The Impact of Pulsed Nd:YAG Laser Energy and Wavelength on Human Teeth Enamel: In Vitro Study

Mays S. Tareq[1], * Tagreed K. Hamad[2], Salam A. W. Al-abassi[3]

Authors affiliations:
1*) Applied Science Department, University of Technology, Baghdad, Iraq.
mays.s.tareq@uotechnology.edu.iq

2) Dept. of Laser and Optoelectronics Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq.
tagreed.k.hamad@nahrainuniv.edu.iq

3) Department of Electron Devices, Faculty of Electrical Engineering and informatics, Budapest University of Technology and Economics, Budapest, Hungary.
sal-abassi@edu.bme.hu

Paper History:

Received: 1st Jun. 2024

Revised: 4th Aug. 2024

Accepted: 31st Aug. 2024

Abstract

The aim of the research was for evaluation the morphological and chemical alterations that result from the Nd:YAG laser treatment of dental enamels using optical microscopy (OM) with Energy dispersion X-ray spectroscopy (EDX), respectively. Two human enamel samples were obtained, the samples were exposed to the Nd: YAG laser irradiation. The micrographs obtained by optical microscopy demonstrated morphological changes. The concentrations of carbon (C), calcium (Ca), phosphorus (P), and oxygen (O) in crater sites and its environs were measured using EDX, as well as trace amounts of manganese, magnesium, and silicon. However, due to their low concentration, these trace elements were neglected. We obtained the maximum depth profile of carters on tooth enamel surface at 1200 µm with laser pulse of 532 nm with 500 mJ energy/pulse, while the minimum depth profile of carters at 200 µm with laser pulse of 1064 nm with 100 mJ energy/pulse. Dental tissue can be safely treated with a Nd: YAG laser with 200 mJ, 9 ns, and 1064 nm since this laser irradiation range did not induce any noticeable morphological changes. As a result, the Nd: YAG laser offers as an ideal option for clinical treatment.

Keywords: Nd: YAG Pulsed Laser, Tooth Enamels, EDS Diagnostics, Morphological Changing.

تأثير ليزر Nd:YAG النبضي على مينا الأسنان البشرية: دراسة مخبرية

ميس سمير طارق، تغريد خالد حمد

الخلاصة:

كان الهدف من البحث هو تقييم التغيرات المورفولوجية والكيميائية الناتجة عن معالجة مينا الأسنان بليزر Nd:YAG النبضي باستخدام المجهر الضوئي (OM) مع التحليل الطيفي للأشعة السينية لتشتت الطاقة (EDX) على التوالي. تم الحصول على عينتين من الاسنان البشرية، وتم تعريضها لأشعة ليزر Nd: YAG. وأظهرت الصور المجهرية التي تم الحصول عليها بواسطة المجهر الضوئي التغيرات المورفولوجية. تم قياس تراكيز الكاربون (C)، والكالسيوم (Ca)، والفوسفور (P)، والأكسجين (O) في مواقع الحفر وضواحيها باستخدام EDX، بالإضافة إلى كميات ضئيلة من المنغنيز والمغنيسيوم والسيليكون. ومع ذلك، بسبب تركيزها المنخفض، تم إهمال هذه العناصر النزرة. حصلنا على الحد الأقصى لعمق الحفرة على سطح مينا الأسنان عند ١٢٠٠ مايكرومتر مع نبضة ليزر تبلغ ٥٣٢ نانومتر مع طاقة ليزر مقدارها ٥٠٠ مللي جول، في حين أن الحد الأدنى لعمق الحفرة عند ٢٠٠ مايكرومتر مع نبض ليزر يبلغ ١٠٦٤ نانومتر مع طاقة ليزر مقدارها ١٠٠ مللي جول. يمكن معالجة أنسجة الأسنان بأمان باستخدام ليزر Nd: YAG بطاقة ٢٠٠ مللي جول و٩ نانو ثانية و١٠٦٤ نانومتر نظرًا لأن نطاق تشعيع الليزر هذا لم يحدث أي تغييرات شكلية ملحوظة. ونتيجة لذلك، يعتبر ليزر Nd: YAG خيارًا مثاليًا لعلاج الاسنان السريري.

الكلمات المفتاحية: ليزر YAG النبضي، مينا الأسنان، المجهر الضوئي، تشخيص EDS، التغييرات المورفولوجية.

1. Introduction

In dentistry, since 1960, lasers have been used as an alternative treatment. A number of dentistry applications have benefited from their many improvements. When it compared to traditional drilling methods, using a laser in dentistry is quite painless. Thus, dental lasers' utility has increased dramatically over the last several decades [1]–[3].

Dentists often classify lasers according to their wavelength range, the materials they work on, and the problems they treat. According on the kind of tissue, there are two main categories of lasers: hard tissue lasers and soft tissue lasers [4]. The Nd: YAG laser, a versatile tool for both hard and soft tissues, has found widespread use in endodontics, periodontics, preventative dentistry, oral surgery, and a host of other dental specialties [5]. Laser parameters and target tissue features, such as wavelength, emission mode, intensity, pulses number, frequency, exposure time, incident angle, composition of tissue and thickness, determine how the Nd: YAG laser interacts with dental tissues [6], [7]. A tooth's hard tissues consist of enamel, dentin, and cementum. The pulp, located in the tooth's center and containing connective tissues, nerves, and blood vessels, is the fourth type of tissue and is soft and noncalcified. Metals and other chemicals are present in dental tissues like dentin and enamel. Proteins make for 3% of enamel's volume, while minerals account for 85% and water 2%. The amount of dentin is composed of minerals (47%), proteins (33%), and water (20%) [8], [9] The hydroxyapatite Ca10(PO4)6(OH)2 crystals, which forms the mineral component in these tissues, has a range of absorption in the wavelength of near-infrared region of approximately between 1000 and 5000 nm. For this reason, the necessary wavelength range is ideal for the effective application of Nd:YAG lasers in dental applications[10]. The Nd: YAG laser is a valuable tool for cavity preparation , tooth decay prevention, and precisely removing filling material since it may modify the surface, chemical constitution, and structure morphology of human teeth, according to several studies [6], [11]–[13]. The present study aims to study the impact of Nd:YAG laser irradiation affecting changes in the morphology and chemical composition of dental tissues by using optical microscopy and energy dispersive X-ray spectroscopy (EDX), respectively and thus, dentists can enhance their clinical practice by selecting the most appropriate equipment and strategy in light of the potential for future cavity eradication and the impact of laser irradiation on tooth enamel surface.

2. Materials and Method

2.1 Sample (Tooth) collection

For therapeutic purposes, two patients from identical geographic region provided samples of their healthy permanent teeth, which were used in this investigation. Every sample was stored in a 0.1 (wt/v) thymol solution at 4 °C. All tooth samples are then dried and thoroughly cleaned with distilled water in preparation for more studies.

2.2 Irradiation with a Nd: YAG pulsed laser

The samples were treated with Nd:YAG pulsed laser irradiation pulses. The parameters of the laser were adjusted between 100 and 500 mJ for each pulse, with step of 100 mJ each time at first harmonic and second harmonic generation of laser wavelengths (1064, 532) nm , respectively. The pulse width was 9 ns and the repetition rate was 1 Hz. On an XYZ stage, the surface target was set at a right angle to the laser beam. In order to scan the tips vertical to the surface, the irradiation was only done in one direction. Figure 1 shows the setup for the laser irradiation.

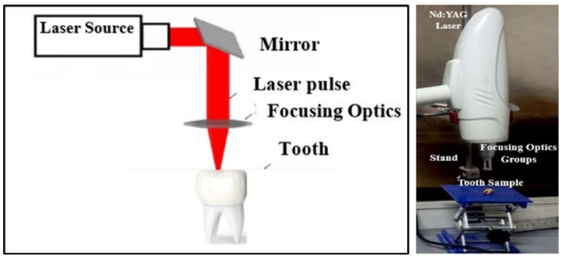

Figure (1): An experimental setup for the laser irradiation.

2.3 Energy dispersive X-ray (EDX)

An EDX of EFI Bruker micro analysis model was used to investigate the tooth samples for their elemental composition. An X-ray source is used as the excitation source in the EDX technique, which is based on the examination of an interaction between the specimen and the X-ray source [14]. One may determine the surface elemental composition of a sample by measuring the radiated unique X-rays [15]. We were able to determine the presence of each element by analyzing the tooth samples.

2.4 Optical microscope

By using high resolution optical microscope (Olympus BX60M) which connected with digital camera, the surface topography of irradiation sample slices was evaluated by positioning them clearly on the microscope stage. By selecting unit for the illuminated field mirror and modifying the brightness intensity using the knob for adjusting the brightness, specimens were magnified to a 600x magnification. After that, the specimen with a 10× objective was focused by fine-tuning the distance between the interpapillary utilizing the fine/coarse focusing knobs. The surface morphology was evaluated by capturing an optical micrograph of the material during nosepiece rotation.

3.Results

3.1 Dental tissue chemical analysis using energy dispersive X-ray spectroscopy

Enamel contains the following four elements: calcium, phosphorus, oxygen, and carbon. See Figure 2 for an illustration of the average values and standard deviations of the weight percentages of the enamel surface elements, as shown in Table 1. As the concentrations of calcium and phosphorus increased, the hardness of the teeth samples increases, but it decreases as the Carbon element's concentration increase.

Table (1): Weight percentages and their standard deviations for each enamel surface element.

Groups	Chemical constitution wt%			
	Ca	**O**	**P**	**C**
S1	50.60	30.22	14.34	6.20
S2	48.75	27.62	5.35	9.82

3.2 Optical microscopy of laser-irradiated dental tissues

The Olympus BX60M optical microscope was set to a magnification of 600×in order to study the enamel surface's morphological changes in response to various laser energy and wavelengths. Figure 3 shows optical micrographs of enamel taken under the same experimenting conditions as the samples, utilizing pulses of 1064 nm and 532 nm and 100-500 mJ energy/pulse. At the crater's periphery, melting was seen. Furthermore, when the laser energy and wavelength were adjusted, the fracture area grew. Anisotropic behavior was shown by the heat distribution. Because of a sudden increase in temperature, a fissure or crack emerged on the surface of the enamel. Figure 4 shows the representative profile of the crater depth of tooth samples taken at various wavelengths and laser energy. Cracks and craters were discovered on the surface of the tooth's enamel. As the laser's energy and wavelength were varied, the crater depth increased and collapsed. The region around the ablation site showed signs of thermal damage. It was discovered that teeth exposed to a 500 mJ laser at a 532 nm wavelength produced craters with a greater depth when compared to other tooth samples.

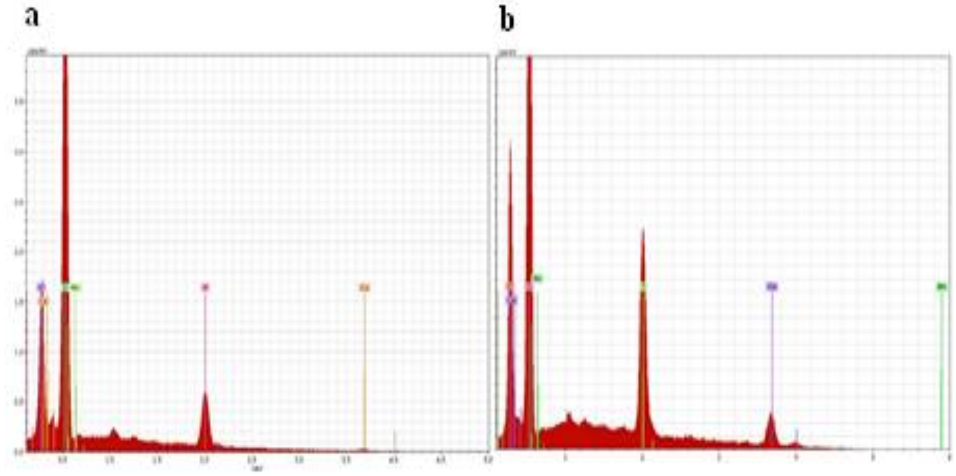

Figure (2): Element distribution in enamel for studied samples (a) S1 and (b) S2.

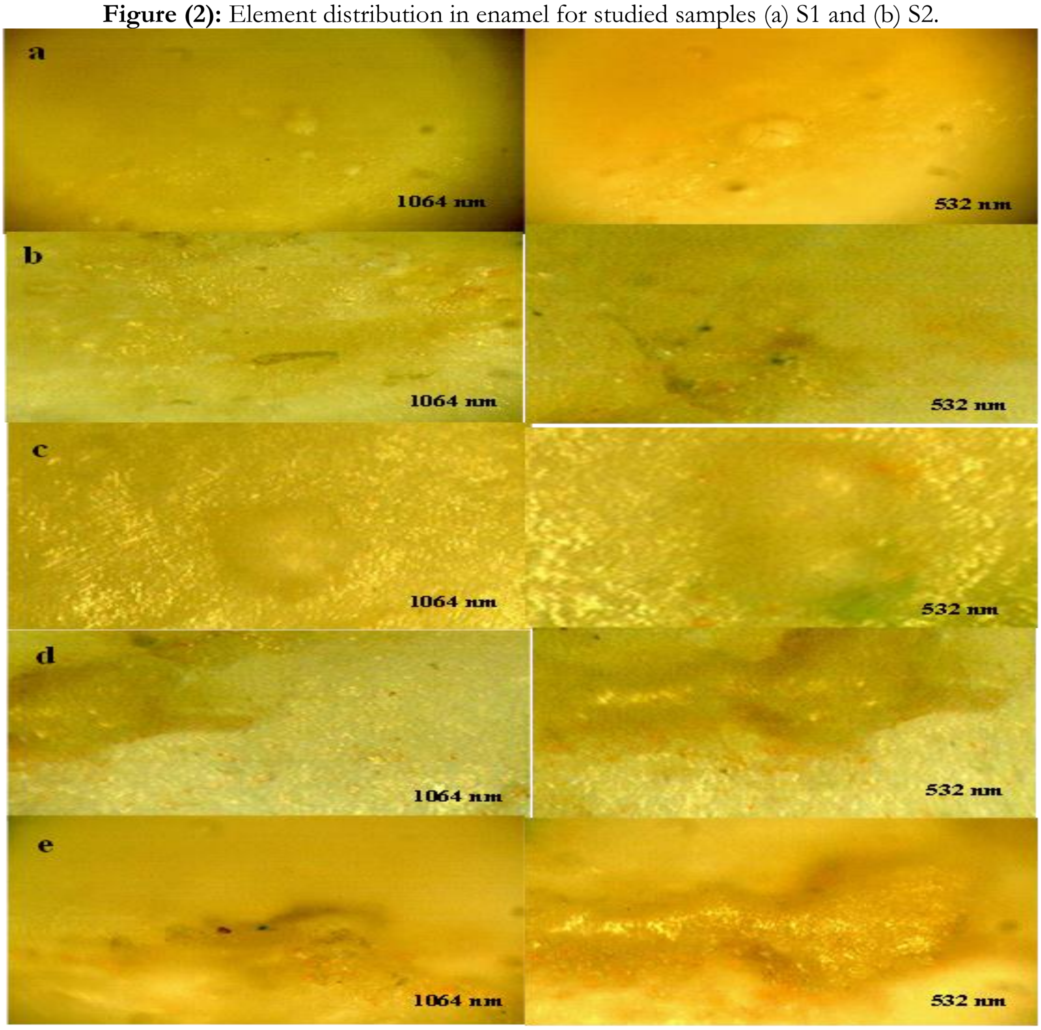

Figure (3): Optical micrographs of tooth enamel surface at laser energies for both (1064 and 532) nm (a) 100 mJ , (b) 200 mJ , (c) 300 mJ , (d) 400 mJ ,and (e) 500 mJ.

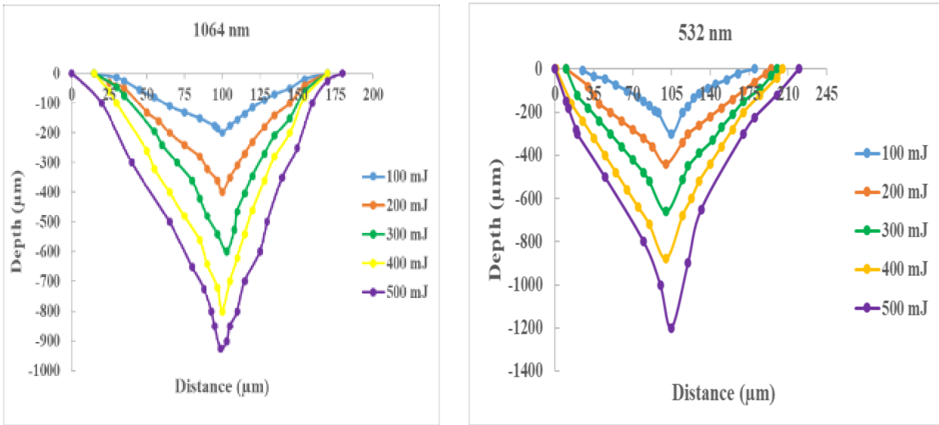

Figure (4): Profile of crater depth of dental samples at different wavelengths using different laser energies.

4.Discussion

Dental tissues were laser-irradiated, which led to localized heating and vaporization of the materials constituted teeth samples. The ablated materials expanded and created the plasma plume. This illustrated the connection between the ablated material and the plasma intensity [16]. An irradiated sample's laser energy is directly proportional to its emitter concentration [17].As a result, the amount of calcium present in the oral tissues is correlated with the laser's intensity. Several factors, including tissue water content, area of irradiated tissue, energy/pulse, and theoretical and experimental investigations, determine the laser energy density threshold that can be used to ablate dental tissues [12], [15], [18]. There were also differences in the concentrations of calcium, phosphorus, and carbon in the tooth structures of the dental samples that were analyzed. Although the most mineralized part of a human tooth is enamel, laser irradiation had little effect on its levels of matrix elements (Ca and P) [19]. dental tissues were too calcified, stiff, and a small laser energy with single-pulsed were unable to break the strong and stable bonding within the teeth structure [20] . This is why 100mJ, 200mJ, 300mJ, 400mJ, and 500mJ high laser energy were used in the experiment. Enamel does not have the same pore structure as dentin, which means it cannot disperse heat as well. On the other hand, dental caries is indicated by an increase in micromineral levels (Mn, Mg, Zn, Fe, Pb, Sr, and Si) and a decrease in Ca content [21]. S1 and S2 include elements of carbon, oxygen, phosphorus, and calcium, as well as trace amounts of manganese, magnesium, and silicon. However, due to their low concentration, these trace elements were neglected. It means that morphological alterations on the enamel could be achieved at these laser energies without structural variations [22] .

The optical microscope results showed that when the density of the laser beam increased, the portion of the enamel heat-affected zone (HAZ) and ablated region expanded [23]. The results clearly demonstrated that the photo-thermal interaction generated a melting impact due to an increase in local temperature [24]. Photons are absorbed by molecules in dentin, leading heat that will be released and dispersed across the tissue [25]. A variety of factors, including molecule structure, light wavelength, and laser energy density, contribute to the overall quantity of energy absorbed [26].

Enamel lacks the ability to dissipate heat due to its distinctive structure, in contrast to dentin's pores, which serve this purpose. The amount of damage and undesirable changes in morphology is directly proportional to the unsuitable laser energy density [27] . Dental tissue can be safely treated with a Nd: YAG laser with 200 mJ, 9 ns, and 1064 nm as, in comparison, this range of laser irradiation did not create any noticeable morphological alterations. These discoveries could have important implications for the use of lasers in dentistry, specifically for procedures like cavity preparation and repair, caries prevention, bacterium killing, and tissue activation.

5.Conclusions

This study aimed to investigate the impact of Nd: YAG laser treatment on the morphological structure and chemical composition of dental tissues. The decomposition of organic molecules, as shown in the exposed surface of the enamel, affects the equal distribution of heat and causes damage to adjacent areas. Nevertheless, it was unable to identify a recognizable pattern in the fluctuations in elemental composition within and surrounding the edges of the crater. When the dental enamel's bioactive glass is melted using a Nd:YAG laser with an irradiation laser energy of 500 mJ, the resulting surface is not uniform and has big pits that absorbed at the wavelength of 532 nm. The dental tissue can be effectively treated using a Nd: YAG laser with laser energy of 200 mJ and a wavelength of 1064 nm.

7. References

[1] Y. Al-Hadeethi *et al.*, "Data fitting to study ablated hard dental tissues by nanosecond laser irradiation," *PLoS One*, vol. 11, no. 5, p. e0156093, 2016.

[2] S. Najeeb, Z. Khurshid, M. S. Zafar, and S. Ajlal, "Applications of light amplification by stimulated emission of radiation (lasers) for restorative dentistry," *Med. Princ. Pract.*, vol. 25, no. 3, pp. 201–211, 2016.

[3] M. Mustafa, A. Latif, M. Jehangir, and K. Siraj, "Nd: YAG laser irradiation consequences on calcium and magnesium in human dental tissues," *Lasers Dent. Sci.*, vol. 6, no. 2, pp. 107–115, 2022.

[4] S. Galui, S. Pal, S. Mahata, S. Saha, and S. Sarkar, “Laser and its use in pediatric dentistry: a review of literature and a recent update,” *Int. J. Pedod. Rehabil.*, vol. 4, no. 1, p. 1, 2019.

[5] A. Kumari, M. Bagati, K. Asrani, and A. Yadav, “Application of laser in dentistry–a literature review,” *RGUHS J. Dent. Sci.*, vol. 13, no. 2, 2021.

[6] S. Parker, M. Cronshaw, E. Anagnostaki, V. Mylona, E. Lynch, and M. Grootveld, “Current concepts of laser–oral tissue interaction,” *Dent. J.*, vol. 8, no. 3, p. 61, 2020.

[7] I. M. Yacoob, S. G. Mahmood, M. Y. Slewa, and N. M. Nooh, “Mathematical Study for laser and its Clinical Applications in dentistry: Review and Outlook,” in *Journal of Physics: Conference Series*, IOP Publishing, 2020, p. 12101.

[8] D. Strakas and N. Gutknecht, “Erbium lasers in operative dentistry—a literature review,” *Lasers Dent. Sci.*, vol. 2, pp. 125–136, 2018.

[9] E. Klimuszko, K. Orywal, T. Sierpinska, J. Sidun, and M. Golebiewska, “Evaluation of calcium and magnesium contents in tooth enamel without any pathological changes: in vitro preliminary study,” *Odontology*, vol. 106, pp. 369–376, 2018.

[10] M. S. Tareq and T. K. Hamad, “In vitro studies the influence of Nd: YAG laser on dental enamels,” *Lasers Med. Sci.*, vol. 39, no. 1, pp. 1–8, 2024.

[11] A. Alkaisi and S. B. A. Abdo, “Modification of enamel surface morphology and strength using Nd: YAG laser with proper and safe parameters,” *Eur. J. Gen. Dent.*, vol. 10, no. 03, pp. 123–128, 2021.

[12] H. Moosavi, S. Ghorbanzadeh, and F. Ahrari, “Structural and morphological changes in human dentin after ablative and subablative Er: YAG laser irradiation,” *J. lasers Med. Sci.*, vol. 7, no. 2, p. 86, 2016.

[13] A. K. Pandarathodiyil and S. Anil, “Lasers and their Applications in the Dental Practice,” *Int J Dent. Oral Sci*, vol. 7, no. 11, pp. 936–943, 2020.

[14] Z. He *et al.*, “Mechanical properties and molecular structure analysis of subsurface dentin after Er: YAG laser irradiation,” *J. Mech. Behav. Biomed. Mater.*, vol. 74, pp. 274–282, 2017.

[15] S. Bordin-Aykroyd, R. B. Dias, and E. Lynch, “Laser-tissue interaction,” *EC Dent. Sci.*, vol. 18, no. 9, pp. 2303–2308, 2019.

[16] M. S. Tareq and T. K. Hamad, “Quantitative analysis of human teeth by using LIBS technology with different calibration methods: in vitro study,” *J. Opt.*, 2024, doi: 10.1007/s12596-024-01866-2.

[17] A. M. Salman, A. F. Jaffar, and A. A. J. Al-Taie, “Studying of laser tissue interaction using biomedical tissue,” *Al-Nahrain J. Eng. Sci.*, vol. 20, no. 4, pp. 894–903, 2017.

[18] F. M. Suhaimi *et al.*, “Morphology and composition analysis of enamel surface with dental adhesive following the application of ND: YAG ablation,” *J. Teknol.*, vol. 82, no. 6, pp. 63–70, 2020.

[19] R. Arjunkumar, “Awareness of laser dentistry among dentists in Tanjore-A survey,” *Biomed. Pharmacol. J.*, vol. 11, no. 3, pp. 1623–1632, 2018.

[20] R. Contreras-Bulnes, L. E. Rodríguez-Vilchis, B. Teutle-Coyotecatl, U. Velazquez-Enriquez, and C. M. Zamudio-Ortega, “The acid resistance, roughness, and microhardness of deciduous enamel induced by Er: YAG laser, fluoride, and combined treatment: an in vitro study,” *Laser Phys.*, vol. 32, no. 7, p. 75601, 2022.

[21] R. Bawazir, D. Alhaidary, and N. Gutknecht, “The current state of the art in bond strength of laser-irradiated enamel and dentin (nd: YAG, CO 2 lasers) part 1: a literature review,” *Lasers Dent. Sci.*, vol. 4, pp. 1–6, 2020.

[22] K. Kuhn, C. U. Schmid, R. G. Luthardt, H. Rudolph, and R. Diebolder, “Er: YAG laser-induced damage to a dental composite in simulated clinical scenarios for inadvertent irradiation: an in vitro study,” *Lasers Med. Sci.*, pp. 1–14, 2021.

[23] C. Fornaini, N. Brulat-Bouchard, E. Medioni, S. Zhang, J.-P. Rocca, and E. Merigo, “Nd: YAP laser in the treatment of dentinal hypersensitivity: An ex vivo study.,” *J. Photochem. Photobiol. B Biol.*, vol. 203, p. 111740, 2020.

[24] A. Khalid, S. Bashir, M. Akram, and Q. S. Ahmed, “The variation in surface morphology and hardness of human deciduous teeth samples after laser irradiation,” *Laser Phys.*, vol. 27, no. 11, p. 115601, 2017.

[25] E.-G. C. Tzanakakis, E. Skoulas, E. Pepelassi, P. Koidis, and I. G. Tzoutzas, “The use of lasers in dental materials: A review,” *Materials (Basel).*, vol. 14, no. 12, p. 3370, 2021.

[26] M. M. El Mansy, M. Gheith, A. M. El Yazeed, and D. B. E. Farag, “Influence of Er, Cr: YSGG (2780 nm) and nanosecond Nd: YAG laser (1064 nm) irradiation on enamel acid resistance: morphological and elemental analysis,” *Open Access Maced. J. Med. Sci.*, vol. 7, no. 11, p. 1828, 2019.

[27] C. M. Cobb, “Lasers and the treatment of periodontitis: the essence and the noise,” *Periodontol. 2000*, vol. 75, no. 1, pp. 205–295, 2017.