as hepatocellular carcinoma (HCC) begins to develop in the cirrhotic liver which loses regeneration capacity and liver failure occurs in last stage. HCC was reported fifth most frequent cancer and third leading cause of cancer-related death, causing more than 800,000 deaths annually in worldwide [2]. Liver metastasis is another malignancy which is risen mostly from colorectal cancer (CRC). Approximately, 50% of patients with CRC were reported as developing liver metastases during the disease [3]. In all these cases, organ transplantation with a healthy liver from a donor maintains last option.

Various ablation methods have been benefited to both stop bleeding after hepatectomy and transplantation and to eliminate liver tumors. While radiofrequency ablation destroys the tumor by delivering 200-500 kHz acoustic waves to the tissue [4]. Microwave ablation is benefited from heat vibration of water molecules at a frequency of 900-2500 MHz [5]. Cryoablation is the process of cooling argon and helium gases to -196 °C degrees and exposing the diseased area to sudden cold-hot cycles between -35 °C and 55 °C degrees [6, 7]. Irreversible electroporation is based on positioning cancer cells between electrodes and exposing them to high energy which is aimed to destroy the cell with a voltage between 1000-3000 V entering the cell nucleus [8]. Another method is the injecting ethanol through a syringe needle into the diseased tissue to dehydrate the tumors. It has been observed that all these applications are more effective in tumors below 5 cm size [9].

In the surgical treatment of liver; insufficient single application, uncontrolled ablation volume and bleeding in lesions after application are among their disadvantages of present techniques. In these ablations, the fact that the instruments are not in direct contact with the tumor or diseased tissue and bleeding continues has shown that laser ablation can be used as an alternative.

The laser was first successfully performed in 1960 by Maiman. Later, it began to be used in various military, cosmetic and health fields. Laser light contains a single wavelength; it does not dissipate as it moves away from the source; it differs from other types of light in that its power, direction and frequency remain



constant. In laser formation, a trigger source is firstly required. This source activates light particles called photons in the substance called medium. In order to prevent the resulting heat from dissipating around, an optical resonator, which includes the source and medium, is used. The mirrors inside the resonator ensure the reflection of the beam inside, and the final laser beam passes through the semi-reflective mirror and exits the system [10].

In laser-tissue interaction, the laser beam can be reflected, passed through, scattered or absorbed. Hemoglobin, water, melanin, and retinoid play a significant role in the absorption of light. This process depends on the wavelength of the incoming light. For instance, melanin and hemoglobin can absorb light between 500-1000 nm, while retinoid protein tends to absorb light below 200 nm more easily. Water has the feature of absorbing almost every wavelength, although it is mostly above 1000 nm [11].

Various types of laser-tissue interactions occur depending on the wavelength of the laser used. Among these, low wavelength lasers such as excimer lasers are used in photo-ablation. For instance, since retinoid protein is found mostly in the eyes, this laser is used to eliminate corneal defects. In photothermal ablation, lasers with wavelengths above 1000 nm such as Nd:YAG, CO₂, Er:YAG, Ho:YAG are used. When these lasers are applied to the tissue, the temperature on the tissue surface increases from generally 37°C to 300°C, resulting in hyperthermia, coagulation, vaporization (ablation), carbonization and melting, respectively.

Liver contains high amount of water and hemoglobin, thus CO₂, Argon and Nd:YAG lasers are used to destroy cancerous or diseased tissues or to separate from healthy tissues. Due to the fact that, laser treatment has demonstrated to reduce the amount of infection caused by the use of scalpels in surgeries. Nd:YAG laser can provide necrosis of the tumors where located deep below the tissue surface [12]. Because the 1064 nm wavelength has the highest optical penetration as 4 mm into the tissue among all wavelengths. In the CO₂ laser with 10600 nm, this effect is more superficial as 0.75 mm [13].

Laser Interstitial Thermo Therapy (LITT) treatment is advantageous laser ablation which based on laser output creating of laser output a three-dimensional coagulation area in the area close to the tumor directly through the tissue. Fiber cables are used to transport the laser beam more easily within the system. In the treatment, the laser beam coming from the source under the guidance of an MRI or CT device travels through the fiber and reaches the target tissue with the help of a transparent catheter previously positioned at the subcutaneous tissue entrance [14]. Generally Nd:YAG and diode laser are preferred over CO₂ lasers in LITT because Nd:YAG laser travels further in the tissue. The fiber tip is positioned within the tumor and the laser exits from this end, ensuring thermo toxic death of the

tumor. In practice, it is important to carry out coagulation slowly in order to avoid damage to the surrounding tissues and to avoid possible vaporization and carbonization [15].

Various studies were conducted after 1980 to better understand the type and extent of thermal damage caused by laser on liver tissue. Among these, Nikfarjam *et al.* applied 1064 nm Nd:YAG and 980 nm diode laser 5 mm below the tissue at a certain power and in two varying second parameters. While lower coagulation occurred with the Nd:YAG laser compared to the diode laser at the shorter time parameter, carbonization was observed only as a result of the application of the diode laser at the high time parameter. Previously, Jacques and his colleagues applied the 805 nm diode laser Nd:YAG on dog and rat livers separately at similar powers and for longer periods of time. The penetration of both lasers on the liver tissues was measured and the vaporization and coagulation zones were determined according to the different color parts of the damage. While the diameter and depth of the damage caused by the 805 nm laser were close to each other, the diameter was higher and the depth was almost zero with the 1064 nm laser [16, 17].

In liver-laser applications, in addition applying laser for certain periods of time to understand coagulation or carbonization damage size, the time until these thermal damage occurrence can be measured to also determine the safe laser and power value. This method was implemented by Yıldız *et al.* using 980 nm diode, 1070 nm YLF and 1940 nm Thulium fiber lasers in various power ranges. As a result of measuring the extent of both types of thermal damage occurring on the server with the help of a caliper and microscope, the found times showed that 980 nm creates high-level thermal damage, 1940 nm is theoretically suitable for ablation because it is absorbed faster on the water side, and 1070 nm is the damage that occurs even at high power density. Since it is close to zero, the 1070 nm has been determined as a safe wavelength [18].

II. MATERIALS AND METHODS

This study aims to evaluate the impact of irradiation duration on liver tissue to establish optimal parameters for 809 nm wavelength diode laser. The experiments were done in two parts. Firstly, the 809 nm diode laser was directly applied on the liver tissue, meanwhile the time was measured until coagulation and carbonization formation occurred on the tissue. In addition to this, the diameter of these thermal damages were measured. In the second part of the experiments, temperature changes were measured with the help of a thermal camera by applying these different power, time and energy parameters, and morphological changes were observed on the tissue surface.

The first part of the experiment of this study was performed at Bahçeşehir University Faculty of Dentistry using SOLASE Dental Diode Laser device which is a circuit consisting of a smartphone nest, a fiber cable

connected to it, a handpiece, a disposable type and a foot pedal connected via Bluetooth. Tip type, type of the operation mode and varying laser powers were adjusted separately for each application in a smartphone.

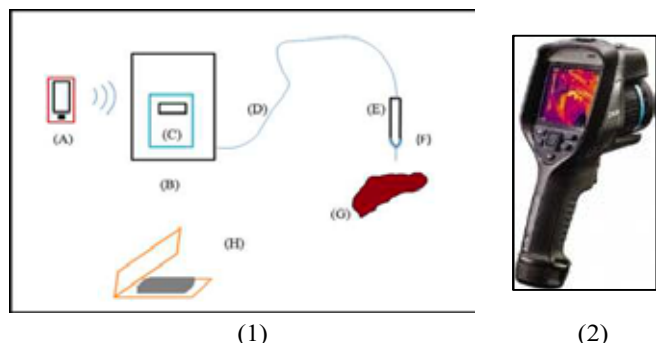


Fig. 1. (1) Portable 809 nm Diode Laser System Circuits; (A) smartphone, (B) laser source, (C) phone nes, (D) fiber cable, (E) handpiece, (F) 400 µm diameter disposable tip, (G) liver tissue sample and (H) foot pedal, (2) Handpiece Thermal Camera

Depending on the capacity of the device, ranges of 1-6 W for 809 nm were used. Finally, by pressing the foot pedal, lasers with 809 nm wavelength was applied to the liver surface. Approximately 10 laser applications were performed at the same power value at all wavelengths.

Measurements of coagulation and carbonization threshold times and diameter measurements of two types of thermal damage occurring in the tissue were made with the help of calipers. The found threshold time data were multiplied by the required values to be applied to obtain the required energy values for the optimum parameter.

After taking the average and standard deviation of the measurements taken with the same parameters, student-t-test ($p \leq 0.05$) was calculated between the measurement groups at any two power values via Excel program to determine whether there was a significant difference between the groups and to find the optimum lasing parameters for that wavelength.

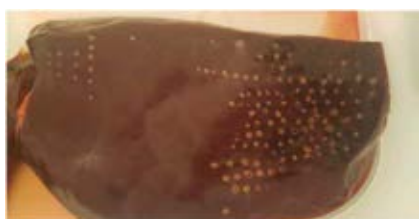


Fig. 2. Thermal damage points after 809 nm laser application

Second part of the experiment was performed in Boğaziçi University Biophotonics Laboratory with using the Flir-E4 brand handpiece thermal camera

which was held between THORLAB brand metal holders. In order to make a comparison based on the same energy values, 4 W 6 sec at 809 nm. During the applications, temperature increases on the tissue surface were measured separately for both wavelengths.

In addition, with the same wavelength laser, regardless of the threshold times, using the same power values as in the previous experiment, between 1-6 W, the liver tissue was first injected with sequential energy values as similar as possible, with increasing time values for each power value, for example, both 3 W and 4 W. The energies of the applied lasers were calculated as 6 j, 12 j, 24 and 36 j, and these time parameters were determined according to the purpose.

III. RESULTS

At the 809 nm wavelength used in this study, the average coagulation threshold times decreased from 14.96 seconds to 1.62 seconds as the power increased from 1 W to 6 W in Fig. 4. Although the laser was applied for 40 seconds at 1 W to determine the average carbonization threshold time, no measurement was recorded because carbonization was not observed. For power levels ranging from 2 W to 6 W, the onset times for carbonization decreased from 12.52 seconds to 5.13 seconds in Fig. 3. Generally, a decrease in these times was observed for both types of thermal damage with increasing power. This is expected, as higher laser power facilitates faster heat transfer to the tissue. The required energy values, as shown in Table I, demonstrated a decreasing trend for coagulation, ranging from 23.1 J to 9.74 J with increasing power. In contrast, the energy values for carbonization ranged from 20.4 J to 38.06 J, showing no significant change with increasing power from 2W.

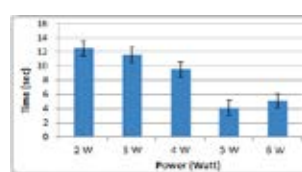


Fig. 3. Measurements of carbonization times in applications with 809 nm laser

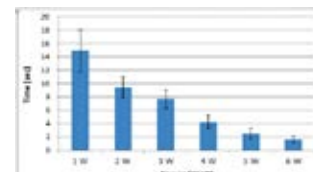


Fig. 4. Measurements of coagulation times in applications with 809 nm laser

TABLE I. REQUIRED ENERGY DATA FOR 809 NM LASER APPLICATION

Power (Watt)	Energy Values (Joule)	
	Coagulation	Carbonization
1	14.96	-
2	18.93	25.06
3	23.1	33.53
4	17.1	38.06
5	12.66	20.41
6	9.74	30.8

In the 809 nm laser application, the t-test values for the times of 9.46 and 2.53 seconds at 2 W and 5 W, respectively, and 7.69 and 1.62 seconds at 3 W and 6 W, respectively, were found to be below 0.05, indicating a significant difference between these time measurements. However, the carbonization threshold times, which were 12.52, 11.17, and 9.51 seconds at 2 W, 3 W, and 4 W, respectively, showed the opposite trend with t-test values of 0.08 and 0.06. The only significant difference was observed between 4 W and 5 W, with times of 9.51 seconds and 4.08 seconds, respectively, and a t-test value of 1.3×10^{-6} . Generally, considering the t-test values and the trend that threshold times decrease with increasing power, it can be concluded that the difference between coagulation and carbonization threshold times increases inversely as the applied power decreases.

The coagulation diameters of 809 nm laser in the tissue was found at wider range than carbonization diameter ranges, which were below 1 mm, at same applied time and power values. For instance when coagulation diameters were found between 1.66-2.67 mm at 6, 9 and 12 sec laser application at 2 W, carbonization were found between 0.66-1.36 mm. Only at 4 W, diameter ranges of coagulation and carbonization thermal damage was at almost same width as 2.08-2.41 and 0.75-1.05 mm respectively at same applied seconds. In both thermal damage diameter ranges, there was a decrease of up to 4 W and an increase of 6 W with increasing power. Although lower application times were used at 6 W, the higher diameter range showed that the power parameter rather than time is more effective in diameter size.

IV. CONCLUSION

In this study, we identified the optimal safe wavelength and power settings for laser applications by measuring thermal damage threshold times, temperature changes, and damage diameters in tissue. The 809 nm wavelength was found to have significantly high threshold times and caused low damage to liver tissue at the same duration and power parameters. This supports the theory that the absorption coefficient of water is lower at the 809 nm wavelength.

Future research could involve modifying the time intervals to milliseconds, microseconds, or nanoseconds in continuous-wave (CW) applications and examining temperature changes during laser application to determine the onset time. This could help in finding appropriate parameters to prevent excessive tissue irradiation or burning of liver tissue during surgeries. Additionally, understanding the coagulation threshold times for lasers, as determined in this study, may assist in evaluating the duration of liver tumor surgeries and choosing between laser ablation methods such as LITT or hepatectomy.

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