Journal of Lasers in Medical Sciences

J Lasers Med Sci 2023;14:e37

Original Article

http://journals.sbmu.ac.ir/jlms

doi 10.34172/jlms.2023.37

Analysis of the Temperature Elevation of the Dual-Wavelength Diode Laser and the Er, Cr: YSGG Laser in Oral Soft Tissue Incisions

Alaa Jamal Al-Ani[1*], Ammar Saleh Al-Alawi[2], Hanan Jafer Taher[3]

[1]Medical and Biological applications Branch, Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq
[2]Laser/Dentistry (Oral Surgery), Al-Emamein Al-Kadhemein Medical City, Baghdad, Iraq
[3]Photonics Units, Institute of Laser for Postgraduate Studies, University of Baghdad, Baghdad, Iraq

***Correspondence to**
Alaa Jamal Al-Ani,
Email: aalaa.jamal2102m@ilps.uobaghdad.edu.iq

Received: May 22, 2023
Accepted: July 26, 2023
Published online September 25, 2023

Abstract

Introduction: Lasers are one of the most advantageous tools that have been used in a variety of medical fields. Soft tissue management is an important part of oral and maxillofacial surgery. There are different surgical procedures for management; one of them is laser surgery. The purpose of this study was to compare the dual-wavelength diode laser and the Er, Cr: YSGG laser to choose the most effective laser for a soft tissue incision in oral and maxillofacial surgery regarding temperature elevation.

Methods: A dual-wavelength diode laser (810 and 980 nm) with 1.5 W and 2.5 W power outputs and an Er, Cr: YSGG (2780 nm) with 2.5 W and 3.5 W power outputs were used to make 50 incisions in six freshly dissected sheep tongues. The temperature means were measured at initial, maximum temperatures, as well as the temperature rise (difference between initial and maximum), and all were compared between the groups of soft tissue.

Results: The lowest mean temperature rise was observed with a 2.5 W Er, Cr: YSGG laser, and the highest mean temperature rise was observed with a 2.5 W diode laser, and all samples from the two lasers showed a statistically significant difference ($P<0.05$) in the temperature rise except the 1.5 W diode, which is higher but not statistically significantly different from the 3.5 W Er, Cr: YSGG laser ($P=0.100$).

Conclusion: The power output of 2.5 W of an Er, Cr: YSGG laser produced low levels of temperature rise compared to a diode laser and produced surgical incisions with a lower probability of heat damage to surrounding tissues.

Keywords: Diode laser; Er, Cr: YSGG laser; Soft tissue incision; Temperature elevation.

Introduction

The oral cavity is an important and complex part of the skull, which includes hard and soft tissue structures. Soft tissue management is an important part of oral and maxillofacial surgery. Oral soft tissue lesions are divided into benign superficial, neoplastic, vascular, and cystic lesions. Widespread lesions of the oral mucosa and sub-mucosa are benign fibro-epithelial hyperplastic lesions; their treatment includes the complete excision of these lesions with biopsy techniques.[1] There are several suggested surgical procedures, including excisional and incisional biopsies with a cold scalpel, an electrosurgical scalpel, or a laser. Also, soft tissue surgery must be done for further therapeutic procedures such as prosthodontics, orthodontics, implantology, and cosmetic dentistry.[2]

Conventionally, scalpels and electro-scalpels are the basic instruments for a soft tissue incision in both oral and periodontal surgery. Also, lasers are now highly advantageous tools used for soft tissue management. Unlike the scalpel, the laser instantly disinfects the surgical wound (bactericidal effect), creates a hemostatic field (without blood), and provides effective tissue ablation and good visual access. Moreover, another advantage of laser application is fewer pain issues through and after soft tissue ablation.[3,4]

Two wavelengths of diode lasers that are widely used nowadays in dentistry are around 810 nm and 980 nm, radiating in the near-IR range of the electromagnetic spectrum because of their good absorption of hemoglobin and therefore good control of bleeding, which is a major benefit in surgical treatments.[5,6]

The Er, Cr: YSGG laser with a wavelength of 2780 nm in the mid-IR spectrum range is a solid-state laser intended for use in hard and soft tissues.[7,8]

When a laser is applied to soft tissues, light energy is converted into thermal energy, which then produces heat

Please cite this article as follows: Al-Ani AJ, Al-Alawi AS, Taher HJ. Analysis of the temperature elevation of the dual-wavelength diode laser and the Er, Cr: YSGG laser in oral soft tissue incisions. *J Lasers Med Sci.* 2023;14:e37. doi:10.34172/jlms.2023.37.

on the target tissue to have the desired effect. If the tissue is viewed under an optical microscope, this photothermal impact may cause changes in the tissue that can make it challenging to interpret the histopathology. Hence, it is crucial for oral pathology to minimize peri-incisional heat injury.[5,9-11]

The conversion of light energy into heat due to the photothermal effect of laser tissue interaction may cause a rise in temperature and then damage to the surrounding area of the incision on both vertical and horizontal plane,[12] which will have an effect on the histopathological diagnosis and the healing of the tissue.

The heat is diffused laterally to the tissue according to either laser type or high power, so the current research is concerned with the use of the dual-wavelength diode laser, which is a combination of the most commonly used wavelengths (810 and 980 nm) nowadays in soft tissue incisions. The second thing is using different lower power outputs of the diode and ER, Cr: YSGG lasers, which are used to remove soft tissue lesions from power outputs used in previous research. This ex vivo study aimed to compare Er, Cr: YSGG and dual-wavelength diode lasers in the temperature elevation of the peri-incisional area to determine the thermal damage extent of both lasers.

Materials and Methods

Samples Preparation

In this ex vivo comparative study, six tongues of Iraqi sheep (1–1.5 years of age) were used within four hours after slaughter. The tongues were saved and humidified at the same temperature in an ice box. Each tongue was split into two longitudinal sections and pinned to a cork dish. Incisions were done at the lateral side of the tongue (Figure 1). The whole number of incisions was 50. For the pilot study, the number of samples was ten; six samples were for the diode laser and four of them were for the Er, Cr: YSGG laser. For the main study, the whole number was 40, half of them were for the diode laser (n = 20) and other half were for the Er, Cr: YSGG laser (n = 20), ten for each power setting.

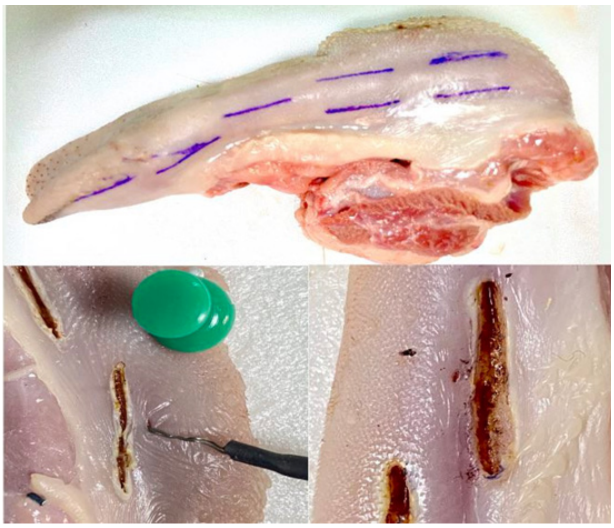

Figure 1. Sample Preparation and Temperature Measurement During the Soft Tissue Incision With 1.5 W and 2.5 W of the Diode Laser

Laser Parameters

The laser parameters used in this ex vivo study were chosen according to the soft tissue surgery setting of the devices, clinicians' use, and previous research. Slight variations were made between them for the objective of this study.

A dual-wavelength "810 and 980 nm" diode laser (Quicklase 12W dual 4 (810 nm 50% + 980 nm 50%), England, UK) was used with fiber optics (FC 400 μm single file multimode) adjusted to utilize two separate powers in contact mode: 1.5 W and 2.5 W in continuous wave mode (CW), and the power was adjusted through the cut of the fiber optic with a power meter (PINTUDY, Guangzhou, CN).

The diode laser fiber was initiated before starting the incision with each power output by adjusting the laser to a low power output of 0.5 W, then the fiber optic was applied to the articulating paper, and the laser was activated until a perforation was seen in the articulating paper and until the blame formed.

The erbium, chromium-doped yttrium, scandium, gallium, and garnet (Er, Cr: YSGG) laser (Waterlase iPlus Biolase, California, USA) was used with the tip MZ6 (diameter 600 μm, length 6 mm) in contact mode for two different settings: 2.5 W and 3.5 W in pulsed wave (PW) mode (Table 1). These power outputs were chosen after training on a method with several power outputs in a pilot study.

Pilot Study

The samples were irradiated by a diode laser divided into two groups: the first one was in CW mode, where three incisions were made with 1.5 W, 2.5 W, and 4 W power settings. Another group used 3 W, 5 W, and 7 W incisions in PW mode, all with the same frequency of 20 Hz and pulse duration of 50 seconds.

The remaining three samples were irradiated by the Er,Cr:YSGG laser at three power outputs: 2.5 W average power (50 mJ/pulse), 3.5 W (70 mJ/pulse) and 5 W (100 mJ/pulse). Each one of these power outputs was in PW mode, frequency of 50 Hz, Pulse duration of 700 µ., water 10%, and air 10%. Another incision was made with the same setting of 2.5 W but with water at 1% and air at 1%.

Surgical Procedure

To avoid any undesirable outcomes that might arise due to interpersonal variability, all of the incisions were performed by the same experienced operator. By directing the laser radiation perpendicular to the lateral surface of the tongue, linear incisions were created.

A linear incision was adjusted with a 15 mm length, a 20 seconds exposure time adjusted by a stopwatch, and a 0.75 mm/s speed of movement for all parameter sets in both lasers.

Temperature Measurements

A K-type thermocouple (Pro'sKit MT-1820, Taiwan) with a 0.5 mm diameter probe that can withstand temperature changes between -20 and 400 °C was placed at a depth of 2.5 mm in the midline of the incision, 1 mm from the border of the incision, to measure the temperature. During ablation, the monitor displayed records of temperature variations until the whole incision had been completed, then the computer saved whole record as a file in Excel for every incision to compare the initial and maximum temperatures and the difference between them, which is the rise in temperature for each power setting of the laser.

Statistical Analysis

All data sets were statistically evaluated using SPSS software. A two-sample t-test was used to compare two groups of both devices, and a one-way ANOVA test and a post hoc Tukey test were used to compare four separate groups using the mean and standard deviation (SD) of the data. A significance level of 0.05 was used.

Results

Results of the means of the initial, maximum, and rise in the temperature of the samples that were irradiated by the diode laser device (n = 20) were compared with those of the Er, Cr: YSGG laser (n = 20). There was no statistical difference between them in initial degrees ($P > 0.05$), and there was a statistical difference ($P < 0.05$) between groups in both maximum and rise in temperature according to the two-sample t-test (Table 2) (Figure 2). The diode laser showed a statistically more thermal rise in the peri-incisional area than the Er, Cr: YSGG laser.

When the results of the means in initial, maximum, and rise in temperature of each group were compared with each other, it was found that there was no statistically significant difference between the initial degrees of all four groups ($P > 0.05$), but there was a significant difference between the groups in both maximum temperature and rise in temperature according to the ANOVA test ($P < 0.05$) (Table 3).

According to the post hoc Tukey test between all groups, there was a significant difference, but in maximum temperatures between G1 (1.5 W diode) and G4 (3.5 W Er, Cr: YSGG), as well as between G3 (2.5 W Er, Cr: YSGG) and G4, there was an increase in the *P* value. In addition, with the rise in the temperature, there was an increase in the *P* value or a slight difference between their means between G1 (1.5 W diode) and G4 (3.5 W Er, Cr: YSGG), which means a slight difference in the temperature rise between their samples (Table 4, Figure 3).

Discussion

Compared to a scalpel incision, the laser light's heat destruction of the surrounding tissues may cause a wound to heal slowly.[9,12] The optimal laser should maintain a safe heat threshold and avoid the heat destruction of adjacent tissues.[12,13] The laser surgical tissue ablation and thermal rise depend on different intrinsic and extrinsic parameters used (wavelength, power, pulse duration,

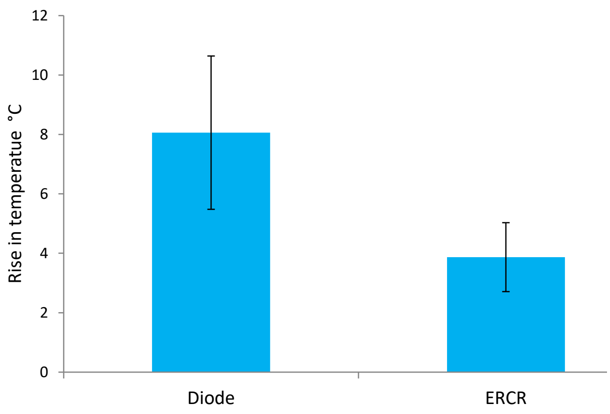

Figure 2. The Difference in the Temperature Rise Between Diode and Er, Cr: YSGG Lasers

Table 2. Comparison of the Initial Temperature, Maximum Temperature, and Rise in Temperature Between Diode and Er, Cr: YSGG Lasers by Two-Sample t-test

Temperature (°C)	Diode (n = 20)	Er,Cr:YSGG (n = 20)	*P* Value
	(Mean ± SD)	(Mean ± SD)	
Initial	18.72 ± 1.18	18.31 ± 0.98	0.245
Maximum	26.78 ± 2.89	22.18 ± 1.51	< 0.001
Rise	8.06 ± 2.58	3.87 ± 1.16	< 0.001

Table 1. Laser Parameters in This Study

Laser Group	λ (nm)	Average Power (W) & Energy Per Pulse	Pulse Duration (μs)	Frequency (Hz)	Fiber optic/ Tip Diameter (μm)	Power Density (PD) W/cm²	Peak Power (W)	Water/ Air Spray %
(G1) diode	Dual 810 & 980	1.5 (CW)	--	--	400	1153.8	--	--
(G2) diode	Dual 810 & 980	2.5 (CW)	--	--	400	1923	--	--
(G3) Er,Cr:YSGG	2780	2.5 (PW) 50 mJ/pulse	700	50	600	892.8	71.43	10/10
(G4) Er,Cr:YSGG	2780	3.5 (PW) 70 mJ/pulse	700	50	600	1250	100	10/10

Table 3. Comparison of the Initial Temperature, Maximum Temperature, and Rise in Temperature Between Different Powers of Diode and Er, Cr: YSGG Lasers by the ANOVA Test

Temperature (°C)	1.5 W Diode (n = 10)	2.5 W Diode (n = 10)	2.5 W Er,Cr:YSGG (n = 10)	3.5 W Er,Cr:YSGG (n = 10)	*P* Value
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
Initial	18.66 ± 1.29	18.77 ± 1.13	18.49 ± 0.72	18.13 ± 1.2	0.594
Maximum	24.72 ± 1.94	28.83 ± 2.11	21.51 ± 0.71	22.84 ± 1.83	< 0.001
Rise	6.06 ± 1.06	10.06 ± 2.02	3.02 ± 0.57	4.71 ± 0.96	< 0.001

Table 4. Comparison of the Initial Temperature, Maximum Temperature and Rise in Temperature Between Each Pair of Power and/or Device (Diode and Er, Cr: YSGG laser) by the Post Hoc Tukey Test

Temperature (°C)	1st Group	2nd Group	*P* Value
Initial	1.5 W Diode	2.5 W Diode	0.996
		2.5 W ERCR	0.986
		3.5 W ERCR	0.708
	2.5 W Diode	2.5 W ERCR	0.941
		3.5 W ERCR	0.572
	2.5 W ERCR	3.5 W ERCR	0.885
Maximum	1.5 W Diode	2.5 W Diode	0.000
		2.5 W ERCR	0.001
		3.5 W ERCR	0.091
	2.5 W Diode	2.5 W ERCR	0.000
		3.5 W ERCR	0.000
	2.5 W ERCR	3.5 W ERCR	0.333
Rise in temperature	1.5 W Diode	2.5 W Diode	0.000
		2.5 W ERCR	0.000
		3.5 W ERCR	0.100
	2.5 W Diode	2.5 W ERCR	0.000
		3.5 W ERCR	0.000
	2.5 W ERCR	3.5 W ERCR	0.026

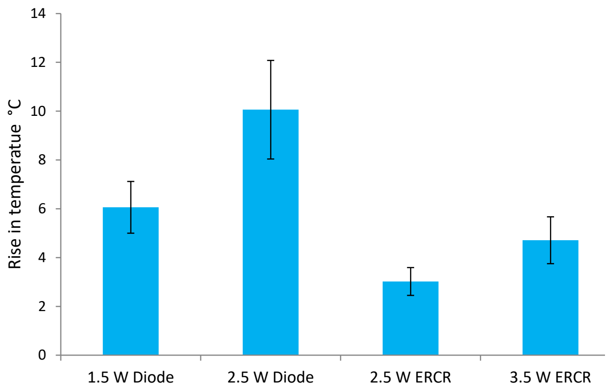

Figure 3. The Temperature Rise in Four Different Study Groups

frequency, mode of emission beam profile, and spot size), exposure time, tip type, speed of incisions, and optical and chemical properties of the target tissue. [4,14]

The results of this study showed no significant differences between the initial degrees of temperature of all groups because all circumstances at the beginning of the incisions were the same. The means of the samples showed an increase in temperature between diode groups, as G2 (2.5 W) significantly increased compared to G1 (1.5 W) due to the power increase. Thus, the power density increased and more thermal changes came from the same optical fiber in the same area of tissue as Tenore et al reported in their diode laser review of thermal damage.[12,13,15-18]

Pigments (melanin, hemoglobin, and protein) are the main chromophores in the range of diode lasers (808–1064 nm). However, water, which makes up more than 70% of most tissues, is not a chromophore and creates almost minimal interaction at diode wavelengths. This shows that the diode laser is a poor laser for cutting soft tissue because the laser energy spreads through a vast region of tissue and there is a high chance of major collateral damage; nevertheless, excellent coagulation and hemostasis are produced by the strong blood absorption of this energy.[19]

In this current study, the means of the samples from Er, Cr: YSGG laser group 3 (2.5 W, 50 mJ/pulse) had a slight increase in temperature compared to the means of the samples from group 4 (3.5 W, 70 mJ/pulse) due to the slight increase in energy per pulse. In this regard, Fornaini et al have reported that in the pulsated laser, the stop between pulses protects the tissue from overheating due to thermal relaxation time.[11,13,18] Sindel et al reported that the minimal difference in the temperature rise between groups in two lasers comparison was between the power outputs of Er, Cr: YSGG lasers (2780 nm) and the lowest rise in temperature was with 2.75 W of the Er, Cr: YSGG laser.[12]

In this study, it was also noticed that the mean of G3 of Er, Cr: YSGG was lower in the temperature rise than G1 and G2 of the diode laser. However, G4, which had the highest power output of the Er, Cr: YSGG laser, was lower in the thermal rise than G2 but similar in the thermal rise with some samples of G1, which was the lower output of the diode laser (Figure 4). The reason for that is (in addition to the emission mode and cooling system of the Er, Cr: YSGG laser decreasing the temperature[12,20]) the dual-wavelength and the lower irradiation of the diode laser, which was used for the first time in such a comparative study of the thermal effect of lasers on the temperature rise and histological evaluation.[15] Also,

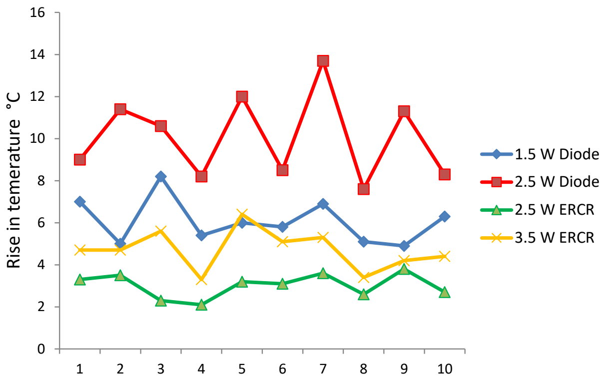

Figure 4. The Rise of Temperature in Each Specimen in Different Study Groups

Kawamura et al reported that 1 W of the 808 nm diode laser gave a mean rise in temperature of 8.1 ± 1.7, which is higher than that of 1.5 W of the diode in this study with the dual-wavelength.[4] This result was also lower when compared with the result reported by other temperature rise research on diode laser.[18,21]

Better coagulation is provided by 810 nm wavelength energy, which is preferable in larger-scale procedures on highly vascularized tissue. Better ablation and more limited tissue involvement are provided by radiation at the 980 nm wavelength. It would be encouraged in regions with less vascularized tissue and regions where the involvement of narrower tissue is suggested. Most oral soft tissue lesions are vascularized and fibrous, so mixing the two wavelengths in this study provides better coagulation and ablation with low thermal damage in soft tissue incisions.[22]

In this study, the means of the samples of the diode laser showed a significant increase in temperature compared to the means of the samples of the Er, Cr: YSGG laser due to the different wavelengths (810 nm and 980 nm diode lasers in the near IR spectrum and the 2780 nm Er, Cr: YSGG laser in the mid-IR region of the spectrum), different modes of emission (the diode laser in CW mode and Er, Cr: YSGG in PW mode), different delivery systems (the diode laser with an optical fiber and the Er, Cr: YSGG laser with the glass tip of gold handpieces), and different absorption spectra. Kawamura et al reported that the minimal temperature rise and thickness of the thermally affected layer were observed with Er: YAG and Er, Cr: Y SGG lasers, followed by CO2, diode, and Nd: YAG, respectively. The use of water/air spray with Er: YAG and Er, Cr: YSGG significantly reduced the thermal effect for both.[4] Erbium lasers are a great option for surgical soft tissue operations since they feature water as their principal chromophore (the water absorption spectrum of the Er, Cr: YSGG laser is 0.4×10^2 cm^{-1}). Water is the most prevalent component of biological tissue. In a few microns of tissue, the Er: YAG and the Er, Cr: YSGG lasers are both effectively absorbed. There is little collateral tissue injury since there is less energy transmission to the surrounding area.[19]

Conclusion

In the current study, it has been concluded that the Er, Cr: YSGG laser (2780 nm) can be used more safely and efficiently than the dual-wavelength diode laser (810 nm and 980 nm) in oral soft tissue incisions regarding the thermal rise in the deep surrounding tissue.

The 2.5 W output power of the Er, Cr: YSGG laser has the lowest temperature rise, while the 2.5 W output power of the diode has the highest temperature rise in all groups.

Acknowledgements

The authors have not received any financial or other forms of support for this study.

Authors' Contribution

Conceptualization: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi.
Data curation: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi.
Formal analysis: Alaa Jamal Al-Ani.
Funding acquisition: Alaa Jamal Al-Ani.
Investigation: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi, Hanan Jafer Taher.
Methodology: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi.
Project administration: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi, Hanan Jafer Taher.
Resources: Alaa Jamal Al-Ani.
Software: Alaa Jamal Al-Ani.
Supervision: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi, Hanan Jafer Taher.
Validation: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi, Hanan Jafer Taher.
Visualization: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi, Hanan Jafer Taher.
Writing–original draft: Alaa Jamal Al-Ani.
Writing–review & editing: Alaa Jamal Al-Ani, Ammar Saleh Al-Alawi, Hanan Jafer Taher.

Competing Interests

The authors have no conflicts of interest relevant to this article.

Ethical Approval

This study does not contain any involving human participants or animals. For this type of ex vivo study, no ethical committee was needed; this study is in accordance with the ethical standards of the Institute of Laser for Postgraduate Studies, University of Baghdad at Iraq (number: 817 with project no.43 in 25/1/2023).

References

1. Kahn MA, Michael Hall J, American Dental Association. The ADA Practical Guide to Soft Tissue Oral Disease. Hoboken, NJ: Wiley; 2018.
2. Hupp JR, Tucker MR, Ellis E. Contemporary Oral and Maxillofacial Surgery. Philadelphia, PA: Elsevier; 2019.
3. Ortega-Concepción D, Cano-Durán JA, Peña-Cardelles JF, Paredes-Rodríguez VM, González-Serrano J, López-Quiles J. The application of diode laser in the treatment of oral soft tissues lesions. A literature review. J Clin Exp Dent. 2017;9(7):e925-e8. doi: 10.4317/jced.53795.
4. Kawamura R, Mizutani K, Lin T, Kakizaki S, Mimata A, Watanabe K, et al. Ex vivo evaluation of gingival ablation with various laser systems and electroscalpel. Photobiomodul Photomed Laser Surg. 2020;38(6):364-73. doi: 10.1089/photob.2019.4713.

5. Gill K, Sandhu SV, Sethi N, Bhandari R. Biopsy of oral soft tissue lesions by 808 nm and 980 nm diode laser: a morphological and histochemical evaluation. Lasers Dent Sci. 2021;5(4):207-22. doi: 10.1007/s41547-021-00132-z.
6. Hanke A, Fimmers R, Frentzen M, Meister J. Quantitative determination of cut efficiency during soft tissue surgery using diode lasers in the wavelength range between 400 and 1500 nm. Lasers Med Sci. 2021;36(8):1633-47. doi: 10.1007/s10103-020-03243-4.
7. Parker S, Cronshaw M, Anagnostaki E, Mylona V, Lynch E, Grootveld M. Current concepts of laser-oral tissue interaction. Dent J (Basel). 2020;8(3):61. doi: 10.3390/dj8030061.
8. Kiomarsi N, Espahbodi M, Chiniforush N, Karazifard MJ, Kamangar SSH. In vitro evaluation of repair bond strength of composite: Effect of surface treatments with bur and laser and application of universal adhesive. Laser Ther. 2017;26(3):173-80. doi: 10.5978/islsm.17-OR-12.
9. Merigo E, Clini F, Fornaini C, Oppici A, Paties C, Zangrandi A, et al. Laser-assisted surgery with different wavelengths: a preliminary ex vivo study on thermal increase and histological evaluation. Lasers Med Sci. 2013;28(2):497-504. doi: 10.1007/s10103-012-1081-8.
10. Azevedo AS, Monteiro LS, Ferreira F, Delgado ML, Garcês F, Carreira S, et al. In vitro histological evaluation of the surgical margins made by different laser wavelengths in tongue tissues. J Clin Exp Dent. 2016;8(4):e388-e96. doi: 10.4317/jced.52830.
11. Prado MCO, Nwizu NN, Patel SA, Streckfus CF, Zezell DM, Barros J. Thermal damage and excision time of micro and super pulsed diode lasers: a comparative ex vivo analysis. Clin Exp Dent Res. 2022;8(6):1655-63. doi: 10.1002/cre2.670.
12. Sindel A, Dereci Ö, Hatipoğlu M, Özalp Ö, Dereci ON, Kocabalkan B, et al. Evaluation of temperature rise following the application of diode and ErCr:Ysgg lasers: an ex vivo study. Eur Oral Res. 2018;52(3):131-6. doi: 10.26650/eor.2018.479.
13. Palaia G, Impellizzeri A, Tenore G, Caporali F, Visca P, Del Vecchio A, et al. Ex vivo histological analysis of the thermal effects created by a 445-nm diode laser in oral soft tissue biopsy. Clin Oral Investig. 2020;24(8):2645-52. doi: 10.1007/s00784-019-03123-4.
14. Grzech-Leśniak K, Matys J, Jurczyszyn K, Ziółkowski P, Dominiak M, Brugnera Junior A Jr, et al. Histological and thermometric examination of soft tissue de-epithelialization using digitally controlled Er:YAG laser handpiece: an ex vivo study. Photomed Laser Surg. 2018;36(6):313-9. doi: 10.1089/pho.2017.4413.
15. Tenore G, Mohsen A, Nuvoli A, Palaia G, Rocchetti F, Di Gioia CRT, et al. The impact of laser thermal effect on histological evaluation of oral soft tissue biopsy: systematic review. Dent J (Basel). 2023;11(2):28. doi: 10.3390/dj11020028.
16. Palaia G, Renzi F, Pergolini D, Del Vecchio A, Visca P, Tenore G, et al. Histological ex vivo evaluation of the suitability of a 976 nm diode laser in oral soft tissue biopsies. Int J Dent. 2021;2021:6658268. doi: 10.1155/2021/6658268.
17. Jin JY, Lee SH, Yoon HJ. A comparative study of wound healing following incision with a scalpel, diode laser or Er,Cr:YSGG laser in guinea pig oral mucosa: a histological and immunohistochemical analysis. Acta Odontol Scand. 2010;68(4):232-8. doi: 10.3109/00016357.2010.492356.
18. Fornaini C, Merigo E, Sozzi M, Rocca JP, Poli F, Selleri S, et al. Four different diode lasers comparison on soft tissues surgery: a preliminary ex vivo study. Laser Ther. 2016;25(2):105-14. doi: 10.5978/islsm.16-OR-08.
19. Coluzzi DJ, Parker SP. Lasers in Dentistry--Current Concepts. Cham: Springer International Publishing; 2017.
20. Vescovi P, Merigo E, Fornaini C, Rocca JP, Nammour S. Thermal increase in the oral mucosa and in the jawbone during Nd:YAG laser applications. Ex vivo study. Med Oral Patol Oral Cir Bucal. 2012;17(4):e697-704. doi: 10.4317/medoral.17726.
21. Fornaini C, Merigo E, Rocca JP, Lagori G, Raybaud H, Selleri S, et al. 450 nm blue laser and oral surgery: preliminary ex vivo study. J Contemp Dent Pract. 2016;17(10):795-800. doi: 10.5005/jp-journals-10024-1933.
22. Ostler CD, Kengike LM, Kengike M. Histological Evaluation 810nm vs 980nm Wavelength Laser Radiation on Pig Liver Tissue. Quicklase Website. 2018. Available from: http://quicklase.com/wp-content/uploads/2013/08/DrDruain_Article.pdf.