INVESTIGATION OF THRESHOLD ENERGY, ABSORPTION COEFFICIENT AND THERMAL LOADING IN GLASS IONOMER CEMENT LASER REMOVAL

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ABSTRACT

Purpose: *Various kinds of lasers have been developed for the diagnostic and operative application. In dental restoration, the laser is used for removal of remaining dental material. The main benefits of laser applications are patient comfort and pain relief. The primary concern in laser application is a better result for the specific area applied compared to the traditional method. Quality result of laser irradiation could be promised with appropriately controlled laser parameter. Thus, this work aims to determine laser energy threshold, absorption coefficient, and thermal loading of glass ionomer cement (GIC) through the application of Beer-Lambert's law to enhance the use of Nd:YAG laser in the restorative dental application.*

Method: *132 tooth samples were collected from the Advanced Medical and Dental Institute, Universiti Sains Malaysia. All the tooth sample were drilled and filled up with GIC dental material. Spectron Pulse Nd:YAG Laser System, SL-805G (1064 nm) was used to irradiate all the samples with various parameter applied; laser energy, number of shots and beam size, thus the depth of GIC removal was obtained.*

Results: *Graph of depth GIC removal against laser energy, was plotted for each number of shots, and beam size that considered in measuring the average of GIC removal efficiency. As a result, the general ET, α, and γ were obtained at 46.82 mJ, 10.79 mm-1 and 505.18 mJ mm-3 respectively.*

Conclusion: *These results were recommended as the best estimation of laser depth penetration into GIC dental material.*

Keywords: Glass ionomer cement, Laser removal, Nd:YAG laser, Thermal decomposition

1.0 INTRODUCTION

Laser, the acronym of light amplification by stimulated emission of radiation, is a coherent and monochromatic source of electromagnetic radiation with wavelength ranging from the ultraviolet to the infrared range [1, 2]. Lasers have wide-ranging applications in different materials processing [3, 4]. The introduction of laser in dentistry, in the 1960s, by Miaman [5], has led to continuous research in the various applications of lasers in dental practice.

The laser has an ability of precise control of the material and at what rate energy is deposited [6-8]. From that, to achieve desired material modification a proper selection of laser processing parameter is needed. A spatial intensity of laser profile used in controlling the deposited energy to the desired region [9].At the point when light strikes the surface of the materials, some portion of the light will be reflected, and the rest will be transmitted into the material [10]. The reflection process is due to the discontinuity in the real index of refraction. Besides, the reflectivity of the given material will rely upon on the frequency of the light source through the dispersion relation of its index of refraction[10, 11]. Besides, surface reflectivity depends on the temperature of the material through the changes in the permittivity, band structure, plasma oscillation or material phases [6, 12]. In the case of small scale or structured materials, additional optical resonance is required for improved absorption or reflection due to the details of the photon-electron interaction.

Laser absorption process will occur depending on the type of material and also on several different parameters used [6, 8, 13]. In general, photons will be coupled into the available electronic or vibration states in the material and it will depend on the photon energy. In insulators or semiconductors, the absorption of laser is likely to occur through resonant excitations like transitions of valence bands electrons to the conduction band or within the band [14]. The excited electronic states transfer their energy to lattice photons. Photons with energy below than material bands gap will not be absorbed.

The response of the materials can be classified as a result of raised in temperature. The temporal and spatial evolution of the temperature field inside a material given by the heat equation [6, 15]. The details of the material response will depend on the material system and the laser processing conditions. The materials will respond, and it will be the function of the local material heating and cooling rate. Maximum temperatures reached and all of which can be determined from the solution to the heat equation for the given irradiation conditions. The transient pool of molten material on the surface will occur if the energy deployed is above the threshold of melting [16-18].

To enhance the removal of glass ionomer cement (GIC) dental material and to limit the risk of the tooth damage and health implications, the important factors identified to these issues must be addressed. Laser removal of GIC material can only promise great quality results if the operational process parameters, for example, laser energy (E), number of pulses (N), beam size (BS) and any related factors are appropriately controlled [19].

The information of how far a laser beam is absorbed by GIC surface is intrinsically influenced by laser wavelength (λ), laser energy(E), beam size (BS) and repetition rate (RR). This information is essential for effectiveness, quality, and its efficiency of GIC laser removal process in the dental application. Increasing of E will increase the removal efficiency of GIC dental material. However, there should be a maximum depth of GIC thickness that can be reached by increasing the E until all the GIC had been removed. In addition, E is needed to ablate GIC material and depending on the threshold energy (E_T) of GIC material and N of the laser.

Thus, this study aimed to investigate the E_T, α and γ over GIC dental material irradiated by Nd:YAG laser. Beer-Lambert law was applied to obtain the results from the plotted graph.

2.0 MATERIAL AND METHODS

2.1 Tooth Sample Preparation

A total of 132 tooth samples was obtained from hospital and private dental clinics around Bertam, Penang Malaysia. The permission to collect human teeth and to conduct this study human ethic has been obtained from the Human Research Ethics Committee of Universiti Sains Malaysia. Only healthy and non-erupted human incisor tooth was collected in this study.

Deciduous incisors that were chosen, without obvious decay or sign of fluorosis, fractures or fillings. After exfoliation or extraction, the teeth were stored in a 0.2% thymol solution to prevent desiccation of dental tissues. In order to minimize variability, tooth samples collected must be approximately the same in dimension. The teeth were then transported to the Craniofacial and Biomaterial Laboratory to be cleaned and stored. During tooth transport, all extracted teeth were placed in a well-built container with a secure lid to avoid any leakage.

All tooth samples were cleaned from gross debris and visible blood for educational purposes. Besides that, the tooth samples were required to be maintained in a hydrated state. The tooth samples were gently brushed with a soft brush and finally rinsed with water to eliminate all gross debris and visible blood. Next, the tooth sample was stored in a chiller at 5°C in 0.2% thymol solution before the dental drill test was conducted. Also, all the guidelines for handling the extracted tooth were fulfilled.

Lastly, all these tooth samples were drilled to obtain a hole of 2 mm diameter with 2 mm depth using a round shape bur handpiece dental drill and filled with GIC (3M ESPE Ketac Molar Aplicap, GI) material before being irradiated with certain laser parameters as shown in Table 1. Each parameter was repeated three times. Thus, the total number of 132 samples was performed in this study.

Table 1: Laser parameters considered for 0.5mm and 1mm BS with varies in laser Energy, Number of shots and Repetition rate

Sample number	Number of shots	Beam sizes (mm)	Laser energy (mJ)	Repetition rate, RR (Hz)
1	5	0.5	100	0.08
2	10	0.5	100	0.17
3	20	0.5	100	0.33
4	30	0.5	100	0.50
5	40	0.5	100	0.67
6	50	0.5	100	0.83
7	5	1	100	0.08
8	10	1	100	0.17
9	20	1	100	0.33
10	30	1	100	0.50
11	40	1	100	0.67
12	50	1	100	0.83
13	5	0.5	130	0.08
14	10	0.5	130	0.17
15	20	0.5	130	0.33
16	30	0.5	130	0.50
17	40	0.5	130	0.67
18	50	0.5	130	0.83
19	5	1	130	0.08
20	10	1	130	0.17
21	20	1	130	0.33
22	30	1	130	0.50
23	40	1	130	0.67
24	50	1	130	0.83
25	5	0.5	160	0.08
26	10	0.5	160	0.17
27	20	0.5	160	0.33
28	30	0.5	160	0.50
29	40	0.5	160	0.67
30	50	0.5	160	0.83
31	5	1	160	0.08
32	10	1	160	0.17
33	20	1	160	0.33
34	30	1	160	0.50
35	40	1	160	0.67
36	50	1	160	0.83
33	5	0.5	200	0.08
34	10	0.5	200	0.17
35	20	0.5	200	0.33
36	30	0.5	200	0.50
37	40	0.5	200	0.67
38	50	0.5	200	0.83
39	5	1	200	0.08
40	10	1	200	0.17
41	20	1	200	0.33
42	30	1	200	0.50
43	40	1	200	0.67
44	50	1	200	0.83

2.2 Operating Principle

Nd:YAG laser system Spectron Laser System, SL-805G, the US with a maximum energy output of 1300 mJ and a pulse duration of 6 ns is used. In this study, a set-up of Nd:YAG laser system irradiation was developed. The GIC filling material of the tooth was perpendicularly irradiated as shown in Figure 1. A pinhole laser beam was used to remove the unwanted multiple order energy peaks and bypass the central maximum of the diffraction pattern known as a Gaussian beam. Meanwhile, the addition of the focusing lens allows the adjustment of the size of the beam needed for the irradiation procedure.

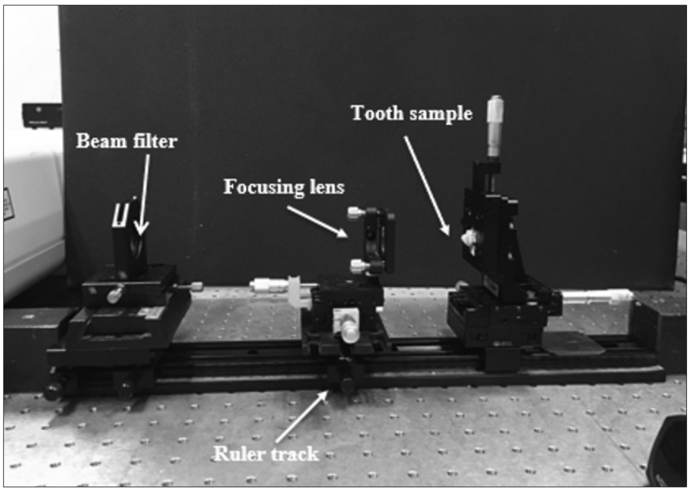

Figure 1: Experimental set-up for laser glass ionomer cement removal on tooth sample

2.3 Sample Analysis

Bowers Micro-Gauge 2 Point Bore Gauge, Camberly England designed particularly for the precise measurement of bores from 0.01 mm to 10 mm. This gauge was used to analyze 132 irradiated crated depths to obtain the depth thickness and diameter of laser penetration (*d*). For this study, depth versus laser energy graph was plotted for each beam size and number of shots. Hence, the ϵ of GIC dental material can be determined by measuring its inclination of the fitted linear graph. The best laser energy threshold, E_T for GIC dental material was selected from the interception of a fitted linear graph of ϵ with their X-axis. This can be described by using Beer-Lambert. Graph depth, d versus Laser energy, E was plotted to derive a general E_T for GIC dental material from the interception of the fitted linear graph with the X-axis.

3.0 RESULTS AND DISCUSSIONS

By plotting a graph of variation removal GIC depth versus the changes in laser energy as shown in Figure 2 and Figure 3, E_T can be easily established from the interception of the fitted linear line of the x-axis.

According to Figure 2 and Figure 3, only one linear line shows the interception at X-axis which was referred to the E_T of the GIC dental material. From the graph, the minimum energy required to remove GIC dental material was at 48.62 mJ for pulse Nd:YAG laser with 0.5 mm beam size and 10 number of shots. The selection of a E_T was based on the linear line that intercepts certain laser energy and the E that intercept at the X-axis should be greater than zero.

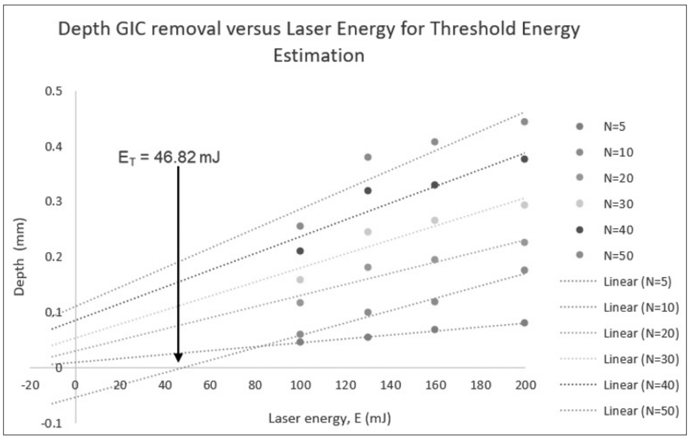

Figure 2: Fitted linear graph of GIC dental material for 0.5 mm beam size

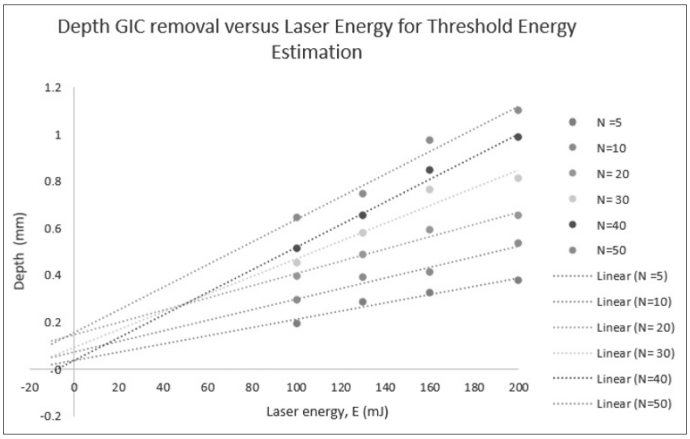

Figure 3: Fitted linear graph of GIC dental material for 1 mm beam size

Based on Figure 2, the E_T indicated the general threshold energy for GIC dental material. The linearity of the data points shown in Figure 2 further validates the use of the approach for the examination of continuous wave (CW) lasers.

Since the energy deposition profile will be governed by the optical absorption coefficient, α (mm^{-1}), then the depth, *d* of material removed is given by Beer-Lambert's law:

$$d = \frac{1}{\alpha}\, ln\,(\frac{E}{E_T}) \quad (1)$$

Where E_T is the threshold value of the laser energy for GIC material removal occurs [20], α is the absorption coefficient (mm^{-1}). Equation (1) is the absorption coefficient of incident radiation by the plume of removed GIC dental material.

As demonstrated by the works of Schmidt *et al.* [21] and Andrew *et al.* [20], the simple form of Equation 1 can be rearranged as follows:

$$\alpha = \frac{ln\,(E/E_T)}{d} \quad (2)$$

By introducing the ablation depth, d and the corresponding value of laser energy, for each data point into Equation (2), it is possible to calculate the absorption coefficient of Nd:YAG laser radiation into the surface of the GIC dental material under the actual experimental conditions.

The thermal loading, γ (mJ mm^{-3}) of GIC dental material laser removal can be found based on Equation (3).

$$\gamma = \frac{E_T}{\alpha} \tag{3}$$

The material that has been evaporated and removed from the surface of the component known as material ablation. This material is removed upon laser impact. Hence, the GIC removal mechanism begins after the absorption of laser intensity to the GIC exceeds the ablation threshold of the material as shown in Equation 1 above.

It is concluded that GIC tooth sample of 0.5 mm coupled with 10 pulses gives the best result to estimate the optimum efficiency of GIC dental material removal. After identifying the value of E_T, at a certain depth, an α and γ were determined.

When GIC removal at 0.1 mm depth and its corresponding laser energy of 137.73 mJ, the general value of α and γ can be obtained, as shown in Table 2. Then, the removal efficiency of GIC material can be determined as shown in Table 3.

Table 2: Summarization of general E_T, α and γ for GIC dental material

Energy (mJ)	Depth (mm)	Threshold Energy, E_T (mJ)	α (mm^{-1})	γ (mJ mm^{-3})
137.73	0.1	46.82	10.79	505.18

Table 3: Removal efficiency of GIC material for N=10 and beam diameter of the laser was 0.5 mm

Energy (mJ)	Depth (mm)	Fluence (mJ mm^{-2})	GIC removal efficiency, ϵ (mm^2 mJ^{-1})
100	0.0588	56338.03	1.04×10^{-7}
130	0.0988	29411.76	3.35×10^{-7}
160	0.1185	7222.22	16.4×10^{-7}
200	0.1739	3448.28	50.60×10^{-7}

The removal efficiency is determined based on the volume of GIC removed with a certain amount of laser energy and the number of laser shots. From the results, the highest ϵ for GIC is 50.60μ mm^2 mJ^{-1}, as shown in Table 3.

From the literature, threshold energy, E_T of GIC materials will be reduced by increasing laser energy, E with increasing the ϵ [22, 23]. During this analysis, the results show significant effects in the laser threshold energy, E_T with the increase of the laser energy while remaining with the same number of shots.

The results gave a positive effect in increasing the laser energy, where the average removal efficiency, (ϵ) was also increased, as shown in Table 3. Figure 2 and Figure 3 clearly show that the crater depth was linearly developed into the GIC samples as energy increased. Higher laser energy caused higher thermal energy to dissipate at the GIC target area for the process of thermal decomposition, thus increasing the ϵ of the unwanted layer.

4.0 CONCLUSION

This study concludes that the E_T, α, and γ were obtained at 46.82 mJ, 10.79 mm^{-1} and 505.18 mJ mm^{-3}, respectively. The GIC removal efficiency, ϵ in GIC removal, depends on the function of laser parameters sort of laser energy, beam size, number of pulse and repetition rate. Furthermore, the mechanism of the photothermal and photochemical process contributes to the ϵ. The physical and chemical factors of GIC material and laser beam characteristics play a role in the absorption coefficient efficiency onto regions of interest (ROI) as well. Hence, the optimum operation of laser parameters should be applied to achieve the best efficiency in removing GIC using a laser.

In conclusion, this analysis reveals the interaction characteristics of GIC material laser irradiation in terms of threshold energy, E_T (mm^{-2} mJ), absorption coefficient, α (mm^{-1}) and thermal loading, γ (mJ mm^{-3}). This research proves that the effectiveness, quality and efficiency of GIC removal process can be obtained by using Spectron Nd:YAG laser System, SL-805G with a proper selection of laser parameter.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper. ■

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PROFILES

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