ORIGINAL ARTICLE

Effect of Multiple Exposures of Nd:YAG Laser on The Human Teeth

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ABSTRACT

Introduction: Laser treatment can cause a temperature rise either to the tooth surface or dental pulp. Significant temperature changes may potentially threaten the vitality of the pulp and consequently results in pulpal necrosis. This study aims to identify the temperature changes on the enamel and dental pulp of the teeth following multiple exposures of a pulsed Nd:YAG laser irradiation. **Methods:** Eight healthy molar teeth extracted for orthodontics treatment were exposed to Nd:YAG laser at a fluence of 200 J/cm^2, pulse width duration of 100 ms, and a repetition rate of 1 Hz. The teeth were irradiated repeatedly up to ten exposures at a constant fluence and pulse width. A thermocouple probe was placed on the enamel surface and into a tooth's pulp chamber during laser irradiation. The temperature of the enamel surface and the pulp chamber was recorded throughout the irradiation process. **Results:** The average temperature of the pulp and the enamel surface increased when the number of exposure increased. The mean temperature of the enamel is 7.99°C, slightly lower than the mean temperature of the pulp that is 9.65°C. The pulp's temperature changes are more remarkable upon laser exposure (44.57%) compared to the temperature changes of the enamel (39.68%). **Conclusion:** This study shows temperature changes at the enamel and pulp of a tooth following multiple exposures of laser irradiation. As the number of exposure increases, the temperature changes are also increasing. However, no significant difference between temperature changes in pulp and enamel of the teeth.

Keywords: Dental pulp, Enamel, Laser irradiation, Nd:YAG laser, Temperature

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INTRODUCTION

Lasers are widely used in medicine and dentistry for many types of procedures. Among the laser commonly used in dentistry are carbon dioxide (CO_2), Neodymium Yttrium Aluminum Garnet (Nd:YAG), Erbium-doped Yttrium Aluminium Garnet (Er:YAG), Erbium, Chromium: Yttrium-Scandium-Gallium-Garnet (Er,Cr:YSGG) and diode lasers (1-4). The applications include photodynamic therapy for malignancies, aesthetic gingival recontouring and crown lengthening, various tissue removals, cavity preparation, caries and restorative removal, etching, and dental hypersensitivity treatment (1,5-7).

Several interactions occur when a laser is irradiated to a tissue, such as photoablation, photothermal, and photochemical. The most concerning aspects of the laser are the amount of heat deposited when the laser light passes through a material (8). The wavelength of the laser resonates well with atoms and molecules in the material, thereby setting them into motion that interpreted as heat. In dentistry, the increase of the temperature on the teeth is primarily concerned compared to soft tissues. The heat from the dental laser can increase the temperature inside the pulp, where odontoblasts, blood vessels, and tooth nerves are located, hence causing some damages to the structure.

Pulse Nd:YAG laser has low-grade absorption by mineralised structure of the teeth such as dentine and enamel (4). Hence, it is not recommended to be used on hard tissues. However, it is highly absorbed in the pigmented tissue, making Nd:YAG a very effective surgical laser for cutting and coagulating dental soft tissues, with good hemostasis (6). Besides surgical applications (6,9), Nd:YAG laser has been used for nonsurgical sulcular debridement, particularly in periodontal disease control (10,11). By applying photosensitiser, the Nd:YAG laser is highly absorbed and used for ablation and cavitation purposes.

Previous studies indicated that temperature increments above 5.6°C could threaten the vitality of the pulp, and increments over 16°C can result in complete pulpal necrosis (12). Moreover, the feeling of pain is induced in the pulp when the temperature exceeds approximately 45°C. It is thus imperative to remain below these temperatures when striving for clinical applicability (13). Increasing the laser's power also contributes to the increase in temperature of the pulp and enamel surface of the teeth (14-18). Similarly, studies that used Nd:YAG laser with a different power set up also shows the same agreement (19,20).

Other parameters such as fluence, energy, beam diameter, mode of delivery, and exposure duration may also contribute to the temperature changes. A study showed that the exposure duration to a CO_2 laser procedure affect the energy produced and contributed to increased temperature at the crown and pulp (21). There is also a study done to investigate the effect of delivery of very short pulse energy on the pulp temperature (22), but no scientific evidence on the impact of multiple exposures on the pulp's temperature. Thus, this study was aimed to measure and quantify the temperature changes on the teeth' enamel and pulp following multiple exposures of Nd:YAG laser irradiation on the human teeth.

MATERIALS AND METHODS

Sample Preparation

Eight healthy extracted molar teeth due to orthodontics treatment needs were chosen, and their surfaces were cleaned to remove all the remaining soft tissues, debris, and stains. An opening with a width of 3 mm was made at the root furcation to four of the extracted teeth to get access into the floor of the pulp chamber using a 3 mm diameter dental round bur. Then the remnant pulpal tissues in the pulp chamber were cleaned. The tooth was then soaked into normal saline and stored under refrigeration to avoid the sample's dehydration and fungal growth. Ethical approval to collect the samples, audit, and use the data for this study was obtained from the Human Research Ethics Committee of Universiti Sains Malaysia (USM) (USM/JEPeM/14120501).

Temperature Measurement

The temperature was measured using a TEMPer1K4 USB Thermocouple (Rding Tech Co., China). A thermocouple probe was placed on the buccal or lingual surface of the tooth to measure the temperature of the enamel during laser irradiation (23). For better heat conduction from the enamel surface to the probe, a white thermal conducting paste (Prosilican thermal compound, Germany) was used. For the pulpal temperature measurement, the white thermal conducting paste was injected into the pulpal chamber (24). Then, the thermocouple probe was slowly inserted through the opening until it touched the roof of the pulp chamber. The thermal conducting paste was filled until there was no gap between the pulpal wall and the thermal probe. This was to ensure appropriate thermal contact during heat transfer from the pulpal chamber walls to the probe. The TEMPer1K4 thermocouple was connected to a computer that displays the real-time measurement of the temperature at the tip of the thermal probe. Time and temperature were recorded at a sampling rate of 2 Hz, which is 0.5 s intervals between the time recorded. The temperature resolution of the thermocouple is 0.01°C.

Laser Irradiation

Teeth irradiation were performed using an Nd:YAG laser device (Cynosure Inc., Westford, MA, UK). This laser system operates at a wavelength of 1064 nm. A fluence of 200 J/cm^2, pulse width duration of 100 ms, and a repetition rate of 1 Hz were selected. The laser beam was delivered using an optical fibre of a 3 mm sized handpiece. The distance of the handpiece tip to the enamel surface was set at 4 cm. The length of 4 cm was kept constant during the irradiation to ensure a consistent spot size could be produced. No beam divergence has been found during the setting up. During laser irradiation, the laser was placed perpendicularly to the enamel surface for a homogenous irradiation effect. The setting for the experiment is shown in Fig. 1 and Fig. 2. The laser had been directly focused on the enamel

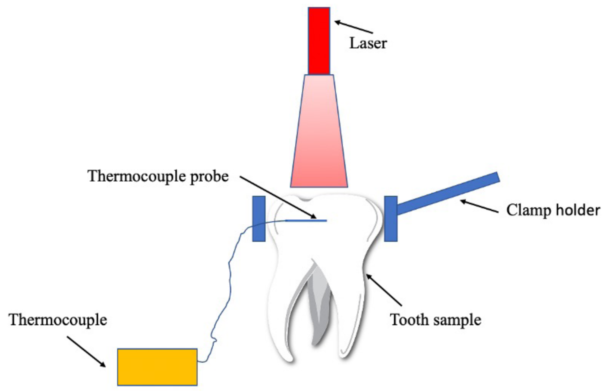

Figure 1: Experiment setup for measuring the temperature changes at the enamel surface of the tooth sample

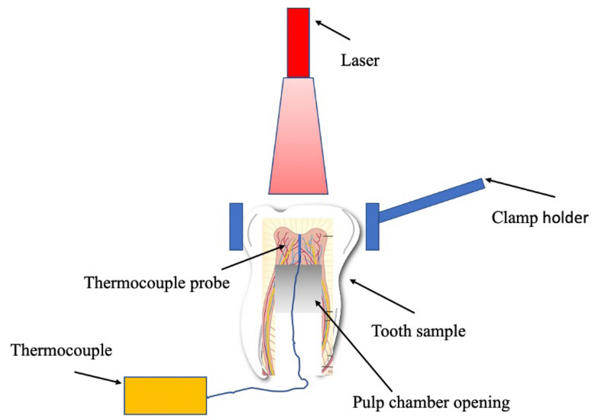

Figure 2: Experiment setup for measuring the temperature changes at the pulp of the tooth sample

surface, where the thermocouple's thermal probe was also placed. At this distance, the spot size produced was 3 mm, which was the actual size of the handpiece aperture. The teeth samples were irradiated using the pulsed Nd:YAG laser multiple times with a pulse width duration of 100 ms. The exposures were given ten times in a row with a 2 s interval between each exposure at a single fixpoint of the enamel surface. Other than the distance of the handpieces, the value of fluence used in this study was also fixed, which is 200 J/cm^2.

RESULTS

Table I shows the average temperature before and after laser irradiation of the pulp based on the number of laser exposure to the samples. The first exposure caused the average temperature to increase to 32.25°C, and the second exposure caused the temperature to rise and became 34.94°C. The temperature keeps increasing up to 40.75°C at the 10th exposure. However, it can be observed that the temperature was slightly decreased at the 9th exposure compared to the 8th exposure. Thus, the percentage difference increases from 1st exposure to the 10th exposure but slightly decreased at the 9th exposure.

Table I: Average temperature of the pulp during multiple exposures of laser irradiation

No of Exposure	Before (°C)	After (°C)	Percentage Difference (%)	Standard Deviation
1	28.19	32.25	14.41	1.33
2	28.19	34.94	23.95	2.78
3	28.19	36.06	27.94	2.55
4	28.19	36.88	30.82	2.54
5	28.19	38.00	34.81	3.17
6	28.19	39.19	39.02	3.34
7	28.19	39.88	41.46	3.98
8	28.19	40.50	43.68	4.08
9	28.19	39.94	41.69	2.98
10	28.19	40.75	44.57	3.33

Similarly, Table II shows the average temperature before and after laser irradiation of the enamel surface based on laser exposure to the samples. Based on Table I and Table II, the average temperature of the pulp and the enamel surface increased when the number of exposure increased. In the beginning, the average temperature of the enamel surface is slightly lower compared to the average temperature of the pulp. The pulp's temperature changes are more remarkable upon laser exposure than the temperature changes of the enamel based on the percentage difference in Table I and Table II.

The mean (±SD) temperature changes obtained for the pulp was 9.65 (±2.78)°C, whereas for enamel was 7.99 (±2.25)°C. Comparison between temperature changes in pulp and enamel, based on independent t-test, did not show any significant mean difference since the p-value

Table II: Average temperature of the enamel during multiple exposures of laser irradiation

No of Exposure	Before (°C)	After (°C)	Percentage Difference (%)	Standard Deviation
1	27.25	31.06	13.99	0.11
2	27.25	32.19	18.12	1.41
3	27.25	34.06	25.00	0.99
4	27.25	34.63	27.06	1.59
5	27.25	35.75	31.19	2.04
6	27.25	36.06	32.34	2.46
7	27.25	36.44	33.72	2.60
8	27.25	36.75	34.86	2.88
9	27.25	37.38	37.16	2.47
10	27.25	38.06	39.68	2.76

obtained exceeded 0.05 (p-value=0.159). Additionally, the mean difference between temperature changes in pulp and enamel also indicated a slight difference of 1.66°C.

Fig. 3 shows the average temperature changes of the pulp and the enamel of teeth samples after being exposed to laser irradiation. The x-axis represents the number of laser exposure to the samples. It is clearly seen that the temperature changes on the pulp were greater compared to the changes on the enamel surface regardless of the exposure amount received by the samples. As the number of exposure increase, temperature changes at both pulp and enamel were also increased.

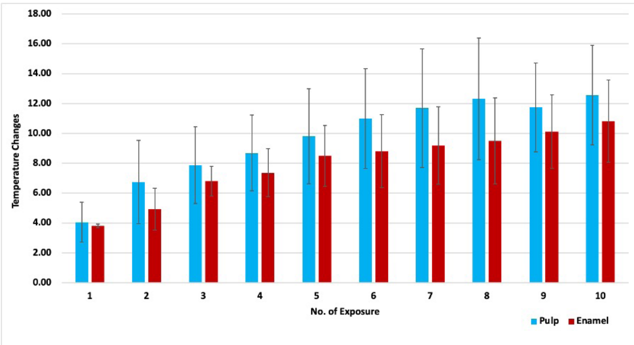

Figure 3: Average temperature changes of the samples measured at the pulp and enamel according to the number of laser exposure

Fig. 4 shows the relationship between laser irradiation number of exposure and temperature changes at the pulp and enamel. The relationship between laser exposure to temperature changes at the pulp can be represented by equation $y_{pulp} = 0.872x + 4.8542$. On the other hand, the coefficient for temperature changes at the enamel surface is slightly lower, which is 0.7182 and represented by the equation $y_{enamel} = 0.7182x + 4.0375$.

DISCUSSION

In this study, the effect of multiple laser exposure on the enamel and dental pulp was investigated. As the

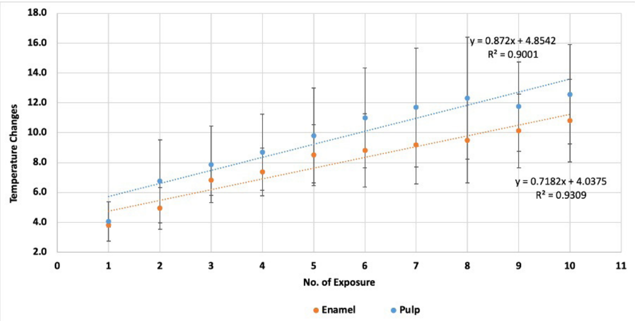

Figure 4: Relationship between laser irradiation number of exposure and temperature changes at the pulp and enamel

number of exposure increases, the temperatures at both pulp and enamel are also increasing, as seen in Fig. 3. Multiple exposures relate to the cumulative energy density received by the target, and thus both parameters changed in the same manner. Physically, the increase in temperature is due to the light to heat conversion or photothermal interaction. A light particle that passes through materials will deposit its energy or absorb it by the tooth and cause vibration within the molecular level. The vibration will be interpreted as heat and cause the temperature of the material to increase.

Based on Fig. 4, the gap between pulp and enamel temperature changes slightly increased from first exposure to the tenth exposure. This indicates that temperature changes in pulp are more prominent than the temperature changes at the enamel. The time interval between laser exposure may cause the temperature to drop slightly due to the heat loss or cooling process. However, further exposure causes an increase in the temperature of the pulp and enamel. For continuous wave mode, the laser is continuously emitting, and there is no room for the cooling process to occur. In contrast, there is a period where the laser stops irradiating, allowing the cooling process to happen in pulse laser. However, a laser with a high pulse repetition rate has less time between pulses, and the tissue has less time to cool between peak pulse energies and thus, temperature increases.

A study showed that the Nd:YAG laser has poor absorption in enamel and dentine, and most of the heat is generated at the pulp (25). Additionally, dentine has poor thermal diffusivity compared to enamel (26). Hence, the change in the temperature at the enamel surface most probably is contributed by heat generated in the pulp, and it diffuses to the outer surface. This explains the higher temperature observed at the pulp compared to the enamel in Fig. 3 and the relationship equation obtained in Fig. 4. Another factor that may have contributed to the variation temperature increase in this study is the thermal conductivity. Thermal conductivity is higher in dental enamel compared to dentine (27). The higher the thermal conductivity, the easier the material to conduct the heat. If heat is generated at the pulp or the dentine's inner part, the temperature at the enamel will be affected by this due to its poor heat conductivity.

In addition, the type of teeth also plays a role (26). Different teeth have different ability to cool down. For instance, the enamel of primary teeth can cool down more quickly than the enamel of permanent teeth. This cooling down process will affect the temperature changes (22). By having thin enamel and dentine, the temperature at the enamel surface is expected to be higher. Several studies have shown that as the thickness of enamel and dentine decreased, the heat at the enamel surface increased (20,23). Interestingly, Nd:YAG laser also has been used in the caries removal procedure. Teeth affected by caries may have different morphology and chemical structure. Thus, it is suggested to investigate the temperature changes at the pulp and demineralized enamel for caries removal procedure using the laser. This will eventually help the clinician to select the appropriate laser parameter based on the treatment objective.

CONCLUSION

From this study, it can be concluded that multiple exposures of laser irradiation caused the temperature of enamel and pulp to increase. However, the pulp temperature changes are greater compared to the enamel, with a mean difference of 1.66°C. The mean temperature change in pulp is 9.65°C, whereas 7.99°C on the enamel. As the number of exposure increase, the temperature change is getting higher, particularly at the pulp. In this study, the pulp and enamel maximum temperature is 40.75°C and 38.06°C, respectively. The maximum temperature increased was 12.56°C at the pulp and 10.81°C at the enamel, which did not exceed the increment that may cause pulpal necrosis. Most of the heat is generated at the pulp, which explains why the pulp's temperature was higher compared to the enamel of the teeth. Temperature changes at the enamel surface were most probably contributed by heat generated in the pulp, diffusing to the outer surface. The relationship between temperature changes and exposure indicates that the coefficient is 0.8720 for the pulp, whereas 0.7182 for the enamel. The linear equation obtained from this study can be used to estimate the temperature changes on the pulp and enamel according to the number of laser exposure received. It is essential to ensure that the temperature changes do not exceed the recommended value to ensure the pulp's vitality and avoid pulpal necrosis. Future studies may investigate the temperature changes at the pulp and demineralized enamel for caries removal procedures using the Nd:YAG laser. Besides, it is also crucial to determine the amount of heat reaching the pulp during caries cleaning or removal procedures.

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