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Effects of elevated temperatures on tooth structure during polymerization of composite resin with a variety of light sources

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ORIGINAL STUDY

Effects of Elevated Temperatures on Tooth Structure During Polymerization of Composite Resin With a Variety of Light Sources

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Abstract

This study investigated the impact of high temperatures on dental tissues during the polymerization of optical fillings using a diode laser and two types of pulsed and continuous LED devices. Three distinct light source units were employed: a laser diode, an LEDition, and a LED.B. Temperature increases were measured at a distance of 1 mm from the thermocouple to the tip of the device. To create an experimental model, we fixed the operational voltage of the polymerization device and maintained a 1 mm gap between the terminal and the thermocouple wire. Temperature readings and thermal background (TO) measurements were taken three times, with 1 h between each measurement, resulting in a total of 60 readings. The continuous mode of the LED.B produced the highest observed temperature increase of 6° Celsius, while the diode laser recorded the lowest temperature rise of 2° Celsius during each test period. These results underscore the importance of selecting the appropriate light-activated unit and curing time during basic restorations with light-activated resin to prevent thermal damage to dental tissues. The study concluded that the diode laser is preferable for phototherapy, as it consistently records lower temperatures, even with extended treatment times.

Keywords: Laser diode, Photo polymerization devices, Polymers and elevated temperatures

1. Introduction

The use of lasers in dentistry has enabled practitioners to address a broader range of dental conditions. Lasers can be employed in nearly any dental procedure, making them a viable alternative to traditional methods. Over the past 20 years, there has been a significant increase in studies and clinical trials focused on lasers in dentistry. The application of lasers allows dental procedures to be completed more quickly and comfortably for a larger number of patients [1−3]. The laser emits a single color of light, with each wave being uniform in size and shape. This characteristic enables laser beams to produce monochromatic and coherent light waves, which can serve as a powerful energy source. Lasers can be classified based on their wavelength, the type of tissue they are applied to (hard or soft tissue), the medium in which they operate (solid or gas), and various other attributes. The most commonly used types of lasers in dentistry include diode lasers, argon lasers, helium-neon lasers, carbon dioxide lasers, Erbium YAG lasers, and Neodymium YAG lasers.

Dental care has advanced significantly in recent years with the introduction of cutting-edge technologies, such as lasers and LED curing units. Manufacturers promote high-intensity LED curing units with short exposure times as tools that reduce polymerization time and enhance efficiency for clinicians. Light-emitting diode (LED) technology is a solid-state semiconductor device that converts electrical energy directly into light. This treatment utilizes radiation with wavelengths ranging from 400 to 500 nm, which falls within the visible light spectrum [7,8].

A diode laser is a solid-state semiconductor laser that typically converts electrical energy into light

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energy by combining elements such as gallium, arsenide, aluminum, and indium. Due to their limited depth of penetration, diode lasers are exceptionally safe for use on soft tissues. They can be employed for various applications, including the diagnosis of dental cavities, teeth whitening, cell stimulation, and the polymerization of dental composites. Several studies have confirmed that the heat generated during the curing of composite resin raises the temperature of the tooth, potentially damaging the dental pulp. The findings of these studies indicate that such damage can harm the cells responsible for dentin production, leading to varying degrees of pulp damage. Ultimately, this damage may result in the necrosis of the dental pulp.

1.1. Dental fillings treated with phototherapy

It involves altering the properties of a substance when exposed to a specific wavelength of light, typically ultraviolet or visible light. One example of a change in characteristics is an increase in the material's hardness. In the 1990s, significant advancements were made in light therapy equipment, with a focus on increasing optical density to enable these devices to treat patients more efficiently and in less time.

There are four primary categories of light sources used in light-curing units, which are as follows:

1- Quart Tungsten Halogen (QTH) Light-Curing Apparatus
2- LED-Based Photo-Curing Apparatus [6,10]
3- Plasma Arc (PAC)
4- Photo-Curing Laser Device [11]

1.2. Laser-matter interactions

Materials can exist in solid, liquid, gaseous, or plasma states, depending on their temperature and pressure. Unlike the other phases—liquid, gas, and plasma—the atoms in a solid are closely packed together. When laser light interacts with a material, the material undergoes a change; however, for this process to be effective, the material's absorption coefficient at the specific wavelength must be significantly higher than the ratio of light that is reflected and transmitted. In cases where light cannot pass through a material, such as with opaque substances, the focus shifts to the light that is absorbed and reflected. This absorbed light has a different wavelength than the incident light, allowing it to penetrate deeper into the material due to the substance's high transmittance coefficient [12].

The thermal interactions resulting from the laser's interaction with the material can be categorized into several distinct types (Fig. 1), as follows [13]:

1. Heating
2. Fusion
3. Evaporation
4. A Plasma Reaction

All of these interactions occur due to the material's ability to absorb laser light and its thermal properties, including melting and evaporation temperatures. Fig. 2 illustrates a non-thermal reaction, which occurs when laser light interacts with the material in the ultraviolet range. This reaction involves the removal of atoms from the material's surface without any thermal interactions occurring within the material itself. This process is the most significant application of laser processing in

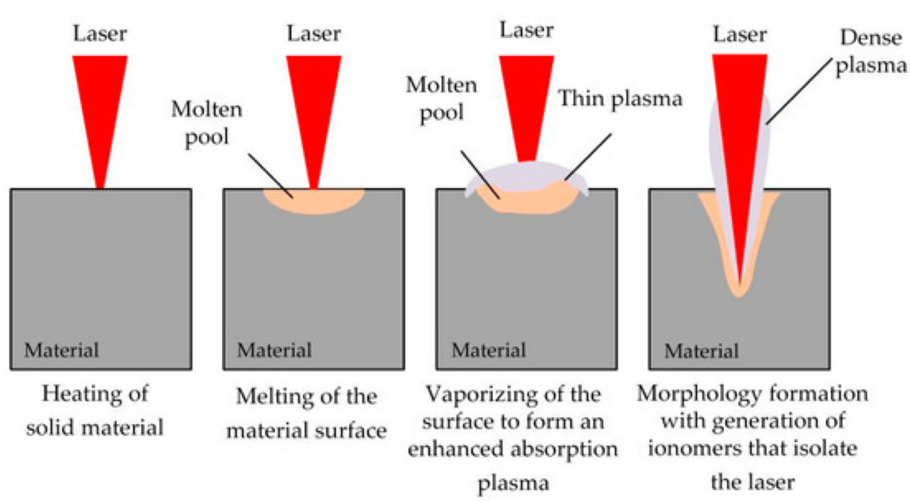

Fig. 1. Depicts a schematic of the interaction between a laser and a material [15].

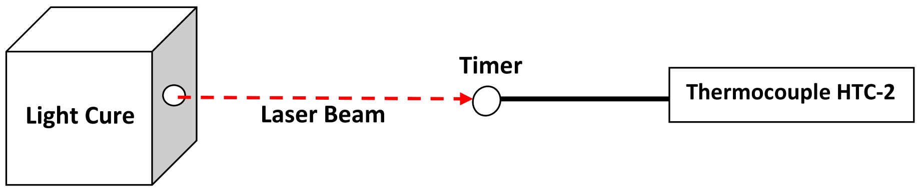

Fig. 2. Shows the study's experimental setup.

materials science, as it utilizes lasers to create solid substances [14].

2. Equipment and operating techniques

In this investigation, three distinct types of dental optical processing unit devices were employed. An LED optical processing unit, as shown in Tables 1 and 2. A laser diode is used in conjunction with the LCD HTC-2 digital thermocouple timer, as illustrated in Table 3.

2.1. Laser diode

Laser diode employed has a wavelength of 405 nm and an energy output of 86.3 MW, both of which were measured using a photo detector prior to the polymerization process. As shown in Fig. 2, a model for the experiment was developed by maintaining a 1 mm gap between the light-processing unit terminal and the thermocouple wire. Additionally, the thermal background (TO) in the laboratory was measured at 17 °C, and the working voltage of the polymerization device was adjusted accordingly. There was a 1-h interval between each set of readings. Subsequently, temperature measurements were taken every 10 s for 1 min, and the average temperature for that minute was recorded.

Table 1. Presents the optical processing unit's device specifications.

Source of light	LED 3 W
Range of wavelength	(490–430) nm
Optic intensity	(Min. 600 mW/cm 2 Max. 900 mW/cm 2)
Source of power	Power pack 100–240 VAC 50/60 Hz

Table 2. Details about the optical processing unit.

Wavelength	(490–440) nm
Intensity of light	1400 mw/cm^2
Source of energy	Ac 220 V (OR 110 V) frequency: 50/60 Hz

Table 3. Digital LCD thermocouple, model HTC-2.

Range temperature measuring	−(50~70°C)
Humidity range	10 % ~ 99 % RH

3. Results

The data presented in Tables 4–7, as well as Figs. (3–6), were obtained following extensive laboratory work [3–7].

Table 4. The effect of temperature on time using a laser diode (continuous mode).

t/sec	T/°C		T_{av}	$T = T_{av} - T_{\circ}$
	T_1	T_2		
10	19.1	19.1	19.1	2.1
20	19.9	19.9	19.9	2.9
30	20.3	20.4	20.35	3.35
40	20.8	20.7	20.75	3.75
50	21.0	20.9	20.95	3.95
60	21.2	21.1	21.15	4.15

Table 5. Changes in time-based on temperature when using Light Cure LED.B (Pulsed Mode).

t/sec	T/°C		T_{av}	$T = T_{av} - T_{\circ}$
	T_1	T_2		
10	19.1	18.9	19	2
20	20.1	19.8	19.95	2.95
30	21.1	20.6	20.8	3.8
40	22	21.4	21.7	4.7
50	22.8	21.9	22.35	5.35
55	22.8	22.5	22.65	5.65

Table 6. Light Cure LED temperature and time variation (continuous mode).

t/sec	T/°C		T_{av}	$T = T_{av} - T_{\circ}$
	T_1	T_2		
10	19.7	19.3	19.5	1.5
20	20.9	21.2	21.05	4.05
30	22	22,9	22.45	5.45
40	23	24,3	23.65	6.65
50	23.3	24.7	24	7
55	23.8	25.3	24.55	7.55

Table 7. Change in time as a function of temperature with the Light Cure (LEDition) device.

t/sec	T/°C		T_{av}	$T = T_{av} - T_{\circ}$
	T_1	T_2		
10	18.4	18.4	18.4	1.4
20	19.1	19.3	19.2	2.2
30	19.7	19.9	19.8	2.8
40	20.1	20.4	20.25	3.25
50	20.6	20.7	20.65	3.65
55	21	21.2	21.1	4.1

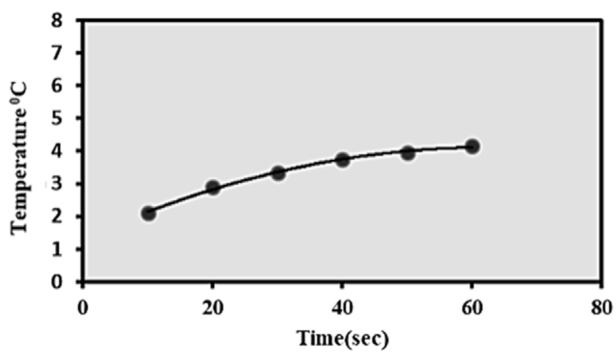

Fig. 3. Diode laser temperature vs. time graph (continuous mode).

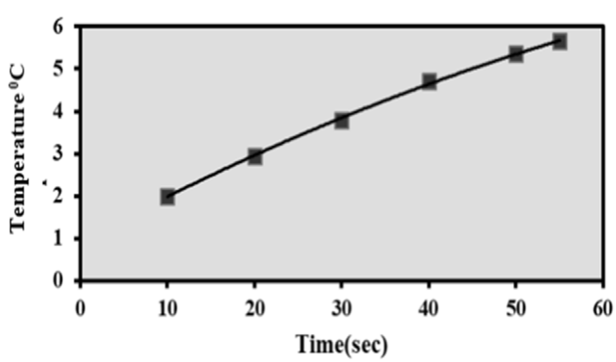

Fig. 4. Shows how the temperature of the Light Cure LED.B changes over time (pulse mode).

Fig. 7 illustrates the changes in temperature over time. There is a distinct upward trend in temperature as time progresses. The Light Cure (pulsed, continuous) method significantly increases temperature compared to the LEDition and laser diode devices, although to a lesser extent. In none of these scenarios does the temperature exceed the critical threshold that affects the tooth structure, which is 11 °C [16].

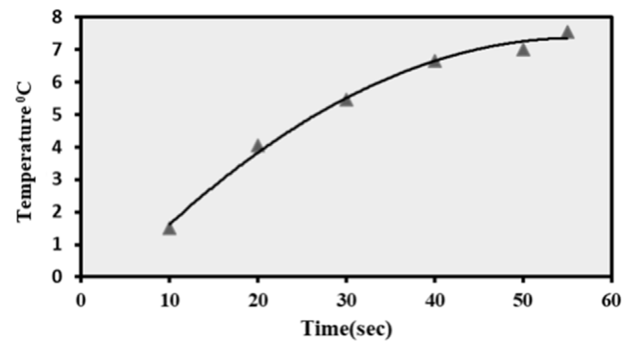

Fig. 5. Shows the relative change in temperature with time for the Light Cure LED.B (continuous mode).

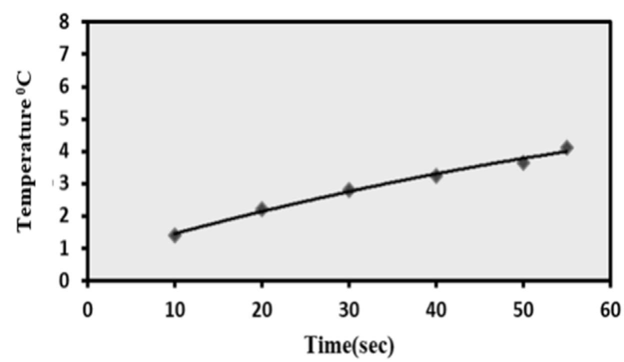

Fig. 6. Shows the time-temperature relationship for the Light Cure (LEDition) device.

4. Discussion

Extreme heat has been identified as a significant contributor to endodontic injury [5]. By directing the laser precisely at the thermocouple, the temperature of the thermocouple increases over time, allowing for the detection of temperature changes. Notably, the temperature increase varies significantly among different devices. A marked rise in temperature over time is evident when using the Light Cure (continuous) device for dental treatment, which corresponds with an increase in the temperature of both the tooth surface and, consequently, the tooth core. Pulpal injuries from external sources may occur during treatment. When utilizing a laser diode, a minor temperature difference was observed. Based on these findings, a diode laser is the optimal choice for dental restorations, as it causes the outer layer of the material to harden almost instantly upon exposure to light, while the inner layers harden as the light exposure time is extended. This technique is employed in dental restoration to reduce the rate of material shrinkage [9].

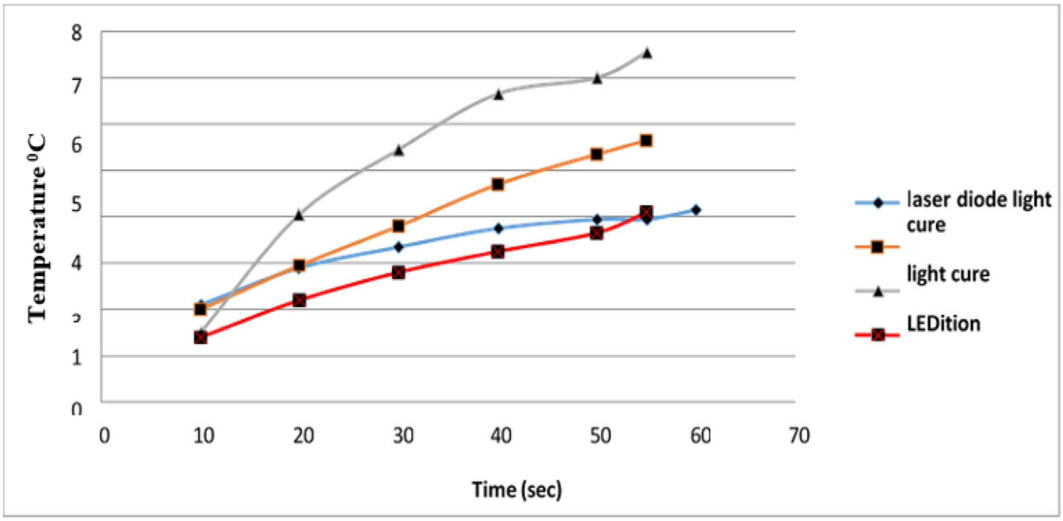

Fig. 7. Shows how the temperature of all the tools used in the study changed over time.

5. Conclusions

The diode laser outperforms the light-cure device because it can maintain lower temperatures for extended periods during therapy, enhancing its effectiveness.

Source of Funding

No funding received.

Conflict of Interest

None.

Ethical Approval

This research is a study of the properties of the material used in dental fillings. It has not been applied to humans.

Data Availability

All data is in the search.

Author Contributions

All research paragraphs, including preparation, decisions, and calculations, were carried out by the researcher.

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