Dr. Z. T. AL-DAHAN
Assist.prof in laser Engineering
Nahrain Unversity

Study of a Dye-Assisted Diode Laser System for Ablation of Dental Caries

Dr. Z. T. AL-DAHAN

Abstract:-
In this work, a continuous wave semiconductor diode laser (GaAlAs) which emits radiation at 810 nm and power of 2W maximum was used to ablate caries enamel and dentine from extracted human teeth in conjunction with specialized diode laser absorbing dye "indocyanine green". This technique offers selective ablation with minimal risk of thermal damage to surrounding dental tissues because the uptake of the dye and its irradiation by the diode laser together control the ablation.
Keywords: *Semiconductor laser ,Dye laser*

1. Introduction

Laser applications define one of the most important areas of dentistry today. Using the laser it is possible to treat a wide variety of conditions in new ways that reduce pain, mechanical stress, noise and postoperative problems, and no anesthesia is needed in the majority of the cases.

Among the first laser effect investigated in the 1960's, was its effect on the dental hard tissues. Many researchers thought that lasers are the obvious replacement for the dental drilling for several reasons, some of theses reasons are [1]:

- Lasers are non-contact tools, and their use produced no vibration as in the conventional drills.
- Lasers are much quieter than drilling, usually; it produced only "popping" sound, which is generally well-tolerated.
- Laser can sterilize as it cut-clearly; this is an advantage in treating caries and in possible endodontic applications.
- Lasers can also be used to seal the tissue at the periphery of the cut.
- Conventional drilling seriously increases the possibility of injuring the eyes of the operator with materials or fragments of tissue.

There are currently four areas of dental care that are enjoying the benefits of laser technology:

1. Cavity removal can be accomplished with various laser machines. These have the ability to remove decay within a tooth, and prepare the surrounding enamel for bonded fillings.
2. Curing or hardening bonding materials is another area where lasers have become important. These lasers drastically reduce the time it takes to finish a filling, and create what some

3. Whitening teeth can be accomplished with special solutions that are applied to the tooth surface in the dental office and activated by laser energy.
4. Periodontal, or gum related care is the forth area benefiting from laser technology.

2 . Materials and Method:

2.1 Samples:

The sample has been selected from a group of Iraqi patients. These samples consisted of, 200 extracted human class II premolars with advanced levels of caries, and 20 healthy extracted human premolars used as controls.
The age of the patients of the sample ranged from 20-25 years old.

2.2 Materials:

The following materials were used in this study:

1. Formalin (10%) used for storage of teeth and for keeping the teeth without any changes until the experiment.
2. Hypochlorite solution (1%) used for storage and sterilizing of teeth.
3. Distilled water used for storage of teeth and for preparation of ICG dye.
4. Indocyanine green dye ($C_{43}H_{47}N_2O_6S_2Na$) (SIGMA-ALDRICH CHEMICAL CO.Gmbb).
5. Paper towel used for drying of the teeth.
6. Non-corrosive microscopic slides: Lames poret. Objects TEGET for microscopic slide preparation.

2.3 Mechanism of Dye-Assisted Diode Laser Ablation of Dental Caries:

Since lasers can remove tissue by non-contact ablative process, they offer the promise of “painless” dentistry, replacing for example, the mechanical drill for caries treatment. While various lasers have been shown to be successful in soft tissue treatment, the efficacy of laser techniques for dental hard tissue is yet to be established.

Studied performed using ruby, carbon dioxide, and neodymium – and holmium – doped yttrium aluminium garnet (Nd:YAG and Ho:YAG) lasers, for example, on dentine and enamel have shown evidence of cracking, melting, charring, fissuring or crazing of tooth surfaces[2].
In addition, inefficient ablation occurs due to the low optical absorption by enamel and dentine at infrared wavelengths, and, with the high laser powers required for ablation, it is difficult to restrict the temperature rise in the pulp to safe levels [3].

The use of an applied chromophore to enhance laser energy absorption in tissue is helpful in confining energy penetration to a small volume, while reducing the total laser power required for ablation [4,5]. The topical application of the photo–absorbing dye indocyanine green (ICG) to carious lesions, in conjunction with laser radiation, allows localized energy deposition. For tissue ablation, this dye has the advantages of binding well to proteins and water [6,7] and thus it tends to bind to the caries rather than to the healthy tissue. The dye exhibits a strong absorption centered at 800 nm [8] as shown in Figure (1), and diode laser light at this wavelength is preferentially absorbed by the dye – caries combination. The coupling of energy to the tissue is followed by non- thermal bond breaking (chemical effects) that leads to ablation of dental caries.
So that the interaction take place between diode laser photons and caries components that chemically were processed with the ICG dye solution which have high absorption properties at diode laser wavelength.

The risk of thermal damage to the surrounding hard and soft tissues is reduced since they absorb near-infrared light in this wavelength region poorly [9].

2.4 Optical Arrangement of the Dye-Assisted Diode Laser Ablation System:

The optical setup consists of the following parts as shown in Figure (2). A 2W continuous wave (CW) GaAlAs semiconductor diode laser, operating at 810nm was placed on the optical bench.

The output beam from a diode laser has a large spot size this lead to low fluence, i.e., small effect on the tooth so we prepared optics design to focus the diode laser beam to a spot size with a diameter of about 0.5mm by a bio-convex spherical converging lens of a focal length (5cm) in order to increase the power density and to lead deeper depth in the carious lesion of the tooth surface. This converging lens was held by a special lens holder on the optical bench.

Two quartz attenuators with different attenuation factors were used to vary the fluence at the specimens (teeth). The ratio of the first attenuator was 50%. Whereas it was 75% for the second attenuator.

A clamp holder was used to hold the specimen (tooth) in such a way that the laser beam was focused on the carious lesion of the teeth. A K-type thermocouple was used to measure the temperature rise in the dental pulp.

The power was measured at the target for each exposure at the start and the end of the experiment using a laser power meter for accurate results. A timer was used to measure the time for each exposure period.

The laser unit was used in CW mode. The power output is (0.5W, 1W, 2W). The exposure time is (60,120,90,180 seconds). The laser beam was collimated and focused to a spot size with a diameter of (0.5mm). The power density and the energy density used for this study can be calculate and present in Table (1).

2.5 Preparation of Different Indocyanine Green Dye Concentrations:

ICG dye solutions of 2%, 3%, and 4% were prepared by dissolving different weights of ICG powder dye in distilled water. The molarity of these three concentrations of ICG dye can be determined from the following equation,

$$C = (W / MW) / V \qquad \ldots (2.19)$$

Where
C : is the molarity measured in (mole/liter),
W : is the Weight measured in (g),
MW : is the molecular weight measured in (g/mole), and
V : is the volume measured in (liter).

So that the molarity of 2%, 3% and 4% ICG dye solutions are 51600 μM, 38700 μM and 25800 μM respectively. The dye was used freshly.

Since the molar extinction coefficient for the ICG dye is equal to 10^5 M^{-1} cm^{-1}[10], then the absorption coefficient (μ_a) for the three ICG dye concentrations can be determined from the following formulae,

$$\mu_a = \varepsilon\, C \ln 10 = 2.303\, \varepsilon\, C \qquad \ldots(2.22)$$

Where
ε: is called the molar extinction coefficient of the solute at the wavelength of measurement (liters/mole-cm),
C : is the molarity of the solute (moles/liter), and
it was equal to 11883.4, 8912.6, 5941.74 cm^{-1} respectively.

2.6 Experimental Procedure

In this study, 200 extracted human class II premolars with advanced levels of caries were used as the specimens and 20 healthy extracted human premolars were used as the controls.

For each carious tooth, the weight of material ablated, and temperature rises in the dental pulp were measured. Before each study, all specimens, which were previously stored in 10% formalin at room temperature, were sterilized with 1% percent hypochlorite solution.

Specimens were then stored in distilled water at room temperature until required. To establish that the measured change in weight of the teeth after laser irradiation was due to material ablation, (and not dehydration), the teeth were allowed to dry on paper towel in air for an hour before laser irradiation. A weight of 10 carious teeth were determined gravimetrically after a period of 90 sec and (after drying for an hour), then the weights of these carious teeth were determined again after a period of 180 sec.

During the first twenty minutes of drying, the specimens lost, on average, a weight of

23 ± 5mg. After this period their weight remained constant.

Temperature studies were conducted to determine the average temperature rise in the pulp during laser exposure. For the 210 teeth treated using diode laser irradiation and ICG dye, the temperature rise in the pulp was measured by placing a thermocouple into the pulp chamber. The thermocouple was inserted after the lower portion of the tooth was removed using a low speed diamond saw, and the dead tissue removed from the pulp chamber with a fine drill.

The amount of dye required varied depending on the amount of caries present in each specimen, but on average, 1.2 mg of dye was absorbed.

2.7 The Irradiated Groups

Irradiation of teeth surfaces is carried out according to the following groups as illustrated in Table (2). And a weight of 10 carious teeth were determined gravimetrically after a period of 90 sec of drying and (after drying for an hour), then the weights of these carious teeth were determined again after a period of 180 sec.

2.7.1 The First Group

Diode laser giving a wavelength at 810 nm with fixed power by means of attenuators was focused on tooth surface using a focusing lens of 5 cm focal length.

A total of 180 extracted human class 2 premolars with advanced levels of caries were used. The amount of material ablated from 180 carious teeth was determined gravimetrically (by using sensitive balance).

ICG dye solution of 2, 3, 4 percent in distilled water was applied to the carious lesion on teeth surfaces. Immediately before laser irradiation and after dabbed a small amount of ICG dye on to the caries by using a dental brush each tooth was weighed.

Laser diode power of 0.5, 1, 2W was then delivered to the dyed caries, with a total irradiation time of 120 sec and 180 sec.

Ninety tooth specimens were irradiated for 60 sec, shaken to remove powdered remain and weighed once again to determine the amount of material removed. This process was repeated on each tooth resulting in a total irradiation period of 120 sec. The total mass of material ablated from the tooth was thus determined.

Another 90 tooth specimens were irradiated for 90 sec, shaken to remove powdered remain and weighed once again to determine the amount of material removed. This process was repeated on each tooth, resulting in a total irradiation period of 180 sec. The total mass of material ablated from the tooth was determined.

2.7.2 The Second Group

To determine, the effect of the dye-assisted diode laser ablation technique on healthy enamel, 10 healthy teeth were irradiated for a total irradiation period of 180 sec. Using ICG dye concentration of 4 percent and laser diode power of 2W.

2.7.3 The Third Group

To determine the effect of the indocyanine green dye on the efficiency of the ablation, 10 carious teeth were irradiated for a total irradiation period of 180 sec using laser diode power of 2W and without adding the ICG dye on the caries lesion.

2.7.4 The Fourth Group

To determine the effect of the diode laser on healthy enamel and without adding the ICG dye, 10 healthy teeth were irradiated for a total irradiation period of 180 sec using laser diode power of 2W and without applying the ICG dye.

3. Results and Discussion:

The results of the experimental work and their discussion in many directions presented in this research were based on the analysis of teeth weight (amount of dental carious material ablated).

3.1 Establishing the Effect of Diode laser Radiation on Carious Teeth

As shown in Table (3), diode laser radiation at the three different laser power applied and three different ICG dye concentration used resulted in a statistically significant reduction in mean carious teeth weight (mean weight of carious material ablated) after 60, 90, 120 and 180 seconds of exposure to laser radiation. A total of 36 experiments with samples of 10 carious teeth each were carried out and concluded that laser radiation had a statistically significant effect in reducing carious teeth weight, which can be attributed to ablation of carious dental material. It will be shown later that the ablated material is carious material only and not sound enamel since laser radiation had no effect on sound teeth. So that the ablation of carious lesions is higher because the dye tends to bind to the caries rather than to the healthy tissue. Therefore the diode laser light removes only the dye–caries combination.

The obtained results exhibit a good agreement with those of McNally KM. et al. [9].

As shown in Table (4), samples of 10 carious teeth were left in room temperature without irradiation for 90 and 180 seconds respectively. The changes observed were both small in magnitude and random in direction (randomly oscillating between small increases and decreases compared to baseline value). The mean change observed was a reduction of -0.05 mg after 90 seconds and an increase of 0.05 mg after 180 seconds, which were not significant statistically. The finding of this experiment establishes two facts: first the weighing scale used was well calibrated, with a difference not exceeding 0.05 (ranging between 0.4 to -0.5) mg. Second the changes observed in weight of teeth exposed to laser irradiation can be attributed to radiation effect and not to weighting scale error or environmental effects (like dryness).

3.2 Establishing the Effect of Diode laser Radiation on Sound Teeth

As shown in Table (5), a sample of 10 sound teeth were exposed to 2 W laser power for 90 and 180 seconds respectively, with adding (4%) ICG dye and without adding it. The changes observed in teeth weight were small in magnitude and random in direction (ranging between a reduction of -0.4 to an increase of 0.4 mg). The mean changes in teeth weight were very small in magnitude (ranging between -0.06 to 0.03) were all not significant statistically. The conclusion is that diode laser radiation has no obvious effect on sound teeth weight whether the dye was applied or not. Since the absorption of laser light by human teeth is mainly dependent on the wavelength of the laser light then this conclusion can largely be explained by the absorption properties of the tooth mineral (carbonated hydroxyapatite) in the radiation region, since it doesn't absorb the diode laser wavelength (810nm) in addition to the water which has relatively very low absorption for this wavelength. This situation offers a minimum thermal damage to the surrounding hard and soft tissues.

These results also are in agreement with those of McNally KM. et al. [9].

4. Conclusions:

The dye-assisted diode laser ablation of dental caries technique performs as well as the mechanical drill with the added advantages of selective ablation and the potential for painless treatment and it could be developed into a practical method for cavity preparation.

The ablation of dental caries by diode laser irradiation can be achieved only with the assistance of the ICG dye.

Ablation of carious enamel and dentine by a dye-enhanced low-power CW diode laser was efficient, and the rise in the pulp temperature was slight. Ablation efficiency and the rise in the pulp temperature were both found to increase with laser irradiance, exposure time, and with dye concentration. Thermal side effects due to the temperature rise in the dental pulp can be controlled by the laser power, exposure time, and the dye concentration used.

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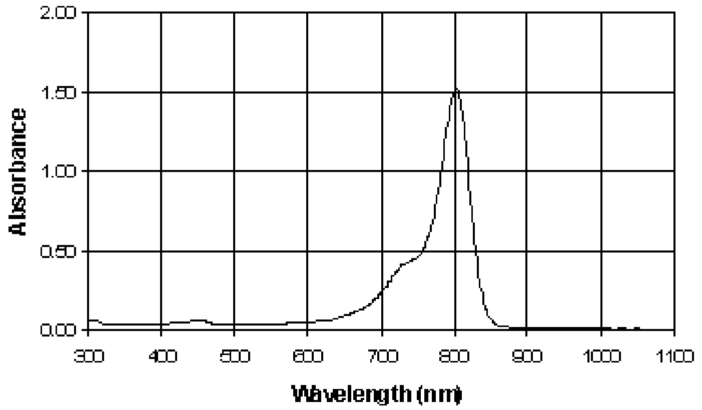

Figure (1): The absorption spectrum of ICG dye [8]

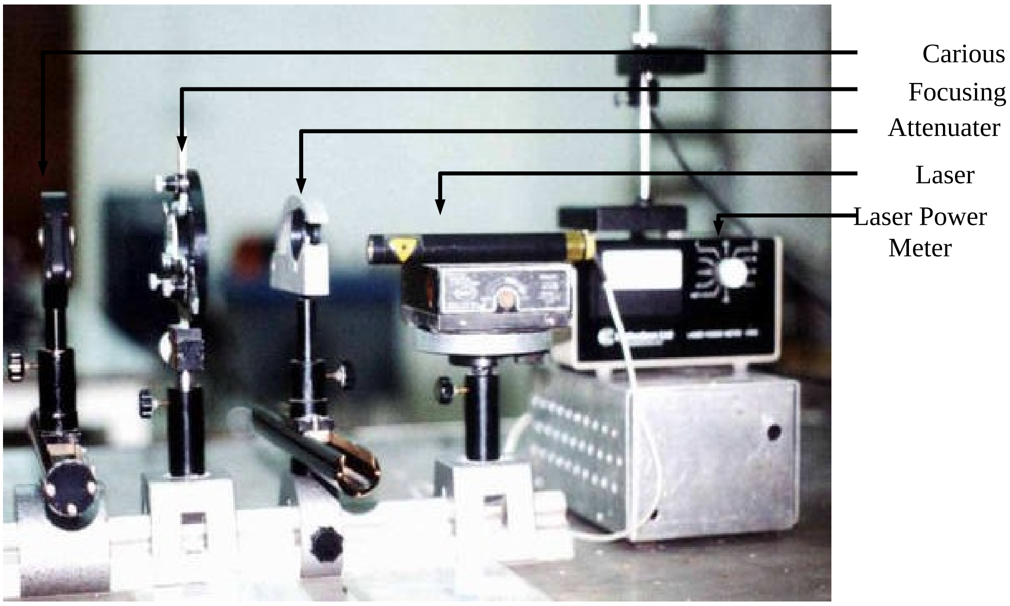

Figure (2): Optical setup of the experimental work

Table (1): Power density and energy density used in this stud

The output power of CW diode laser (watt)	Power densities (watt/cm^2)	Time (second)	Energy densities (Joule/cm^2)
0.5W	254.64	60	15278.8
0.5W	254.64	120	30557.7
0.5W	254.64	90	22918.3
0.5W	254.64	180	45836.6
1W	509.29	60	30557.7
1W	509.29	120	61115.49
1W	509.29	90	45836.6
1W	509.29	180	91673.2
2W	1018.59	60	61115.49
2W	1018.59	120	122231
2W	1018.59	90	91673.2
2W	1018.59	180	183346.5

Table (2): Show the variables include with each group.

THE 1ST GROUP	The 1st subgroup 0.5W output power of CW Diode laser	2% ICG dye	10 carious teeth were ablated with 0.5W output power of CW diode laser	For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
		3% ICG dye		For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
		4% ICG dye		For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
	The 2nd subgroup 1W output power of CW Diode laser	2% ICG dye	10 carious teeth were ablated with 1.0W output power of CW diode laser	For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
		3% ICG dye		For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
		4% ICG dye		For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
	The 3rd subgroup 2W output power of CW Diode laser	2% ICG dye	10 carious teeth were ablated with 2.0W output power of CW diode laser	For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
		3% ICG dye		For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
		4% ICG dye		For a total irradiation period of 120 seconds
				For a total irradiation period of 180 seconds
THE 2ND GROUP	2W output power of CW Diode laser	4% ICG dye	10 healthy teeth were irradiated with 2W output power of CW diode laser for a total irradiation period of 180 seconds	
THE 3RD GROUP	2W output power of CW Diode laser	Without adding the ICG dye	10 carious teeth were irradiated for a total irradiation period of 180 sec and using 2W output power of CW diode laser	
THE 4TH GROUP	2W output power of CW Diode laser	Without adding the ICG dye	10 healthy teeth were irradiated for a total irradiation period of 180 sec and using 2W output power of CW diode laser	

Table (3): The change in carious teeth weight (mg) after 60, 90, 120 and 180 seconds of exposure to laser stratified by laser power used and dye concentration.

		After 60 seconds				After 90 seconds				After 120 seconds				After 180 seconds			
		Mean	SD	SE	N	Mean	SD	SE	N	Mean	SD	SE	N	Mean	SD	SE	N
A)	0.5 W laser power																
-	2% dye conc.	-2.8	0.5	0.17	10	-3.5	1	0.31	10	-5	0.6	0.18	10	-7.4	0.7	0.23	10
-	3% dye conc.	-3.8	0.8	0.24	10	-5.8	0.6	0.18	10	-7.4	0.5	0.17	10	-11.6	0.5	0.16	10
-	4% dye conc.	-5.2	0.8	0.26	10	-7.6	0.5	0.17	10	-10.3	0.5	0.17	10	-14.9	0.6	0.18	10
B)	1 W laser power																
-	2% dye conc.	-5.1	0.4	0.13	10	-7.5	0.3	0.1	10	-10.3	0.7	0.22	10	-14.8	0.5	0.14	10
-	3% dye conc.	-7.5	0.4	0.14	10	-11.2	0.3	0.09	10	-14.5	1.3	0.41	10	-22.1	0.5	0.15	10
-	4% dye conc.	-9.9	0.5	0.15	10	-14.7	0.4	0.12	10	-20.1	0.8	0.25	10	-30	0.6	0.19	10
C)	2 W laser power																
-	2% dye conc.	-10.3	0.6	0.18	10	-14.7	0.6	0.18	10	-20	0.7	0.23	10	-30	0.7	0.23	10
-	3% dye conc.	-14.6	0.7	0.23	10	-22.3	0.5	0.17	10	-30.2	0.7	0.22	10	-44.7	0.5	0.17	10
-	4% dye conc.	-20	0.7	0.21	10	-30	0.6	0.19	10	-40.4	1.6	0.51	10	-59.1	0.6	0.18	10

Table (4): The change in weight of carious teeth (mg) after being left in the experimental conditions for 90 and 180 seconds respectively (intraobserver calibration)

	Teeth weight (mg)				
Tooth number	Dry (baseline)	After 90 seconds	Change	After 180 seconds	Change
1	1479.1	1479.6	0.5	1479.6	0.5
2	1417.3	1417.5	0.2	1417.1	-0.2
3	2118.1	2118.3	0.2	2118	-0.1
4	2231.9	2231.5	-0.4	2231.5	-0.4
5	1993.1	1993	-0.1	1993.5	0.4
6	1321.9	1321.6	-0.3	1321.6	-0.3
7	2351.3	2351.3	0	2351.1	-0.2
8	2177.1	2177	-0.1	2177.5	0.4
9	1434.5	1434.2	-0.3	1434.7	0.2
10	2331.7	2331.5	-0.2	2331.9	0.2
Overall					
Minimum	1321.9	1321.6	-0.4	1321.6	-0.4
Maximum	2351.3	2351.3	0.5	2351.1	0.5
Mean	1885.6	1885.55	-0.05	1885.65	0.05
SD	420.61	420.55	0.28	420.6	0.33
SE	133.01	132.99	0.09	133	0.1
N	10	10	10	10	10
P (Paired t-test)			**0.59** *[NS]*		**0.64** *[NS]*

Table (5): The change in weight of sound teeth (mg) after exposure to 2 W diode laser power laser stratified by dye concentration.

	Change in sound teeth weight (mg)	
	After 90 seconds	After 180 seconds
No dye		
Minimum	-0.3	-0.4
Maximum	0.4	0.3
Mean	0.03	-0.01
SD	0.26	0.26
SE	0.08	0.08
N	10	10
P (Paired t-test)	**0.77** [NS]	**0.91** [NS]
4% dye conc.		
Minimum	-0.4	-0.4
Maximum	0.3	0.4
Mean	-0.06	0.03
SD	0.26	0.27
SE	0.08	0.08
N	10	10
P (Paired t-test)	**0.49** [NS]	**0.73** [NS]

استخدام ليزر شبه موصل لأستئصال نخر اسنان بمساعدةالصبغ العضويه

د.زياد طارق الدهان
جامعة النهرين–كلية الهندسه–هندسة الليزر

الخلاصة

شبه موصل موجةِ مستمرِ للليزر (GaAlAs) الذي يَبْعثُ الإشعاعَ في 810 nm وقوَّة 2 واط كحَدّ أعلى اُستَعملُ لإسْتِئْصال نخر المينا وعاجِ الأسنان الإنسانيةِ المُنْتَزعةِ باستخدام ليزرَ يَمتصُّ صبغاً "أخضر indocyanine ". توفر هذه التقنيةِ بالخطرِ الأقل ما يمكنِ مِنْ الضررِ الحراريِ إلى أنسجةِ المحيطةِ بالأسنانِ لأن منفذَ الصبغِ وإنارتِه بليزرِ شبه الموصل يُسيطرانِ على الإستئصالِ سوية.