

T.C.
BAHCESEHIR UNIVERSITY
GRADUATE SCHOOL OF EDUCATION
THE DEPARTMENT OF BIOENGINEERING

**EVALUATION OF SURFACE ROUGHNESS OF ENAMEL
AFTER LASER IRRADIATION**

MASTER'S THESIS

ALI AHMED KAMAL KHEDHER AGHA

ISTANBUL 2023

T.C.
BAHCESEHIR UNIVERSITY
GRADUATE SCHOOL OF EDUCATION
THE DEPARTMENT OF BIOENGINEERING

**EVALUATION OF SURFACE ROUGHNESS OF ENAMEL
AFTER LASER IRRADIATION**

MASTER'S THESIS

ALI AHMED KAMAL KHEDHER AGHA

THESIS ADVISOR
DR. AYSE SENA SARP

ISTANBUL 2023

T.C.
BAHÇEŞEHİR UNIVERSITY
GRADUATE SCHOOL

...../...../.....

MASTER THESIS APPROVAL FORM

Program Name:	BIOENGINEERING PROGRAM
Student's Name and Surname:	Ali Ahmed Kamal Khedher Agha
Name of The Thesis:	Evaluation of Surface Roughness of Enamel after Laser Irradiation
Thesis Defense Date	May 31 2023

This thesis has been approved by the Graduate School which has fulfilled the necessary conditions as Master thesis.

Prof. Dr. Ahmet ÖNCÜ
Institute Director

This thesis was read by us, quality and content as a master's thesis have been seen and accepted as sufficient.

	Title, Name	Signature
Thesis Advisor:	Assist Prof. Ayşe Sena Sarp	
2nd Member	Assist Prof. Elif Merve Özcan	
3rd Member (Outside)	Assist. Prof. Seda Nilgün dumlu	

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

**Ali Ahmed Kamal Khedher
Agha**

Signature

ABSTRACT

EVALUATION OF SURFACE ROUGHNESS OF ENAMEL AFTER LASER IRRADIATION

Khedher Agha, Ali Ahmed

Master's Program in Bio-engineering

Thesis Advisor: Dr. Ayse Sena Sarp

May 2023, 76 pages

Polishing enamel is a dental procedure that involves a rotating brush to remove surface stains and smooth any rough areas on the teeth.

Laser technology has been tested in all dentistry fields to enhance the quality of the treatment. The aim of this study is to define the optimum parameters for laser power and irradiation time in decreasing the roughness of the enamel and having a smooth, healthy surface in a long-term prognosis using a new wavelength in a dental era, 1940-nm Thulium Fiber Laser (TLR-5-1940; IPG Laser GmbH, Germany).

After preparing teeth samples, preliminary experiments were done by a laser and thermal camera set-up while applying different lasing powers varying between (0.25 W and 5 W) and an irradiation time from (1 sec to 12 sec), which produced energy from (0.25J to, 15 J). The main experiments were performed using Hirox 3D microscope to determine parameters' effects. The areas for both pre and post lasing surfaces were graphed, the differences in values were examined and compared.

In the main experiment, irradiating a total of 3 joules energy on the enamel surface showed non-significant differences between the area under the curve of before-lasing and after-lasing enamel surface area were not significantly different. On the record 0.75 Watt was the most promising parameter which resulted in a decrease in

the surface area while other parameters showed an increase in enamel surface roughness. By applying laser powers from 0.25 Watts to 5.0 Watts showed no carbonization effect or observable cracks under microscope.

Keywords: Laser Irradiation, Temperature, Surface Roughness.



ÖZ

LAZER IŞINLAMASI SONRASI DIŞ MİNESİ YÜZEY PÜRÜZLÜLÜĞÜNÜN DEĞERLENDİRİLMESİ

Khedher Agha, Ali Ahmed

Biyomühendislikte Yüksek Lisans Programı

Tez danışmanı: Dr. Ayse Sena Sarp

Mayıs 2023, 74 Sayf

İyi bir ağız sağlığı, bir kişinin özgüveni ve genel refahı üzerinde olumlu bir etkiye sahip olabilir. Diş minesini cilalama işlemi, dişlerin yüzey lekelerini ve pürüzlerini gidermek için döner bir fırça kullanılarak yapılan işlemidir. Bu, dişlerin görünümünü iyileştirirken yüzey lekelerini ve pürüzlülüğü azaltarak dişlerde biriken bakteri miktarını azaltmaya yardımcı olur. Ancak, diş minesini aşırı cilalamak, diş minesine zarar verip, çürümeye daha yatkın hale getirebilir.

1960'lardan bu yana, lazer teknolojisi, tüm diş hekimliği alanlarında her dalga boyu ve enerjiden en iyi parametreleri elde etmek ve tedavinin kalitesini artırmak için test edilmiştir. Bu çalışmanın amacı, diş hekimliği alanında yeni bir dalga boyu, 1940-nm Tulyum Fiber Lazer (TLR-5-1940; IPG Laser GmbH, Almanya) kullanarak mine pürüzlülüğünü azaltmak ve uzun vadeli bir prognozda pürüzsüz, sağlıklı bir mine yüzeyine sahip olmak için optimum lazer gücü ve ışınlama süresini belirlemektir.

Ön çalışmalarda, diş örnekleri hazırlandıktan sonra, farklı lazer güçleri (0,25 W ile 5 W arasında değişen) ve ışınlama süresi (1 saniye ile 12 saniye arasında değişen) uygulanarak (0,25 J ila 15 J arası ışınlama enerjisi üreten) farklı deneyler yapıldı.

Belirlenen parametrelerin etkilerini deęerlendirmek iin ana deneyler Hirox 3D mikroskop kullanıldı. Hem ıřıma ncesi hem de sonrası iin yapılan lmlerin alanları grafiklere aktarıldı, bu deęerler arasındaki farklar incelendi ve karřılařtırıldı.

n alıřmalar, bu dalga boyu iin mine zerindeki termal etkilerin gven aralıęı geniřlięini oluřturan sıcaklık lmleri ieriyordu. Ana deneyde, mine yzeyine toplam 3 joule enerji ıřınlamak, alanlarda artıř ve azalmalara neden oldu, ancak lazerin ıřıması ncesi ve sonrası elde edilen deęerler anlamlı derecede farklılık gstermediler. Bu alıřmanın sonucuna gre belirlenen gvenli sıcaklıklıęı saęlayan parametrelerde 0,75 Watt en umut verici parametre olarak ortaya ıktı ve yzey alanında azalmaya neden oldu. Uygulanan dięer parametreler ise mine yzey przllęnde artıř gsterdi. Bu sonulara ek olarak bu alıřmada, 0,25 Watt ile 5,0 Watt arasındaki lazer glerinin mikroskop altında gzlemlenen karbonlařma etkisi veya atlakları olmadıęı grld.

Anahtar Kelimeler: Laze ıřınlaması, Sıcaklık, yzey przllę

ACKNOWLEDGMENTS

First of all, I wish to express my deepest gratitude to my supervisor Assist. Prof. Dr. Ayse Sena Sarp for her guidance, advice, criticism, encouragement, and insight throughout the research.

I am grateful to the Bahcesehir University Scientific Research Project department for their support. This study is a part of BAP 2021-01.39 NAP Research Project.

Finally, I would like to dedicate this thesis to my family. I would like to thank my parents, Prof. Dr. Ahmed Kamal and Semiramis Mohammed Tawfik, for their great support and constant encouragement throughout my life. Without their understanding and continuous support, I would have never been able to aspire to this level of education and complete this study.

TABLE OF CONTENTS

ETHICAL CONDUCT.....	iii
ABSTRACT	iv
ÖZ	vi
ACKNOWLEDGMENTS	viii
TABLE OF CONTENT	ix
LIST OF TABLES	Error! Bookmark not defined.
LIST OF FIGURES	xi
LIST OF ABBREVIATIONS	xv
Chapter 1 Introduction.....	1
1.1 Motivation And Objectives.....	1
Chapter 2 Literature Review	3
2.1 Dentistry	3
2.2 Polishing Enamel Surface	6
2.2.1 Polishers	8
2.2.1.1 Porte polisher	8
2.2.1.2 Polishing strips.....	8
2.2.1.3 Engine-driven polishers	8
2.2.1.4 Air-powder polisher.....	9
2.2.1.5 Comparison of different polishing techniques.....	10
2.2.1.6 Vector system.	10
2.3 Laser	11
2.4 Lasers in Dentistry	12
2.4.1 Application of lasers in dentistry.	13
2.4.2 Limitations of lasers.....	14
2.4.3 Types of lasers.....	15
2.4.3.1 Neodymium, Yttrium Aluminum Garnet (Nd: YAG) Laser.	15
2.4.3.2 Carbon dioxide laser.	15
2.4.3.3 Diode laser.	15

2.4.3.4 Argon lasers	15
Chapter3 Methodology	19
3.1 Teeth	19
3.2 Sample preparation	19
3.3 Experimental Procedures:	20
3.3.1 Preliminary Experiments:.....	20
3.3.2 Main Experiments:	25
Chapter4 Results	31
4.1 Temperature Measurements	31
4.2 Irradiation Effect.....	39
Chapter 5 Discussion & Conclusion	49
5.1 Discussion.....	49
5.2 Conclusion.....	52
References	54

LIST OF TABLES

<i>Table 1. Chemical and structural characteristics of teeth, bone, and hydroxyapatite. (Jabr S Al-Sanaban et.al, 2013.).....</i>	<i>6</i>
<i>Table 2. Lasing parameters of the Preliminary Experiments</i>	<i>24</i>
<i>Table 3. Laser parameter of the main experiment</i>	<i>27</i>
<i>Table 4. Lasing parameters of the preliminary experiment.....</i>	<i>31</i>
<i>Table 5. Average and the standard deviation of the temperature increase each time for the 0.25W.....</i>	<i>32</i>
<i>Table 6. Average and the standard deviation of the temperature increase each time for the 0.5W.....</i>	<i>33</i>
<i>Table 7. Average and the standard deviation of the temperature increase each time for the 0.75W.....</i>	<i>34</i>
<i>Table 8. The average and the standard deviation of the temperature increase each time for the 1.0 W.....</i>	<i>35</i>
<i>Table 9. The average and the standard deviation of the temperature increase each time for the 2.5 W.....</i>	<i>35</i>
<i>Table 10. The average and the standard deviation of the temperature increase each time for the 5.0 W.....</i>	<i>36</i>
<i>Table 11. Area of the samples section of pre-lasing and post-lasing area application and the difference between them.</i>	<i>43</i>
<i>Table 12. Average and standard deviation of the area samples section before & after laser application.....</i>	<i>46</i>

LIST OF FIGURES

<i>Figure 1. Anatomy of the oral cavity.....</i>	<i>3</i>
<i>Figure 2. Anatomy of a tooth.....</i>	<i>5</i>
<i>Figure 3. Classification of laser systems due to their different characteristics https://www.researchgate.net/figure/Wavelengths-of-common-medical-lasers-courtesy-of-Dr-Albert-Poet-Shore-Laser-Center_fig1_231009441, 2022)</i>	Error! Bookmark not defined.
<i>Figure 4. The reflection, refraction, absorption, and scattering.....</i>	<i>11</i>
<i>Figure 5. The primary absorption spectra of biological tissues. Also, the absorption coefficients at some typical laser wavelengths.</i>	Error! Bookmark not defined.
<i>Figure 6. Safety measures while using lasers.</i>	Error! Bookmark not defined.
<i>Figure 7. Each tooth sample was embedded in a gypsum block for easy handling during laser radiating, (A) scheme for the gypsum block (B) the gypsum block in the experiment.....</i>	<i>19</i>
<i>Figure 8. Temperature measurement setup: (A) laser eye protection (1800-2000nm) (B) holder (C) Thermometer FLIR E5xt (D) tooth sample (E) laser beam (F) cork barrier.....</i>	Error! Bookmark not defined.
<i>Figure 9. The 1940-nm Thulium Fiber Laser.</i>	Error! Bookmark not defined.
<i>Figure 10. The Power meter</i>	Error! Bookmark not defined.
<i>Figure 11. Thermometer flir 5Ext.....</i>	Error! Bookmark not defined.
<i>Figure 12. Temperature measurement setup.....</i>	Error! Bookmark not defined.
<i>Figure 13. (A) ESCORT-III+ H37L1 35K RPM Marathon Micromotor Handpiece (B) handpiece brush connected to the micromotor (c) normal teeth brush (D) brush attached to an arm used for cleaning and plug removed from the tooth.</i>	<i>25</i>
<i>Figure 14. Hirox digital microscope KH-8700.....</i>	<i>26</i>
<i>Figure 15. Main experimental set-up.....</i>	<i>27</i>
<i>Figure 16. Image obtained from 3D microscope</i>	<i>28</i>
<i>Figure 17. FPGraph tracer program.....</i>	<i>29</i>
<i>Figure 18. The graph shows the temperature increase after applying of 0.25 W Groups with time intervals, 1sec, 2 sec, 3 sec, 4 sec, and 12 sec. There is significant difference in temperature increases only between 2 sec & 3 sec (*) groups. There is no other significant difference ($p \leq 0.05$, student t-test).</i>	Error! Bookmark not defined.

Figure 19. As shown in the Temperature Increase After Application of 0.50 W Groups 1sec, 2 sec, 3 sec, & 4 sec have significantly higher temperature increases (*) ($p \leq 0.05$, student t-test). **Error! Bookmark not defined.**

Figure 20. As shown in the Temperature Increase After Application of 0.75 W Groups 1 sec, 2 sec, & 4 sec have significantly higher temperature increases (*) ($p \leq 0.05$, student t-test). **Error! Bookmark not defined.**

Figure 21. As shown in the Temperature Increase After Application of 1.0 W Groups 1 sec and 3 sec have significantly higher temperature increases (*) ($p \leq 0.05$, student t-test). **Error! Bookmark not defined.**

Figure 22. The temperature increases are shown in the graph after the application of 2.5 W of the teeth at lasing in CW mode. There are significant differences between the irradiated groups (*) ($p \leq 0.05$, student t-test).

..... 35

Figure 23. The graph shows the temperature increases after applying of 5.0 W Groups with time intervals, 1 sec, 2 sec and 3 sec. There is significant difference in temperature increases between groups ($p \leq 0.05$, student t-test). 1 Second lased group is significantly different from other two experimental groups ($p \leq 0.05$, student t-test). Also, there is a significant difference between 2 second and 3 second lased groups ($p \leq 0.05$, student t-test) (*)

..... 36

Figure 24. Temperature difference between lasing groups. 37

Figure 25. Comparison of varying lasing times according to the temperature increase. 37

Figure 26. The difference between (A) 0.25_12s_s1_pre and (B) 0.25_12s_s1_aft. 38

Figure 27. The difference between (A) 0.25_12s_s2_pre and (B) 0.25_12s_s2_aft. 39

Figure 28. The difference between (A) 0.25_12s_s3_pre and (B) 0.25_12s_s3_aft.39

Figure 29. The difference between (A) 0.75_4s_s1_pre and (B) 0.75_4s_s1_aft..... 39

Figure 30. The difference between (A) 0.75_4s_s2_pre and (B) 0.75_4s_s2_aft. **Error! Bookmark not defined.**

Figure 31. The difference between (A) 0.75_4s_s3_pre and (B) 0.75_4s_s3_aft. **Error! Bookmark not defined.**

Figure 32. The difference between (A) 1.0_3s_s1_pre and (B) 1.0_3s_s1_aft. **Error! Bookmark not defined.**

Figure 33. The difference between (A) 1.0_3s_s2_pre and (B) 1.0_3s_s2_aft.. **Error! Bookmark not defined.**

Figure 34. The difference between (A) 1.0_3s_s3_pre and (B) 1.0_3s_s3_aft.. **Error! Bookmark not defined.**

Figure 35. Curves drawn by MATLAB for (A) 0.25_12s_s1_pre and (B) 0.25_12s_s1_aft.	Error! Bookmark not defined.
Figure 36. Curves drawn by MATLAB for (A) 0.25_12s_s2_pre and (B) 0.25_12s_s2_aft.	Error! Bookmark not defined.
Figure 37. Curves drawn by MATLAB for (A) 0.25_12s_s3_pre and (B) 0.25_12s_s3_aft.	Error! Bookmark not defined.
Figure 38. Curves drawn by MATLAB for (A) 0.75_12s_s1_pre and (A) 0.75_12s_s1_aft.	Error! Bookmark not defined.
Figure 39. Curves drawn by MATLAB for (A) 0.75_12s_s2_pre and (B) 0.75_12s_s2_aft.	Error! Bookmark not defined.
Figure 40. Curves drawn by MATLAB for (A) 0.75_12s_s3_pre and (B) 0.75_12s_s3_aft.	Error! Bookmark not defined.
Figure 41. Curves drawn by MATLAB for(A) 1_3s_s1_pre and (B)1-3s-s1-aft.....	45
Figure 42. Curves drawn by MATLAB for (A)1_3s_s2_pre and (B)1-3s-s2-aft.....	45
Figure 43. Curves drawn by MATLAB for (A) 1_3s_s3_pre and (B) 1-3s-s3-aft....	45
Figure 44. Figure 14. This graph illustrates the comparison of the areas of sample section before and after laser application. Statistical analyses show that there is no significant difference between the post-lasing & pre-lasing area samples section of all the powers ($p \leq 0.05$, student <i>t</i> -test)	
.....	47

LIST OF ABBREVIATIONS

LASER	Light Amplification by the Stimulated Emission of Radiation
Nm	nanometer
CW	Continuous Wave
° C	Celsius degree
FDA	United States Food and Drug Administration
CO ₂	Carbon dioxide
Nd: YAG	Neodymium-doped Yttrium Aluminum Garnet
KrF	Krypton Fluoride
Tm: YAP	Thulium Ytterbium Aluminum Phosphate
GaAlAs	Gallium Aluminum Arsenate
CEJ	Cementum-Enamel Junction
Cl	Chloride
F	Fluorine
K	Potassium
Na	Sodium
Ca ₁₀ (PO ₄) ₆ (OH) ₂	Hydroxyapatite
μm	micrometer
mm	millimeter
NIR	Near Infrared
N	Newton
W	Watt
sec	second(s)
kPa	kilopascal
cm ²	centimeter square
mm ²	millimeter square
MPa	Megapascal
cm	centimeter
kg	kilogram
J	Joule(s)

SEM	Scanning Electron Microscope
A	Ampere
US	United States
ADA	American Dental Hygienists Association
psi	Pounds per square inch
APD	air-polishing device
EMPs	Extracellular matrix proteins



Chapter 1

Introduction

1.1 Motivation And Objectives

In most dental treatments, the roughness of the enamel is an important parameter as part of oral prophylaxis. Smooth surfaces give teeth a glossy, lustrous appearance and prevent bacteria adhesion and biofilm formation. The removal of soft deposits and stains from tooth surfaces has been referred as polishing, cleaning, and polishing (Daniel and Harfst., 2004)

A patient feels more confident parallel to their oral health. The tooth enamel becomes discolored and engaged in various eating and drinking habits. Most dental offices have traditionally associated smoothing with the prophylaxis procedure, to prevent biofilm formation (Sawai *et al.*, 2015). However, excessive use of the polishing technique results in wear of the tooth's surface structure. This would cause local deposits to accumulate more quickly. Additionally, the process of regenerating the fluoride-rich-layer of the tooth is lengthy. As a result, smoothing of enamel is no longer recommended as part of regular oral prophylaxis procedures but is done as-needed for each patient. Terms like plaque, biofilm, stains are all removed during polishing, which is explained in this article, along with various methods and polishing agents used for the process.

In many medical fields, lasers were first used in the late 1960s. Dentistry is one of the first areas experienced by lasers in medicine after the US Food and Drug Administration approved several different types (FDA). In general practice, dental lasers have been used in many areas like root disinfection and cleaning in endodontics, lithotripsy, cavity preparation, filling removal, micro-retention surface-etching, removal of hard dental tissues, and removal of soft dental tissues, tooth whitening, caries management, and debonding ceramic brackets. Besides these areas, bacterial infections and bleeding are reduced due to using lasers in dentistry. Moreover, dental laser procedures may not require stitches, and wounds heal more quickly. Also, some laser dentistry procedures can be performed without anesthesia (Jelínková *et al.*, 2008). Lasers are given different names depending on the dynamic medium. Color, gases like argon and carbon dioxide, solid-state crystal rods like neodymium: YAG and Erbium:

YAG, or semiconductors like diode lasers can all be used as the medium. (Wigdor *et al.*, 1995) With their significant improvements in clinical applications, lasers are anticipated to set a benchmark in dentistry.

Lasers can be used in many areas of dentistry because they can treat both hard and soft tissues without direct contact, vibrations, or pain. Due to a lack of research discussing the process of polishing and bleaching with lasers, which uses specific lasers like (neodymium: YAG (Nd: YAG), Erbium: YAG), the majority of researches discusses the process of bleaching using conventional mechanical and chemical methods (Er: YAG).

The aim of this study is defining the optimum parameters for laser power and lasing time in decreasing the roughness of the enamel and having a smooth, healthy surface in long term prognosis using a new wavelength in dental era, 1940-nm Thulium Fiber Laser (TLR-5-1940; IPG Laser GmbH, Germany)

Chapter 2

Literature Review

2.1 Dentistry

Dentistry focuses on detecting, avoiding, and treating diseases affecting the teeth, oral cavity, and neighborhood structures. The tongue, palate, and teeth form the boundaries of the oral cavity. There is a lower and an upper jaw. The lower jaw is referred to as the mandible, and the upper jaw is referred to as the maxilla. There are 32 teeth in the mouth that are fixed in the socket in maxilla and mandible, the upper and lower jaws, respectively. The ones that are enmeshed within the alveolar process of the maxilla, the teeth of the upper arch are known as maxillary teeth. Similarly, the ones that are located within the mandible's alveolar process, the teeth of the lower arch are known as mandibular teeth.

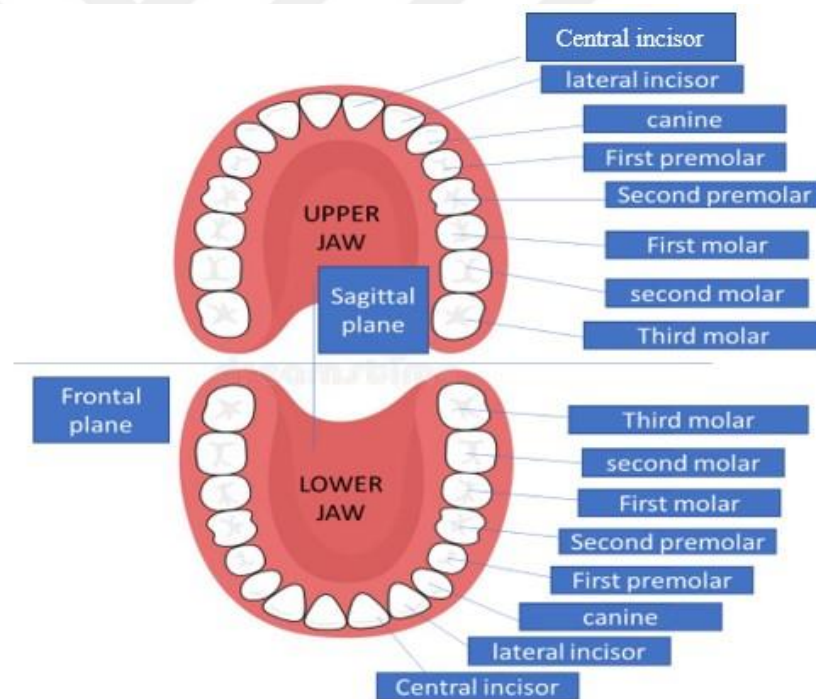


Figure 2. Anatomy of the oral cavity

The order of the teeth from front to back is incisors, canines, premolars, and molars. The incisors used for biting have evolved into canines, used for tearing, and the molars and premolars, used for chewing (Figure 1).

The Median Sagittal Plane is the name given to the accepted imaginary plane in the middle that divides the dental arch from right to left. On that plane, the imaginary line that splits the dental arch in half in the middle is known as the median line.

The terms distal and mesial refer to directions relative to the dental arch's median (center) line. The distal surface is the one which is away from the midline, while the mesial surface is toward it. Facial refers to the lips or cheeks. Buccal refers to the facial surface of anterior teeth, whereas labial refers to the facial surface of anterior teeth.

Towards the tongue is lingual. The biting surface, also known as the occlusal, is the surface that contacts an adversary's tooth in the opposing arch. Incisal refers to the leading edge of anterior teeth, and apical refers to the root tip closest to the apex (Rodrigo S. Lacruz *et al.* 2017).

A tooth has a pulp core encircled by dentine and covered by enamel on the crown which is the exposed tooth surface. The area of the tooth covered in enamel is referred to as the anatomical crown. The visible portion of the tooth above the gum line is known as the clinical crown. The anatomical crown is made of enamel. As known, in the body, enamel is the hardest material. Most teeth are made of dentin, which is covered by cementum on the root and enamel on the crown. It is not as hard as enamel, when exposed, dentin is frequently sensitive to air, temperature changes, and touch via dentinal tubules. The cementum-enamel junction is where the cementum, which covers the tooth's root and lies over the dentin, joins the enamel (CEJ). Cementum's primary purpose with the aid of attachment fibers secure the tooth to the bony socket—the portion of a tooth's root covered in cementum and embedded in the alveolar process. The anterior foramen is the opening at the root tip, and the apex is the end of the root tip. Blood vessels and nerves are in the pulp through the apical foramen make up the pulp tissue. It contains connective tissue that facilitates the movement of pulp and dentin.

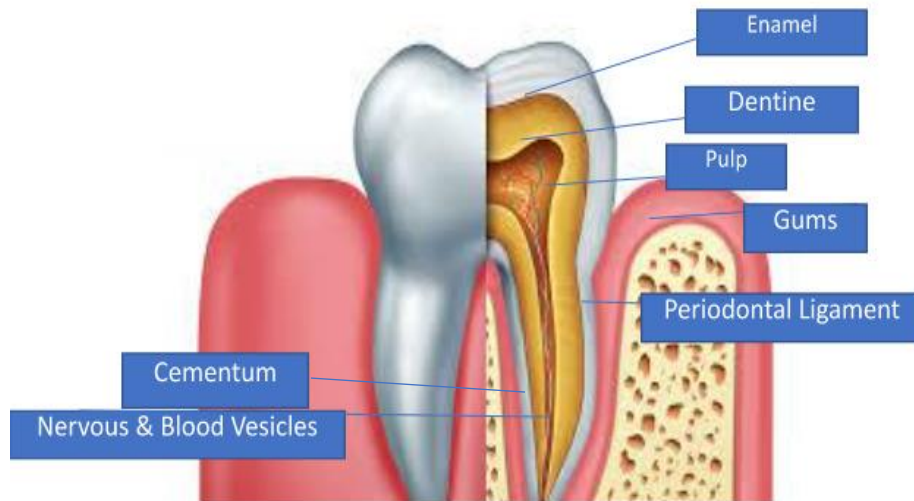


Figure 2. Anatomy of a tooth.

(https://www.tuxedodental.ca/dental_library/the-anatomy-and-structure-of-a-tooth/ , 2018)

Tooth structure is not homogeneous. Dentin contains different amounts of organic and inorganic elements than enamel, both in terms of quantity. Enamel covers the crown. It creates a conservational wall of the tooth against all physical, thermal, and chemical pressures which damage the tissue in the underlying as the tooth's pulp. Given that enamel's structure and makeup also determine its optical characteristics, Changes in enamel structure due to developmental flaws or external factors are frequently seen as opacity or color changes. Because enamel tissue is acellular and does not remodel after becoming mineralized, unlike bone, the effect of developmental injuries on enamel is crucial. The only epithelial-derived tissue in animals that mineralizes in nonpathological conditions is the enamel of the teeth. (Bones and dentin areas, are the other main mineralized tissues, which originated from mesenchymal cells. Extracellular matrix proteins (EMPs), which create the organic structure of the matrix in which enamel develops, are a distinct collection of proteins with minimal homology to other tissues and proteins. A assorted population of cells create the enamel. The ameloblasts are from one of those groups which create a monolayer, and it is mainly in charge of the process of enamel formation and mineralization. Amelogenesis is the process of enamel formation. Ameloblasts release enamel matrix proteins into the enamel space, where other ameloblasts break down and remove them by proteolysis enamel matrix proteins into the enamel space, where they are subsequently broken down and removed by proteolysis by other ameloblasts. The generated enamel has a distinctive prismatic appearance and is made up of interrod

enamel, which surrounds the enamel rods, and rods produced by individual ameloblasts that extend from the dentin-enamel junction (DEJ) to the enamel surface. The completely formed (mature) enamel contains traces of EMP peptides, which are thought to have contributed to the final shape and given that the enamel has distinctive morphological and biomechanical characteristics which is made up of 95% hydroxyapatite ($\text{Ca}_{10}(\text{P O}_4)_6(\text{OH})_2$), nearly 4% water, and at least 1% organic material. Dentin, the layer below the enamel, is much softer than the enamel and contains 70% hydroxyapatite ($\text{Ca}_{10}(\text{P O}_4)_6(\text{OH})_2$), 20% organic material (primarily collagen fibers), and 10% water (Table 1). A mineralized substance with the chemical formula ($\text{Ca}_{10}(\text{P O}_4)_6(\text{OH})_2$) is hydroxyapatite. Tiny crystallites that are part of its substructure create what is known as enamel prisms. Cl, F, Na, and K^+ were inserted into the crystal lattice (Rodrigo S. Lacruz *et al.* 2017).

Table 1.

Chemical and structural characteristic of teeth, bone, and hydroxyapatite. (Jabr S Al-Sanaban et.al, 2013)

Composition, wt%	Enamel	Dentine	Bone	HA
calcium	36.5	35.1	34.8	39.6
phosphorus	17.1	16.9	15.2	18.5
Ca/P ratio	1.63	1.61	1.71	1.67
Total inorganic (%)	97	70	65	100
Total organic (%)	1.5	20	25	---
Water (%)	1.5	10	10	---

2.2 Polishing Enamel Surface

As the roughness of the enamel is an important parameter for the post treatment period, smooth enamel surfaces provide a glossy appearance and prevent bacteria adhesion and biofilm formation. Polishing is the removal of the stain and deposit soft tissue from the tooth, cleaning and polishing are involved to give a better look and fo hygienic procedures (Daniel and Harfst, 2004).

The polishing process on teeth enamel was firstly introduced by Pierre Fauchard by removing dental stains using softly ground coral, eggshells, ginger, or salt, as cited in the Greek and Roman writings. (Ring., 1967).

Over time, the smoothness of enamel surface gained more importance in order to increase the esthetic appearance and oral health. As a milestone in preventive dentistry, Dr. Fones, began teaching his assistants how to polish coronal teeth when he launches the first dental hygienic school in year 1913. Stains were found not to cause any destructive processes, so the removal of stains was done for aesthetic. (Ring., 1967) Thus, Wilkins applied polishing as a selective procedure. Before the 1970s, patients considered polishing a required component of dental visits (Wilkins and Wilkins., 1976). (Putt *et al.*, 1982) Additional evidence in the 1990s and 2000s helped to justify the use of selective polishing. (Badwal R *et al.*, 2002) However, many, if not all, dental hygiene procedures still employ the idea of full mouth polishing. Worldwide hygiene schools prefer the selective polishing protocol instead of including the polishing at all maintenance appointment.

Many terms are used to express brushing and polishing teeth. On the other hand, in dentistry "polishing," term is used it means as the combination of these two procedures, "cleaning" and "polishing". The American Dental Hygienists Association (ADA) uses terms "cleansing" and "polishing" to express the act of making the teeth enamel smooth and glow. According to the American Academy of Periodontology, tooth polishing is "scaling and polishing is used to remove plaque, calculus, and stains from the teeth's exposed and hidden surfaces as a preventative measure for the management of regional irritants." (Wilkins and Wilkins., 1976; Felton *et al.*, 2011) Other terms, which are frequently used in polishing:

1. Therapeutic polishing is a kind of polishing to express the exposed root surfaces during surgery to reduce endotoxin and microflora on the cementum.
2. Cosmetic or coronal polishing is another kind to express to make the tooth free of plaque and extrinsic stains. (Felton *et al.*, 2011) It is related with an abrasive material with a fine to extra-fine grit so that the surface scratches are smaller than the wavelength of visible light (0.05 m), and make a smooth, enamel surface. Cleaning may also be included in the definition of coronal polishing. (Felton *et al.*, 2011)
3. Superficial polishing is a term used to describe the polishing of the tooth's crown. Nowadays, it is viewed as a cosmetic procedure with a little therapeutic value.
4. Selective polishing is a term that hygienists frequently employ. It is related to cleaning and polishing procedures only when it is necessary to remove stains visible on tooth surfaces. Everything depends on the patient's assessed needs. It indicates that already stain-free surfaces do not require cleaning or polishing. (Felton *et al.*, 2011)

2.2.1 Polishers

You can choose between manual and engine-driven polishers. The engine-driven polishers employ hand parts to polish, whereas the manual polishers are handheld equipment. The most popular technique for polishing teeth involves using a mechanical tool and a polishing chemical, a few mechanical devices are widely used in dental clinics is as follow:

2.2.1.1 Porte polisher

A Porte polisher is a tool which can be applied to several dental issues. It uses a wooden point that is wedge-shaped, tapered, or pointed to rub the abrasive substance against the tooth surface. (Sawai *et al.*, 2015) Porte polisher has some pros which is portable easy to be handled inside the mouth, produce little thermal heat, and no noise produced like rotary tools. Hardly any bacterial aerosol. (Daniel and Harfst *et al.*, 2004), More hand strength is needed for the instrumentation, and tooth polishing takes longer time which is considered as cons of using the Porte polisher. (Rethman *et al.*, 2009).

2.2.1.2 Polishing strips

The polishing strip is a kind of tool in order to work well for line angles and interproximal areas. They are, however, abrasive. When polishing, care must be given to prevent cutting or to abrade the nearby soft tissues. (Rethman., 2009)

2.2.1.3 Engine-driven polishers

Dentists and hygienists use this instrument since they're effective. These polishers are linked to straight or contra-angled prophylaxis angles. After sterilization, they're disposable or reusable. Prophylaxis angles have a rubber cup or brush. The handpiece is used at 2500–3000 rpm. (Rethman., 2009). On the other hand, there are studies declared that that dental hygienists use an average 2500 rpm because estimating that using a higher rpm is difficult clinically, the slow-speed handpiece always rotates at the possible lowest rpm. Whining or high-pitched sounds indicate too high rpm (Christensen and Bangerter., 1984).

Most surfaces can be polished in 2–5 seconds using a gentle, consistent pace and patting action. Christensen and their Ancestors mentioned that 4.5 seconds of polishing for each tooth is adequate for smooth the surface (Christensen and Bangerter., 1984).

There are studies comparing the rubber cups and air polishing mentions that it takes 10 minutes in total, 3.4 seconds per tooth, to polish the entire mouth. (Hodges., 1998) Due to the polishing process, patient compliance and acceptance are high in most clinical applications. On the contrary, to the mentioned advantages, patients with latex or fluoride allergies should use latex-free rubber cups, prophylactic pastes, and pumice slurry.

2.2.1.4 Air-powder polisher

Air powder polishing devices are related with rubber cup polishing paste systems for supragingival plaque removal because they reach inaccessible locations. (Boyde., 1984; Galloway and Pashley., 1987) Thus, a water-sodium bicarbonate slurry is applied under air and water pressure. Air polishers use aluminum trihydride, calcium sodium phosphor silicate, calcium carbonate, and glycine.

The air powder polisher handpiece is connected to the dental unit's air/water clamp as a separate unit or with ultrasonic scalers. The handpiece nozzle pushed the slurry onto the tooth. The nozzle is held 3–4 mm from the teeth. A steady circular motion should be used, interproximal to interproximal sweeping or paint brush action at the center part of the exposed tooth. (Sawai *et al.*, 2015).

Generally, air pressure between 40 and 100 psi and water pressure between 20 and 60 psi is used by the apparatus. (Wilkins and Wilkins., 1976) Francis and Barnes noted that psi varies on the air powder polisher utilized. These are safe and effective extrinsic stain and plaque removal procedures. Studies show that air powder polishers can damage exposed cementum and dentin. (G. J. Petersilka *et al.*, 2003; G. Petersilka *et al.*, 2008) Adjusting water flow and instrument distance reduces abrasive forces.

By modifying the physical properties of air-polishing chemicals, found that abrasive effects on root surfaces can be decreased, and extrinsic stains removed. (G. Petersilka *et al.*, 2008) Previously, alumina or dolomite-using air dent machines were employed. The new air-polishing device (APD) is a good way to remove plaque even from teeth with brackets because it does not affect wires or rubber bands. Moreover, APD does not damage zinc phosphate or resin cement material. APD has some advantages like reducing the operating and patient fatigue, more efficient and time saving. (De Spain and Nobis., 1988)

Plaque elimination from hard-to-reach places like flutings, furcation's, and near root proximities (Boyde *et al.*, 1984). Disadvantages have been acknowledged as

patients with respiratory, renal, or metabolic diseases or with infectious diseases, and the patients who has long-term steroid therapy, or the ones with titanium implants, The aerosols produced by air polishing may pose a risk to infection control, which is another downside. As a result, preprocedural rinses and aerosol reduction devices are always advised. When compressed air is used intra-orally, subcutaneous emphysema can also develop; this emphasizes the risk of iatrogenicity and correctly adhering to the manufacturer's recommendations. (Boyde., 1984) Air powder polishing can help as a replacement for traditional methods that cause less gingival erosion and reduction in abrasiveness on root surface than other methods (Garcia-Godoy., 1988).

2.2.1.5 Comparison of different polishing techniques.

Studies contrasting the efficacy of air-polishing versus rubber cup polishing for removing bacterial plaque and stains show that both methods are equally successful. (Braun *et al.*, 2005) They claimed that both techniques brought on some gingival damage. (Braun *et al.*, 2005) According to Garcia-Godoy and Medlock, air polishers are more efficient at removing plaque and stains from fissures and pits. (Sawai *et al.*, 2015)

2.2.1.6 Vector system.

The teeth are polished using a polishing fluid by the vector system. Plaque and endotoxins are eliminated with little damage to the cementum surface. By using a silicon carbide- or hydroxyapatite-containing abrasive fluid with a resonating device that deflects vibrations directed at the tooth surface. Braun showed how to reduce the forces required to remove tooth material. As a result, less pressure is applied on the superficial part of the enamel as fluid dynamics adequately remove the plaque. Before new calculus, deposits start to form, and after thorough debridement of the existing calculus, this can effectively manage inflammation. (Sawai *et al.*, 2015)

Due to the disadvantages of the traditional polishing techniques, there are some several different polishing techniques developed. Laser polishing technique is suggested as one of these newest techniques that are foreseen to reduce the disadvantages of traditional methods.

2.3 Laser

Light amplification by stimulated emission of radiation is referred to as laser. (Hedge *et al.*, 2018) Lasers produce heat by converting electromagnetic energy to thermal energy. In comparison to other light sources, lasers are a unique light source with high power and higher beam quality. With its enormous improvements in clinical applications, laser technology is anticipated to become a milestone in dentistry. Laser therapy can be used to treat both hard and soft tissues without physical contact, or vibration, in numerous medical fields, laser were first used in the late 1960s. First investigations in dentistry and ophthalmology have been published. According to their wavelength, active material employed, power, or mode of operation, laser systems can be categorized as shown is (Figure 3). One of the most crucial laser characteristics that affect how deeply laser light penetrates tissue is the wavelength (Hedge *et al.*, 2018).

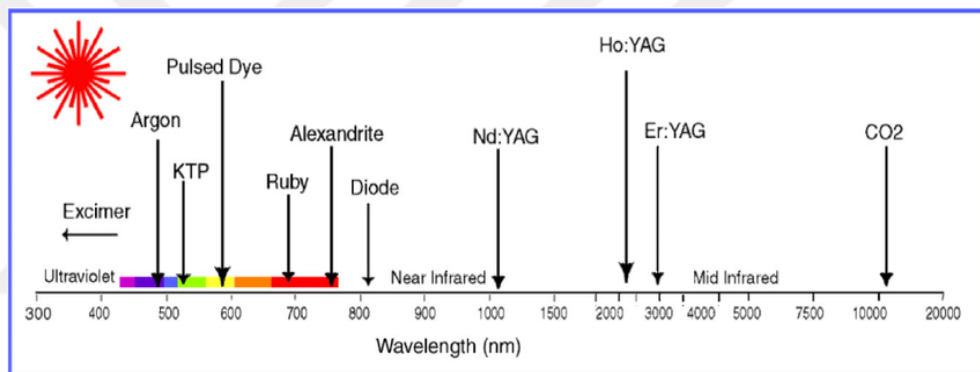


Figure 3. Classification of laser systems due to their different characteristics (https://www.researchgate.net/figure/Wavelengths-of-common-medical-lasers-courtesy-of-Dr-Albert-Poet-Shore-Laser-Center_fig1_231009441, 2022)

Reaction, Refraction, Absorption, and Scattering are the primary four processes that occur when the matter is subjected to light (Figure 4). They are similar to the processes when tissue interacts with medical lasers.

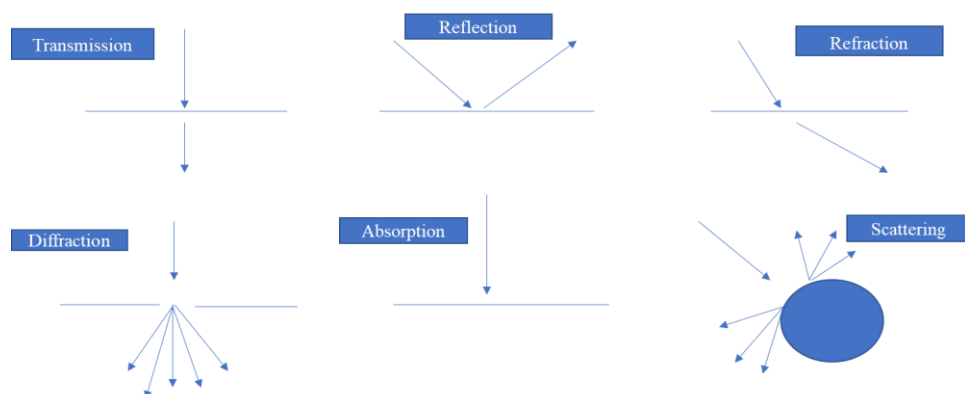


Figure 4. The reflection, refraction, absorption, and scattering.

There will not be a thermal effect if the coming light is reflected by or passed through tissue. However, the light will turn into heat if it is absorbed by the tissue. The most known absorbing agents found in biological tissues are water molecules or macromolecules. Those macromolecules are proteins and pigments (Figure 5). The word used to describe the efficiency of absorption is the absorption coefficient. According to the amount of water in the tissue, infrared absorption rises with longer wavelengths. Water molecules absorb the least amount of light in the red to near-infrared (NIR) range, from the fact that water makes up about 75% of the tissue which may increase or decrease the amount of wave absorption. The diagnostic and therapeutic window is another name for this area, the wavelength of the light affects how it reacts with the tissue. The optical characteristics of the tissue's constituent chemicals and their concentration and distribution within the tissue impact the tissue's optical qualities. The makeup of tooth structure is not uniform. Dentin and enamel have different amounts of organic and inorganic components, meaning that each layer's absorption coefficient is different from the other (Figure 5).

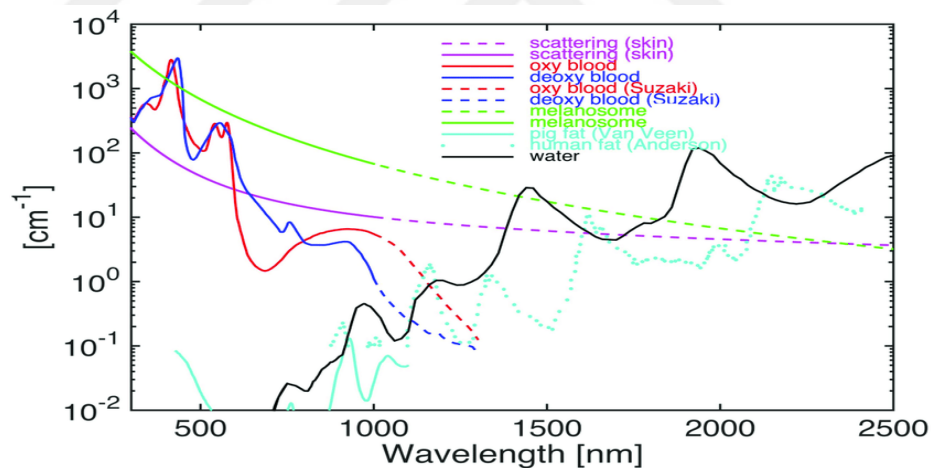


Figure 5. The primary absorption spectra of biological tissues, the absorption coefficients at some typical laser wavelengths.

(Van Phuc Nguyen, Yannis Mantas Paulus., Dec 2018)

2.4 Lasers in Dentistry

Continued growth in laser-based technology seems anticipated, thus it depends on a combination of therapeutic and diagnostic laser approaches. All dental professions now employ lasers far more frequently than they did a few decades ago. Current studies show that laser therapy has a wide range of benefits. Professionals are starting

to recognize it as a substitute for conventional therapy due to its many benefits. A laser in dentistry support group with a global emphasis has also emerged in tandem with the growth in research into the use of laser in general practice during the past ten years. There seems to be rising recognition of the value of lasers in the toolkit of contemporary dental practice, where they can be utilized as a complement or alternative to conventional techniques (Hedge *et al.*, 2018). Lasers were once thought of as a difficult technology with limited clinical applicability.

2.4.1 Application of lasers in dentistry.

Dentistry began deploying lasers starting from 1960s, while, in 1980s and early 1990s US Food and Drug Administration approved a number of different types. The following experimental and clinical research has employed dental lasers (Hedge *et al.*, 2018):

1. Cavity cleaning and preparation.
2. The removal of fillings.
3. Micro-retention through surface etching.
4. Eliminating calculus and tough dental tissues.
5. Eliminating delicate dental tissues.
6. Lithotripsy
7. Endodontic root cleansing and disinfecting.
8. Bleaching your teeth
9. Dental Bridges and Dentures Laser Welding.
10. Care for dental caries.
11. Ceramic brackets being deboned,

Low-level lasers typically operate in the milliwatt range (between 1-500 milliwatts), are more compact, and are less expensive. Biomodulation is the name of this treatment used for the usage in post-extraction sites, dentinal sensitivity, and problems of the temporomandibular joint. (Pandey *et al.*, 2016). Lasers have some advantages when applied in dentistry, firstly, eliminating stitches needed during procedures may reduce bleeding because the intense light beam helps exposed blood vessels clot (coagulate) which may also reduce the amount of tissue damage. Secondly, operations can be completed without anesthetic. Also, the risk of bacterial infection is reduced due to the high-energy produced by the laser. The region being worked on

will be sterilized, and finally, the tissues may renew, and the wounds heal more quickly (Hedge *et al.*, 2018).

Laser safety is another critical issue. Lasers may provide a significant danger of serious harm and substantial property damage. There are three pillars of laser safety starting with the manufacturing process of the instrument, proper device use, patient and patient team personal protection. Everyone around the operating area, including the patient and the operators, must wear protective eyewear as shown in (Figure 6). There are some precautions used in the clinics and laboratories which is: restricting access to the surgical area, posting warning signs, removing shiny surfaces, and verifying the laser is operating properly, incidental exposure to non-target tissue can be avoided. Any vapor plume should be expelled using high-volume suction. A designated Laser Safety Officer is in charge of policing, supervising, maintaining the use of protective eyewear, and coordinating staff training programs. (Hegde *et al.* 2011)

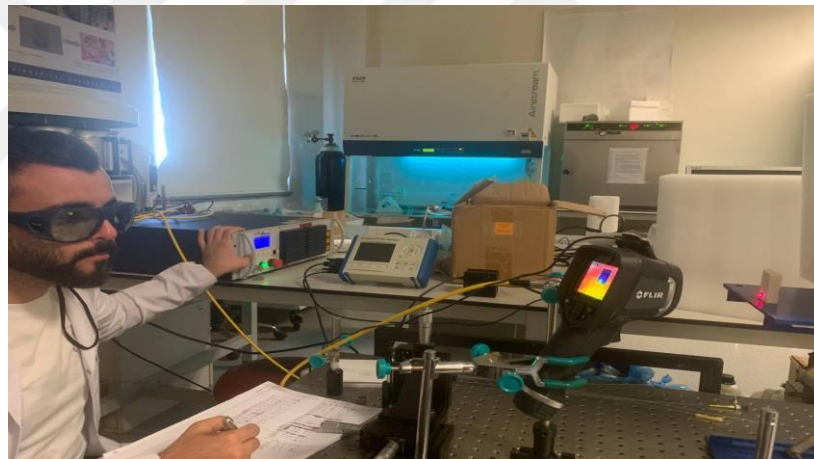


Figure 6. Safety measures while using lasers.

2.4.2 Limitations of lasers.

For clinical usage and applications, what requires extra training and skills. investment in its expensive technology is also another limitation or obstacle. In dental practice, more than one type of laser is required since different wavelengths are required for specific operations. (Hegde *et al.*, 2011)

Types of lasers.

2.4.3 Types of lasers

Uses of Lasers in dental era can be examined into groups based on their wavelength, physical makeup, kind of medium used, tissues they are administered to, and level of danger from accidental exposure. (Pandey *et al.*, 2016). Many laser types have been applied in dentistry, which can be differentiate according to, laser medium, optical cavity, and energy source. (Frentzen and Koort., 1990; Walsh., 2003). Many types have been applied in dentistry.

2.4.3.1 Neodymium, Yttrium Aluminum Garnet (Nd: YAG) Laser.

Dental soft tissues can be sliced and coagulated with a very effective surgical laser because the pigmented tissue significantly absorbs the laser's wavelength. The non-contacted defocused mode may cause a several millimeters crack, which aids in the homeostatic therapy of pulpal analgesia. (Nambiar., 2006)

2.4.3.2 Carbon dioxide laser.

Sterilization is one of carbon dioxide laser uses, reduce scarring, also, preventing hematoma formation by leaving behind "Char," which serves as a dressing and aids in sterilization. Water-loving, capable of cutting and coagulating soft tissue with ease. The fact that it damages hard tissue and is pricey is a drawback (Darling and Fried., 2008).

2.4.3.3 Diode laser.

Diode laser can be acknowledged as a semiconductor and low-level laser. Between silicon wafers in a diode laser the active medium was placed. Dental hard tissues are not very good at absorbing light. Therefore, soft tissue procedures can be done safely. The essential advantage is that a more compact, portable device can trigger fibroblastic proliferation even at low energy levels. (Moritz *et al.*, 1997; Coluzzi., 2002)

2.4.3.4 Argon lasers

Two emission radiations are used in modern dentistry: 488 nm (blue) and 514 nm (blue green). They have been used in periodontics because they are bactericidal to *Prohormones gingivitis* and *Prevotella intermedia* (David and Gupta., 2015). (Verma

et al., 2012) preferred hard tissues in the mouth because they can absorb the most water. It can also be used to burn delicate tissue. (Harashima *et al.*, 2005).

1940 thulium fiber laser (IPG GMBH laser-TLR 1900-2000nm diode laser) is an optical fiber device stoned with rare elements (Von Fraunhofer and Allen., 1993). Fibre lasers have been used in spectroscopy, communications, material processing, and medicine. Fibre lasers have the following benefits over the other types of lasers:

- Light is coupled into a flexible fiber it can easily be transmitted to a mobile focusing element.
- Fiber lasers have active areas that may extend for several kilometers, producing very high optical gain.
- The fiber has high optical quality by the waveguiding properties lessen or eliminate the optical path's thermal distortion.
- Because fiber can be bent and coiled to conserve space, fiber lasers have a compact size.
- Fiber lasers have a long lifespan and excellent vibrational stability.

Although there are many benefits, the heat effect of laser light on tooth tissues can have unfavorable impacts so the effects of increasing temperature in dental tissues have been studied many times in literature. Zach and Cohen were the first scientists who studied the risks of thermal increase in dental tissues. Histological changes were declared at 2°C of temperature change when the sample teeth's buccal surfaces were heated with a soldering iron set. They discovered that irreparable damage occurred when the temperature increased by 5.5°C and the pulpal damage was irreversible over a change of 11.1°C. However, these cutoff points for irreversible pulp damage have been contested by some experts, who contend that they ought to be higher. (Zach and Cohen., 1965). After laser in dentistry get the approval from the (FDA), the influence of CO₂ laser was examined on pulp tissue temperature with a power of 0.5 W and 1 W in a continuous wave, another work was done on Nd: YAG laser irradiation with an energy of 1W and 3 W Nd: YAG laser. The relationship between pressure and temperature in the pulp chamber and the laser's energy density was examined by Srimaneepong *et al.* and they declared that Remaining Dentin Thickness, RDT, was decreased (Srimaneepong, Palamara, and Wilson., 2002). Later that time Mollo *et al.* demonstrated that lasing with a diode laser with 417 µW of power increases the temperature in the pulp to the accepted critical thresholds (5.5°C). According to

Oliveira's study, the highest thermal values were recorded in incisors using a 670 nm wavelength laser and a power of 340 μ W, 272 μ W, and 204 μ W (4.7C, 4.2C, and 3.1C, respectively); whereas canines showed the lowest thermal values (0.8 C-0.3 C) without the influence of power (de Oliveira *et al.*, 2017). As power outputs increased, the thermal rise was seen. Morsi *et al.* declared the safety parameters as 0.2-1 W, CW (continuous mode) up to 60 s; 1.5 W, CW up to 15 s; 2 W, CW, 10 s; and 2.5 W, CW, 10 s for the tooth pulp. (Morsi *et al.*, 2020) In addition to these guide studies, Khouja examined that the importance of the cycling in thermal safety while lasing with an 808 nm diode laser on the outer surface of the tooth with a power of 1W in continuous mode and 5W in pulsed mode for two cycles of 30 s (Khouja *et al.*, 2017).

The understanding of laser-tissue interaction has improved due to developments in laser technology. Much research is being conducted to increase the possible applications of laser technology, such as enhancing composite adhesion, surface roughness, and roughness morphology by modifying the texture of enamel or dentin surfaces.

Higher exposure to laser therapy resulted in the production of microcracks and fissures. Hossain *et al.* indicated in their article on ablation and morphological analyses that lasing with an Er, Cr: YSGG laser could be a good alternative method to the conventional method, acid etching. This study declared that Er, Cr, and YSGG laser irradiation, water spray increases ablation depths at the ablation sites (Hossain *et al.*, 1999). In 2001, another study was done on the analysis of surface roughness of enamel and dentin after Er, Cr, YSGG laser irradiation, which discovered that the laser system significantly increased the surface roughness. Furthermore, scanning electron microscopy research revealed that the irradiated surface generated a rough surface devoid of smear layer and no fissures in enamel or dentin (Hossain *et al.*, 2001).

An article published on the effect of Er: YAG Laser and observed enamel morphology using atomic spectrometry and compared groups according to varying laser powers. Besides reduced demineralization in laser groups, SEM analysis revealed various surface modifications due to the different energy employed. And the concluded that lower energy could diminish enamel solubility without generating significant enamel alterations (Cecchini *et al.*, 2005). In addition to all those studies, a comparison between the acid-etched and Er: YAG laser-treated enamel and declared that there were microcracks on enamel surface using SEM, after laser etching by Er: YAG laser

considerable breaking beneath the surface was observed and thus made adherence difficult. (Martínez-Insua *et al.*, 2000)



Chapter3

Methodology

The experiments in this thesis were performed in two parts, the preliminary and the main experiments, at Bogazici University Biophotonics and Tissue Laboratories, using a 1940-nm Thulium Fiber Laser (TLR-5-1940; IPG Laser GmbH, Germany). After preparing the teeth samples, the preliminary experiments were completed. The initiatory experiments, and temperature measurements, provided a basic and optimum working parameter range for the main experiments. The main experiments of this thesis were also three parts: “Laser Applications”, “Surface Observations and Depth Measurements”, and “Analysis of Surface Depth Distribution”.

3.1 Teeth

Bovine mandibular incisors were selected for this study because they have quite alike physical properties to human teeth. Besides, they can be collected more easily and have a higher hygienic level.

The cattle lower jaws to extract the bovine teeth were obtained from a slaughterhouse. Extracted samples were cleaned from the remnants, blood and calculus. After brushing, all specimens were stored in the isotonic sodium chloride solution at the room temperature. In order to inhibit bacterial growth, the solution was changed at least twice a week. Each tooth was washed with distilled water before use.

3.2 Sample preparation

As each teeth kept in the isotonic sodium chloride solution at room temperature, all samples are washed under running water before the experimental procedure. A gypsum mixture is prepared for each teeth according to the clinical guidelines, and poured in a rectangular mould to obtain rectangular gypsum blocks. Each bovine tooth was embedded in one gypsum-filled-mould as parallel as possible to the vertical axis of the block and only the labial surface of the enamel was seen on the upper face (Figure 7). Embedding teeth in gypsum blocks to make the teeth handling easier and laser irradiating accurately on a specific and controlled area. Each gypsum block was trimmed and corrected by dental gypsum finishing machine. Then each experimental surface area was cleaned underwater, grinded and polished with 600 Grit. sandpaper sheets. After the cooling, the gypsum blocks samples were replaced in a beaker with

distilled water and those samples were stored at 100 % humidity and 37 °C up to the experiment day.

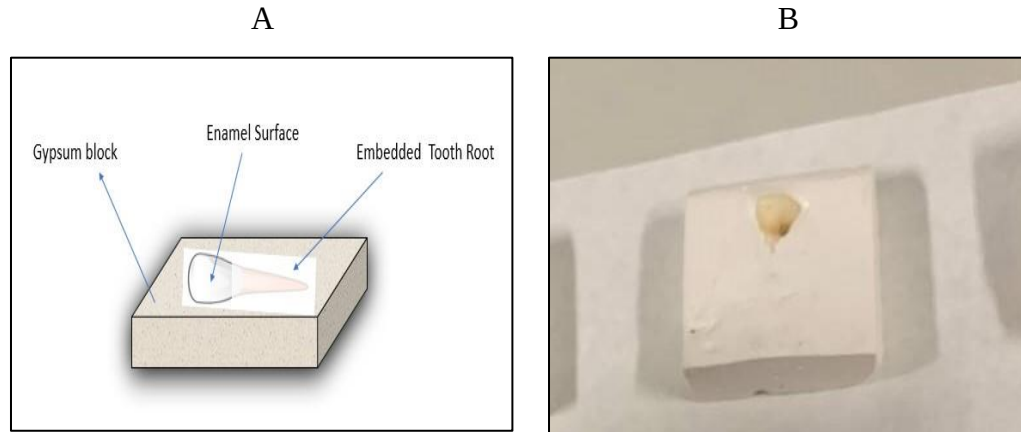


Figure 7. Each tooth sample was embedded in a gypsum block for easy handling during laser radiating, (A) Scheme for the gypsum block (B) The gypsum block in the experiment.

3.3 Experimental Procedures:

In this study experiments consist of two parts:

- 1) Preliminary Experiments
- 2) Main Experiments

3.3.1 Preliminary Experiments:

Preliminary experiments included all the temperature measurements to obtain optimum parameters for the main experiments. The experimental setup for thermal measurements was set before the measurements (Figure 8). The increase in temperature on the enamel was measured during irradiation by a thermal imaging camera (Thermometer FLIR E5XT, Teledyne, Germany)

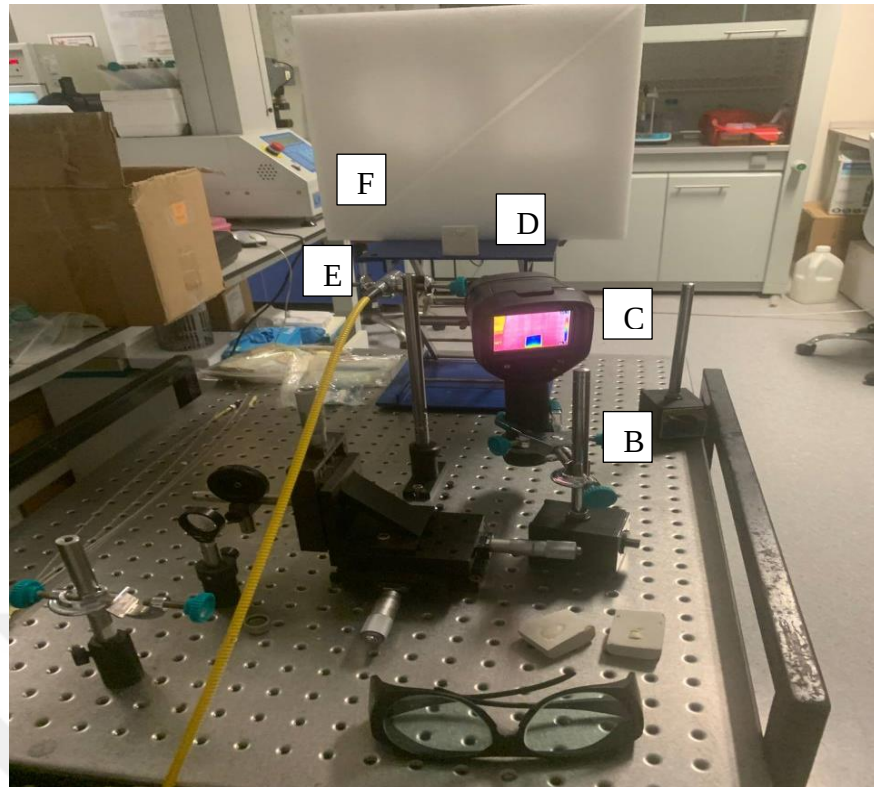


Figure 8. Temperature measurement setup: (A) Laser eye protection (1800-2000nm) (B) holder (C) Thermometer FLIR E5xt (D) Tooth sample (E) laser beam (F) Cork barrier

The laser setup consists of four main parts:

- 1) A 1940-nm Thulium Fiber Laser (TLR-5-1940; IPG Laser GmbH, Germany) as shown in (Figure 9).
- 2) A pulse modulator to control the duty cycle of pulses and a computer for controlling the laser.



Figure 9. The 1940-nm Thulium Fiber Laser

- 3) A power meter (Newport, Model 1918-R, US) to measure the output energy level of the 1940-nm diode thulium Laser. The power meter consisted of a head

for measuring the power and a monitor. The measurements were read as shown in (Figure 10).

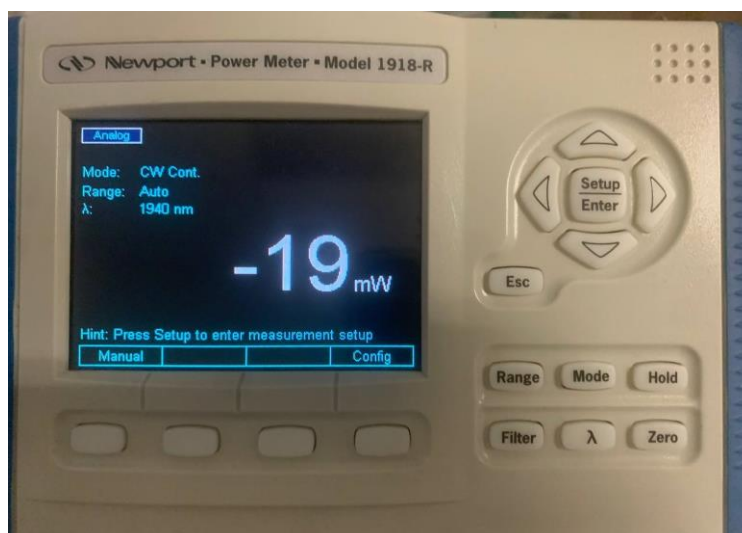


Figure 10. The Power meter (Newport, Model 1918-R)

4) Thermal Imaging Camera

In addition to the Laser Set Up, there is also a thermal imaging camera to measure the temperature differences in enamel during the irradiation of the 1940- nm thulium Laser as shown in (Figure 11).

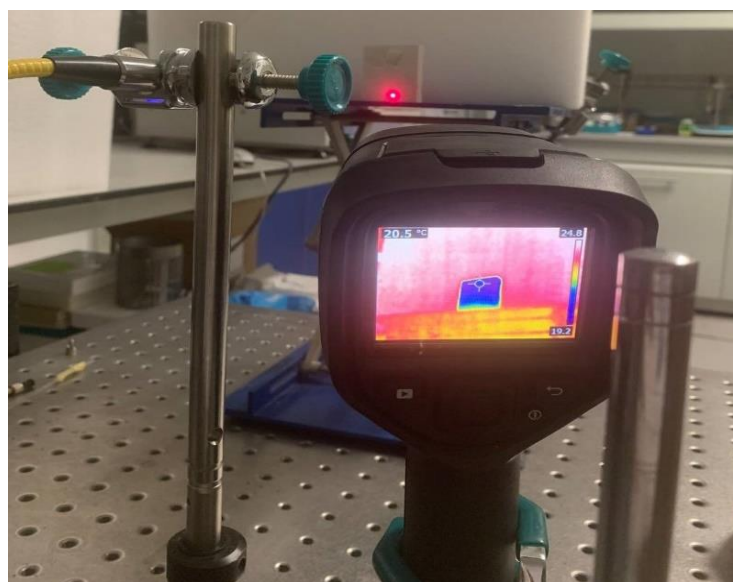


Figure 11. Thermometer flir 5Ext

In the laser set-up, the laser was connected to a modulator and computer. The samples and thermal camera were fixed by the two different metal holders. A cork barrier was replaced at the back of the tooth sample for the laser safety, also, the fiber

Table 2.

Lasing parameters of the Preliminary Experiments

LASING POWER	LASING TIME	TOTAL ENERGY
0.25 W	1 sec	0.25 J
0.25 W	2 sec	0.50 J
0.25 W	3 sec	0.75 J
0.25 W	4 sec	1.0 J
0.25 W	12 sec	3.0 J
0.50 W	1 sec	0.50 J
0.50 W	2 sec	1.0 J
0.50 W	3 sec	1.5 J
0.50 W	4 sec	2.0 J
0.75 W	1 sec	0.75 J
0.75 W	2 sec	1.5 J
0.75 W	4 sec	3.0 J
1.0 W	1 sec	1.0 J
1.0 W	3 sec	3.0 J
2.5 W	2 sec	5.0 J
2.5 W	4 sec	10 J
5.0 W	1 sec	5.0 J
5.0 W	2 sec	10 J
5.0 W	3 sec	15 J

After measuring and recording part, the average thermal increase and standard deviation for each experimental group were calculated. The paired student-*t-test*, ($p \leq 0.05$, student *t-test*), was done for analyzing the results to find the optimum working parameters for the main experiments. The lasing parameters for the main experiments were settled upon the results of those preliminary studies.

3.3.2 Main Experiments:

The defined optimum parameter range was used for the main part of the experiments. The main experiments consist of “Laser Application”, “Surface Observation and Depth Measurements” and “Analysis”. There are five different steps in this part of the study:

- 1) Surface roughness measurement before lasing using a hirox microscope.
- 2) Laser application
- 3) Surface roughness measurement after lasing using a hirox microscope.
- 4) Analysis of surface depth distribution by MATLAB.
- 5) Statistical analysis

Before the examination of surface roughness, the teeth were cleaned by using 1g of ordinal toothpaste (Colgate Sensitive, US) , and a medium soft toothbrush (Oral B, Dual Effect, No:35, US) , applying 30 times for each tooth. 600 grit sandpaper was applied 30 times for each sample to polish the enamel surfaces. Then a micromotor device (ESCORT-III+ H37L1 35K RPM Marathon Micromotor Handpiece) was applied using polishing bur for the polishing purpose. Firstly, a brush was used 30 times for each tooth. Secondly, a diamond burr was applied 10 times for each tooth, and in the end, two sandpapers were involved, soft and coarse, to soften the tooth's surface.

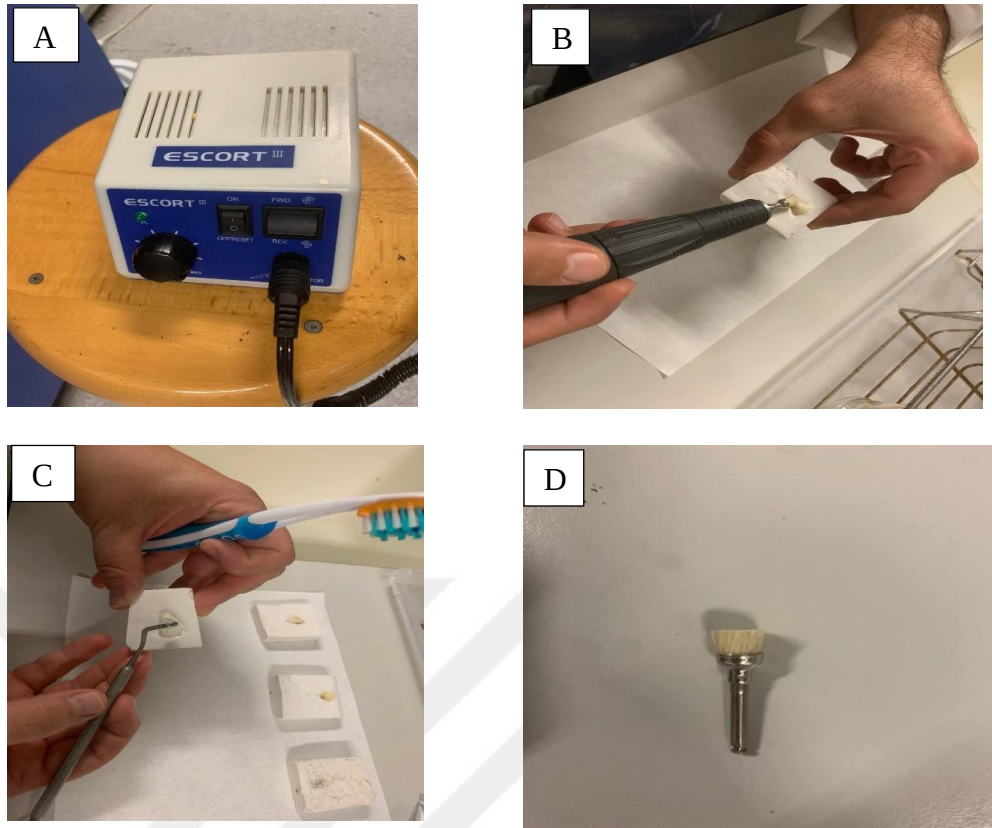


Figure 13. (A) ESCORT-III+ H37L1 35K RPM Marathon Micromotor Handpiece (B) handpiece brush connected to the micromotor (c) normal teeth brush (D) brush attached to an arm used for cleaning and plug removed from the tooth.

After cleaning each sample as defined above, the teeth were dried out. Two red points were put in the middle of the incisal and the crown baselines to make sure that the same line between those two defined points was measured before and after lasing as shown in (Figure 16).

The surface roughness measurements were done under a 3D microscope (Hirox Digital Microscope, KH-8700, JPN) to examine the enamel surface and take recordings for calculatei the surface roughness before radiating the teeth. Hirox digital microscope KH-8700 was used in this part of the study to obtain high-quality images and utilize multiple angles of observation, to achieve quick and accurate 2D/3D results (Figure 13). Hirox 3D microscope is a digital microscope (DM) which is an instrument with an eyepiece replaced by a digital camera (CMOS), that shows the graphically captured picture on a sizable monitor. It can perform a number of additional extended tasks in addition to observation, including dimensional measurements. With a stress-

free observation environment and ease of handling, it can be utilized in various scenes, including research and project development.

For each sample tooth, the sample is replaced under the microscope and each measurement parameter was set for every examination and each setted-parameter was recorded in order to be used after-lasing-measurements.

After obtaining a clear 2D image, the line between two defined points was measured and these measurements were repeated three times. The surface photos are taken in a 2D image set of this microscope and saved.

For the 3D examination part of the study, suitable parameters were set for each related sample. Then, three vertical slices were selected on the defined line, and that information was used for calculating the surface area of the sample before lasing. “Before-lasing” images and calculations for the same selected slices were recorded to be compared with after-lasing images.



Figure 14. Hirox digital microscope KH-8700

After pre-measurements, the sample teeth were replaced in the laser-experimental set-up. This set-up consists of a 1940-nm thulium fiber laser, a laser controller, a power meter, a metal holder, a cork barrier, and computers as shown in (Figure 15).

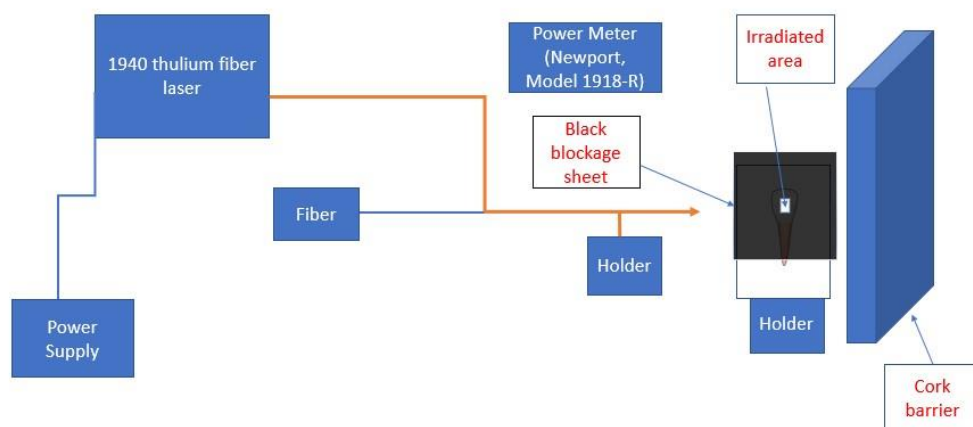


Figure 15. Main experimental set-up

A 1940 nm thulium fiber laser was applied in three different powers (0.25 W, 0.75 W, 1 W) and with 3 different lasing times (12 Sec, 4 Sec, 3 Sec) respectively on specific surface area that was the center of the line between those two defined red points. A black blockage sheet, with a 9 mm² hole on it, was attached on enamel to cover the enamel surface and specify the same lasing area for all the samples. Laser irradiation was done in the same pre-experimental conditions like a room temperature. The following laser parameters were applied on the sample enamel one by one, each laser group had 9 samples.

Table 3.

Laser parameter of the main experiment

LASING PARAMETERS			
Group Name	LASER POWER	LASING TIME	TOTAL ENERGY
0.25-12s-aft	0.25 W	12 sec	3.0 Joules
0.75-4s-aft	0.75 W	4 sec	3.0 Joules
1.0-3s-aft	1.0 W	3 sec	3.0 Joules

Main experimental set up was quite alike the pre-experimental one excluding the thermal camera set-up. Each sample were exposed to laser irradiation in the identified area.

Each sample was lased according to the related group's lasing parameters. After the irradiation part, all samples were transported to the clean room to be examined under the microscope. The same measurement protocols and microscopic adjustments were applied for each teeth before and after lasing.

For each sample teeth, the sample is replaced under the microscope and each measurement parameter was set accordingly. After obtaining a clear 2D image, the same middle line between two defined points was scanned again for the same sample. These measurements were repeated for three times. The surface photos were taken in 2D image set of this microscope, and saved. For 3D examination part of the study, again three vertical slices were selected randomly on the defined line, Then information taken from 3D microscope was used for calculating the surface area of the sample after lasing.

After completing the measurements, MATLAB software was used for the surface depth distribution analysis. In the main part of the experiments, after obtaining the data from the 3D microscope, the 2D images were observed, and the areas of selected slices from 3D images were calculated in two steps:

- 1) The enamel surface depth charts (Figure 16) were obtained from a 3D microscope. This chart was showing the 2D image of the selected slice taken from the sample. It means that the area under the enamel surface could be calculated before and after lasing for the same sample. The modifications on the surface caused by irradiation could be determined by comparing the pre and post images for the same area of the slice.

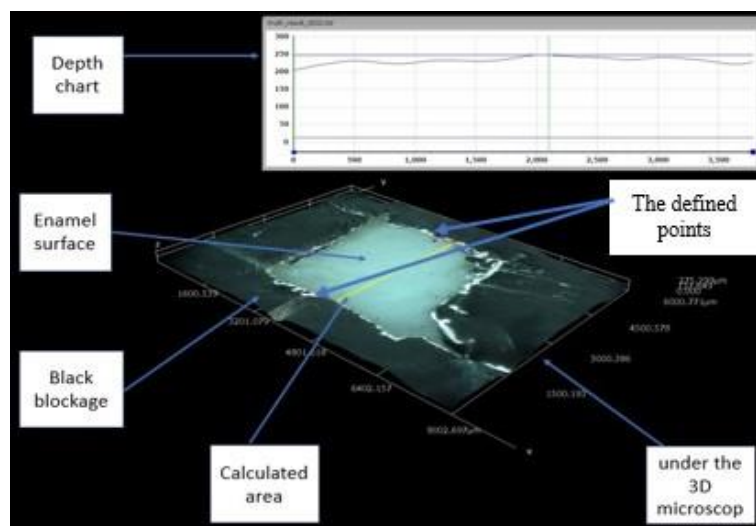


Figure 16. Image obtained from 3D microscope

2) From each depth chart 629 points were randomly selected by using a program called FP Graph Tracer (FP Graph Tracer Programme). It is a simple cross platform tool to trace graphs from image files and output FRD/ZMA files. It is usable by anyone who needs to convert an image of a graph to a list of values. As shown in (Figure 17). the points were taken from the program and pasted into an excel sheet. Using the same points areas were computed using MATLAB. Also, MATLAB was used to calculate the area under the curve.

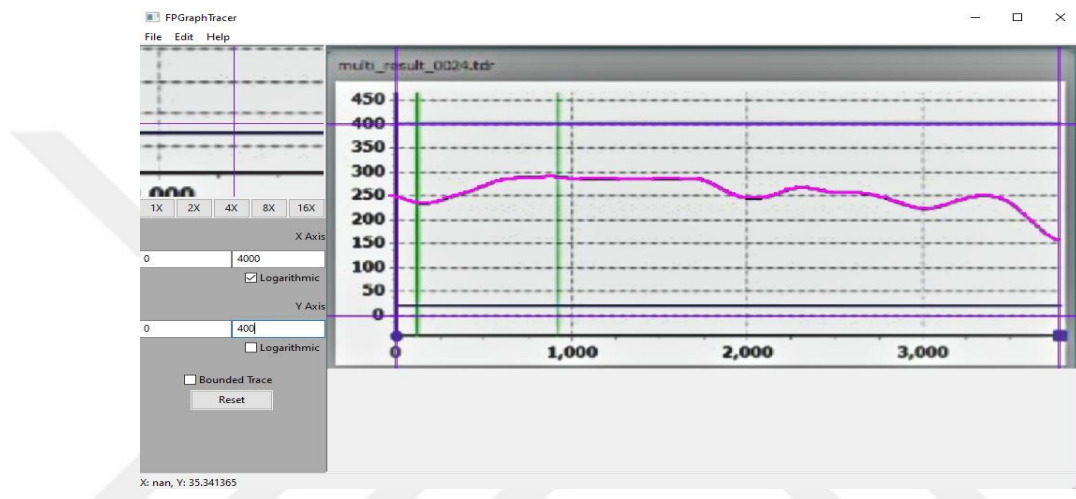


Figure 17. FPGraph tracer program.

The areas for both pre and post lasing surfaces were graphed, the differences in values were examined. The average and standard deviation of the area samples were calculated. pre and post operated areas were compared. The statistical analyzes were completed by the paired student t-test. ($p \leq 0.05$, student t-test).

Chapter4

Results

This experimental study was performed in two parts. In the first part, which was preliminary experimental part, varying lasing times and different power values were applied to the samples in order to find the optimal working ranges.

In the main experiment, the determined laser power and time parameters were used in the application on the sample teeth depending on the temperature measurement analysis.

4.1 Temperature Measurements

The temperature measurement tests were performed by the thermal camera. In the temperature measurement part, six different experimental groups with different powers (0.25, 0.50, 0.75, 1.0, 2.5, 5.0 W) and varying lasing times (1, 2, 3, 4, 12 sec) were selected as shown in (Table 4).

Table 4.

Lasing parameters for the preliminary experiment

LASING POWER	LASING TIME	TOTAL ENERGY
0.25 W	1 sec	0.25 J
0.25 W	2 sec	0.50 J
0.25 W	3 sec	0.75 J
0.25 W	4 sec	1.0 J
0.25 W	12 sec	3.0 J
0.50 W	1 sec	0.50 J
0.50 W	2 sec	1.0 J
0.50 W	3 sec	1.5 J
0.50 W	4 sec	2.0 J
0.75 W	1 sec	0.75 J
0.75 W	2 sec	1.5 J
0.75 W	4 sec	3.0 J
1.0 W	1 sec	1.0 J
1.0 W	3 sec	3.0 J
2.5 W	2 sec	5.0 J
2.5 W	4 sec	10 J
5.0 W	1 sec	5.0 J
5.0 W	2 sec	10 J
5.0 W	3 sec	15 J

The temperature increase for the irradiation area on enamel during lasing was measured for each sample in the thermal experimental set-up. Average and standard deviations for each group were calculated and the results are analyzed.

While 0.25 W of laser power was applied with different lasing periods, all thermal data was measured and recorded. After calculating the temperature increase for each sample, the average and the standard deviation of the temperature increase were calculated. This data is shown in Table 5.

Table 5.

Average and the standard deviation of the temperature increase each time for the 0.25W

Lasing Power	Lasing Time	Average Temperature Increase (°C)
0.25 Watt	1 Second	2.0655 ±0.34 °C
	2 Seconds	3.16 ±1.596 °C
	3 Seconds	7.752± 4.05°C
	4 Seconds	15.23 0±0.58 °C
	12 Seconds	24.2335± 1.26°C

The statistical analysis was done, and each group was compared according to the paired student t-test. ($p \leq 0.05$, student t-test) The comparison of temperature rises in the surface of the tested teeth at each lasing time setting are shown in (Figure 4). There is a significant difference between all the groups except Group 0.25 W 2 sec & Group 0.25 W 3 sec, there is no significant difference between other groups according to the paired student t-test. ($p \leq 0.05$, student t-test).

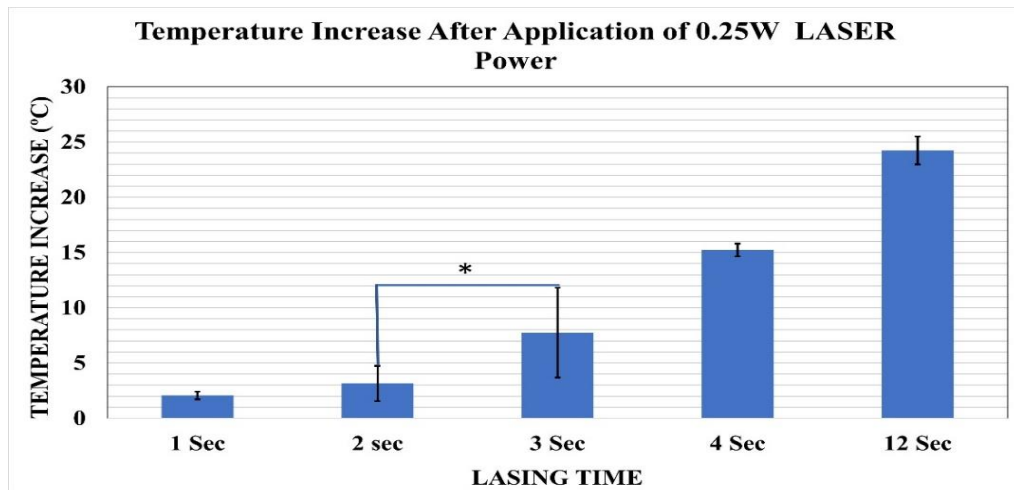


Figure 18. The graph shows the temperature increase after applying 0.25 W Groups with time intervals, 1 sec, 2 sec, 3 sec, 4 sec, and 12 sec. There is significant difference in temperature increases only between 2 sec & 3 (*) sec groups. There is no other significant difference ($p \leq 0.05$, student t-test).

During irradiation of 0.50 W of laser power with varying time ranges, the temperature was recorded, and the obtained data was used to calculate the average and the standard deviation of the temperature increase. The results were shown in the Table 6.

Table 6. Average and the standard deviation of the temperature increase each time by 0.50 W.

Lasing power	Lasing Time	Average Temperature Increase (°C)
0.50 W	1 Second	13.065 ± 1.62 °C
	2 Second	18.8133333 ± 1.11 °C
	3 Second	23.0352941 ± 1.15 °C
	4 Second	26.06 ± 0.48 °C

According to the results of the 0.50 W irradiation samples, the average temperature, standard deviation, and paired student *t*-test ($p \leq 0.05$, *student t*-test) of the temperature rises in the surface of the tested teeth at each lasing time setting are shown in (Tables 6). It's obvious that there are meaningful differences in temperature rises as the lasing time increase, as shown in (Figure 19).

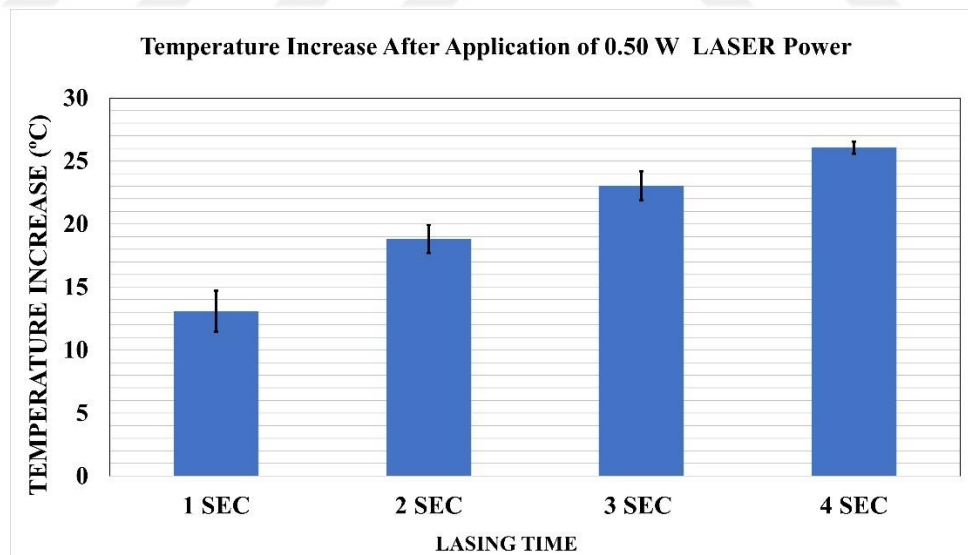


Figure 19. The graph shows the temperature increase after applying 0.50 W Groups with time intervals, 1sec, 2 sec, 3 sec, and 4 sec. Each irradiation time group is significantly different from each other ($p \leq 0.05$, *student t*-test)

While 0.75 W of laser power was applied with different lasing periods, all thermal data was measured and recorded. After calculating the temperature increase for each sample, the average and the standard deviation of the temperature increase were calculated. This data is shown in Table 7.

Table 7.

Average and the standard deviation of the temperature increase each time for the 0.75W

Lasing power	Lasing Time	Average Temperature Increase (°C)
0.75 W	1 Second	16.3428571 ± 1.75 °C
	2 Second	28.14375 ± 3.90 °C
	4 Second	42.5833333 ± 1.86 °C

The statistical analysis was done, and each group was compared according to the paired student t-test. ($p \leq 0.05$, *student t-test*) The comparison of temperature rises in the surface of the tested teeth at each lasing time setting are shown in (Figure 20). It's obvious, that there are significant differences in temperature rises as the lasing time increase between each group, as shown in (Figure 20)

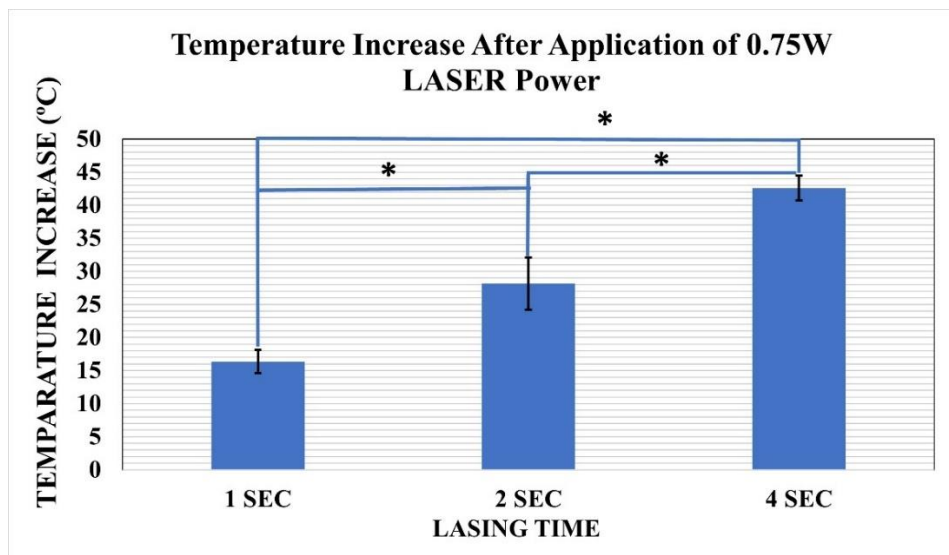


Figure 20. The graph shows the temperature increases after applying 0.75 W Groups with time intervals, 1 sec, 2 sec, and 4 sec (*). There is significant difference in temperature increases between all groups ($p \leq 0.05$, *student t-test*).

During irradiation of 1.0 W of laser power with varying time ranges, the temperature was recorded, and the obtained data was used to calculate the average and the standard deviation of the temperature increase. The results are shown in Table 8.

Table 8.

The average and the standard deviation of the temperature increase each time for the 1.0 W.

Lasing power	Lasing Time	Average Temperature Increase (°C)
1.0 W	1 Second	17.51 ± 3 °C
	3 Second	30.65 ± 11 °C

The statistical analysis was done, and each group were compared according to the paired student t-test ($p \leq 0.05$, *student t-test*). The comparison of temperature rises in the surface of the tested teeth at each lasing time setting are shown in (Figure 21). Both groups were significantly different from each other as shown in the graph.

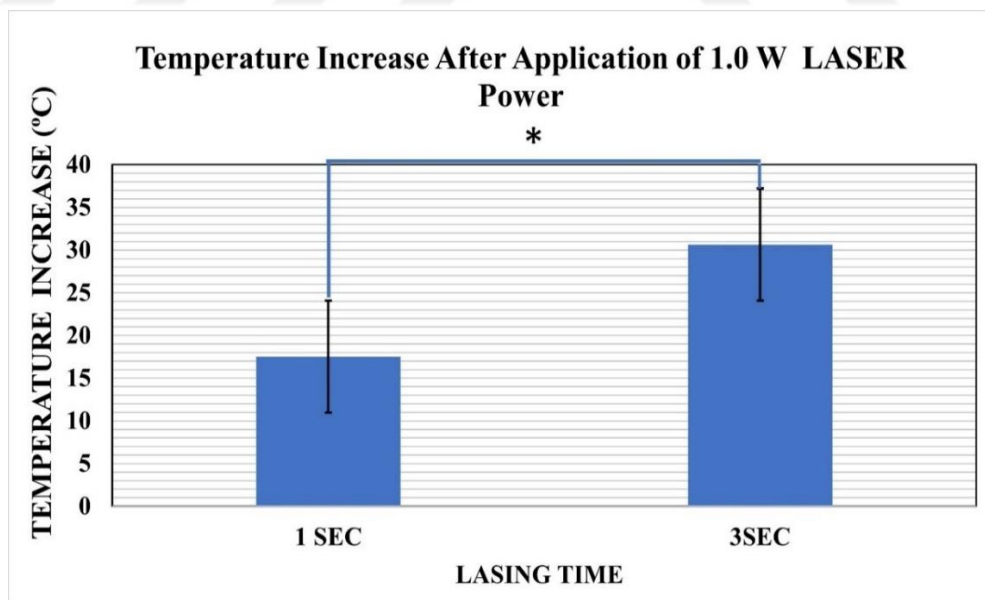


Figure 21. The graph shows the temperature increases after applying of 1.0 W Groups with time intervals, 1 sec, and 3 sec. There is a significant difference in temperature increases between all groups (*) ($p \leq 0.05$, *student t-test*).

After applying 2.5 W of laser power with varying time values are recorded and the obtained data was used to calculate the average, and the standard deviation of the temperature increase were shown the (Table 9).

Table 9.

The average and the standard deviation of the temperature increase each time by 2.5 W.

Lasing power	Lasing Time	Average Temperature Increase (°C)
2.5 W	2 Second	49.527273 ± 15 °C
	4 Second	71.79 ± 4.78 °C

The statistical analysis was done, and each group were compared according to the paired student t-test ($p \leq 0.05$, *student t-test*). The comparison of temperature rises in the surface of the tested teeth at each lasing time setting are shown in (Figure 22). There is a significant difference between two interval groups 2 sec and 3 sec according to the paired student t-test. ($p \leq 0.05$, *student t-test*).

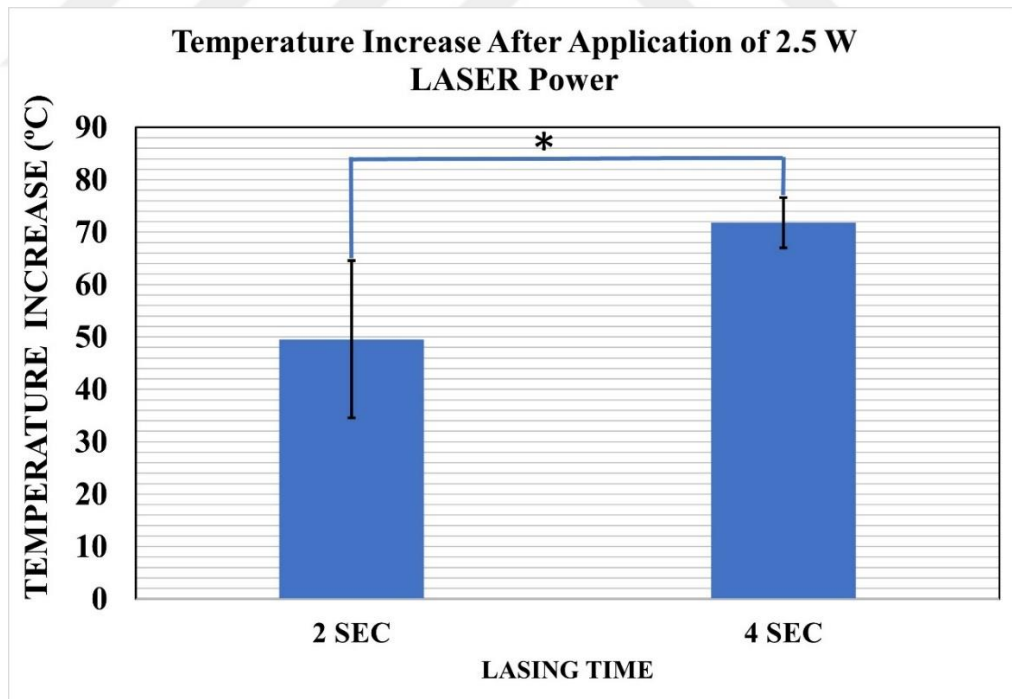


Figure 22. The temperature increases are shown in the graph after the application of 2.5 W of the teeth at lasing in CW mode. There are significant differences between the irradiated groups (*) ($p \leq 0.05$, *student t-test*).

After applying 5.0 W of laser power with varying time values are recorded and the obtained data, the average meaningful and the standard deviation of the temperature increase were recorded. The temperature rises in the surface of the tested teeth at each lasing time setting are shown in (Tables 10).

Table 10.

The average and the standard deviation of the temperature increase each time for the 5.0 W Groups.

Lasing power	Lasing Time	Average Temperature Increase (°C)
5.0 W	1 Second	133.9722 ± 11.2 °C
	2 Second	194.15 ± 30.3 °C
	3 Second	203.43± 37.7 °C

According to the results of the 5.0 W, the average temperature, standard deviation, were calculated and analyzed by paired student *t*-test ($p \leq 0.05$, student *t*-test). 1 second lased group is significantly different from other two groups ($p \leq 0.05$, student *t*-test). Also, there is a significant difference between 2 seconds and 3 seconds lased groups ($p \leq 0.05$, student *t*-test), (Figure 23).

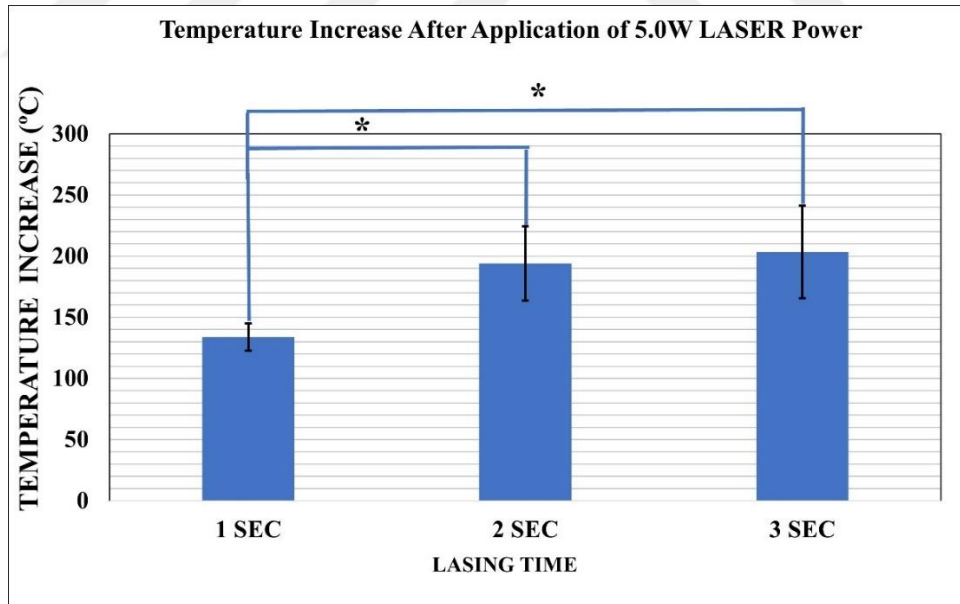


Figure 23. The graph shows the temperature increases after applying 5.0 W Groups with time intervals, 1 sec, 2 sec and 3 sec. There is a significant difference in temperature increases between groups ($p \leq 0.05$, student *t*-test). 1

Second lased group is significantly different from other two experimental groups ($p \leq 0.05$, student *t*-test). Also, there is a significant difference between 2 second and 3 second lased groups ($p \leq 0.05$, student *t*-test) (*)

The optimum laser power and lasing intervals were selected according to the preliminary studies. 3 joules of total laser energy were chosen for the main part of the experimental study because the preliminary studies conducted that it is effective and, also the temperature increase is near the safe range of enamel capacity as shown in (Figure 24). Also, temperature increases for each time interval and lasing power were illustrated on a chart to show the total situation (Figure 25).

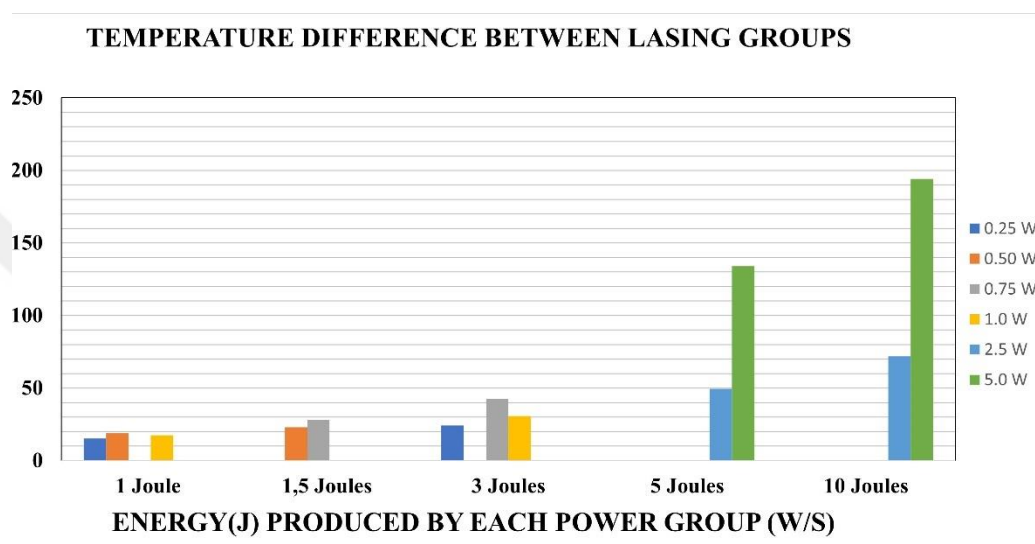


Figure 24. Comparison of varying energy levels according to the temperature increase.

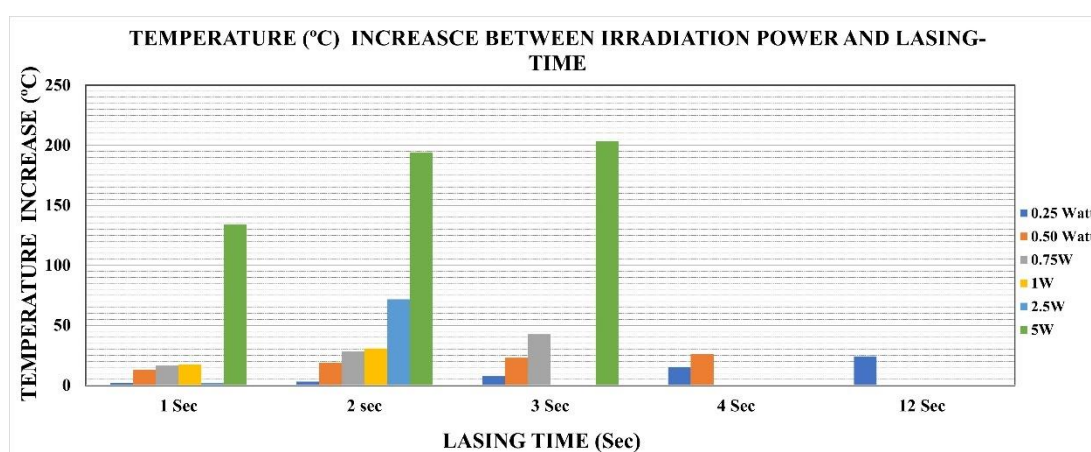


Figure 25. Comparison of varying lasing times according to the temperature increase.

4.2 Irradiation Effect

According to the results of these preliminary thermal studies, 3 joules of total laser energy were chosen for the main part of this experimental study. The sample teeth, the enamel surfaces, were examined under a hirox digital microscope before and after laser irradiation to compare the surface roughness before and after lasing. The samples were divided into three different laser groups (0.25 W, 0.75 W, 1.0 W) with varying lasing time intervals (12 sec, 4 sec and, 3 Sec) respectively.

As explained in material and methods part, “Before-lasing” images and calculations for the same selected slices were done to be compared to after-lasing images. The areas for both pre and post lasing surfaces were graphed, the differences in values were examined. The data collected from the hirox digital microscope, the images were recorded and compared between the samples before and after laser irradiation. As shown in the (Figures 26-34).

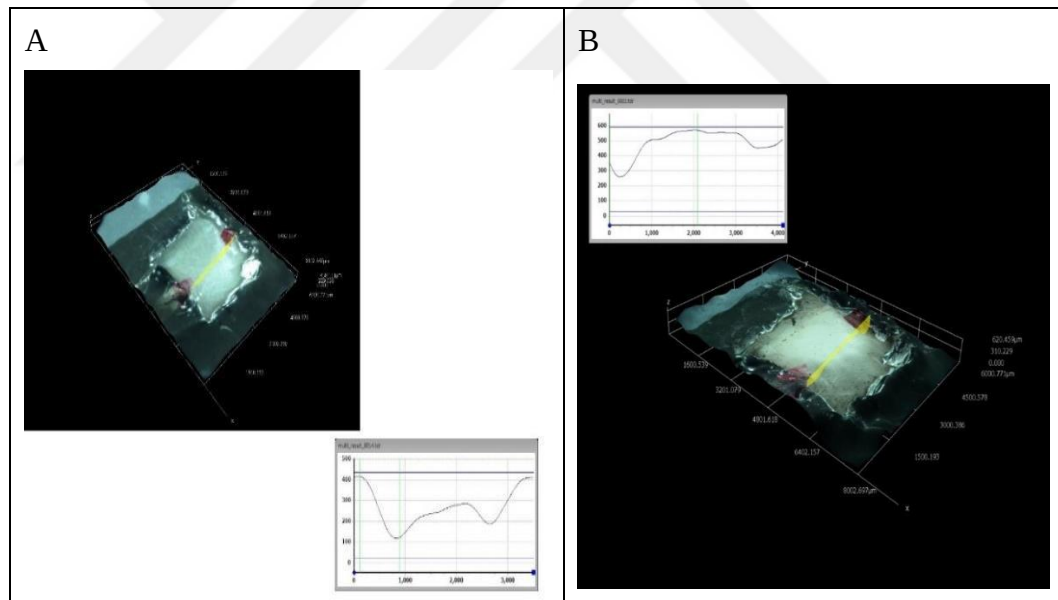


Figure 36. The difference between (A) 0.25_12s_s1_pre and (B) 0.25_12s_s1_aft.

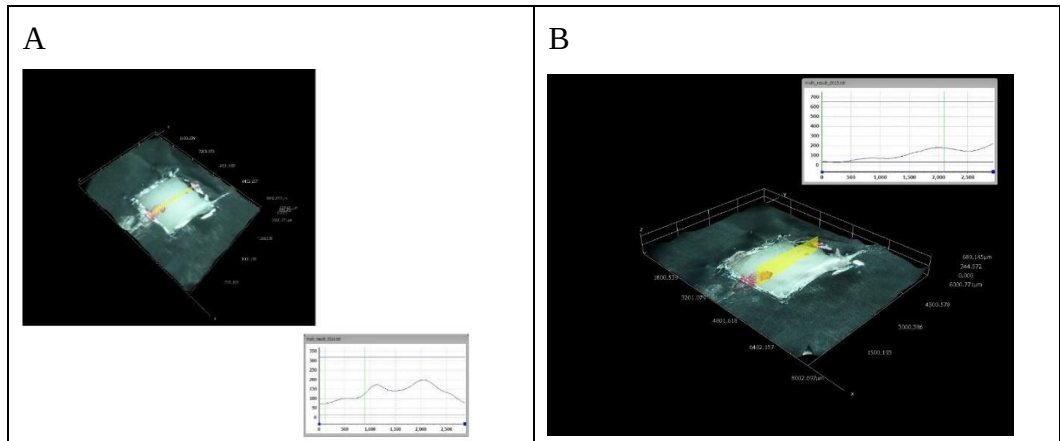


Figure 27. The difference between (A) 0.25_12s_s2_pre and (B) 0.25_12s_s2_aft.

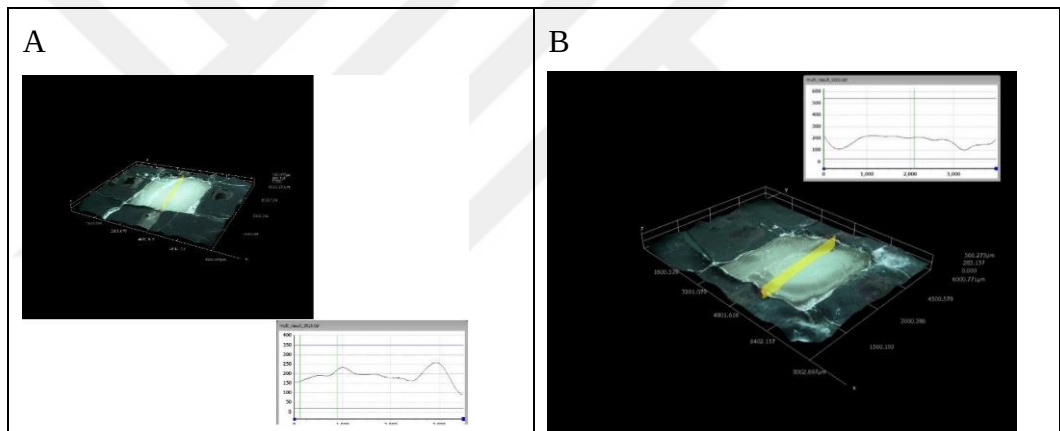


Figure 28. The difference between (A) 0.25_12s_s3_pre and (B) 0.25_12s_s3_aft.

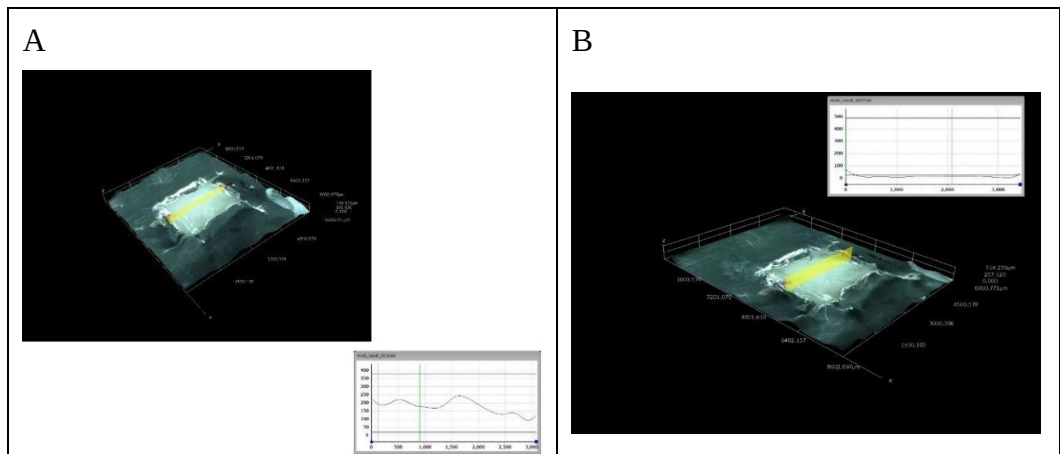


Figure 29. The difference between (A) 0.75_4s_s1_pre and (B) 0.75_4s_s1_aft.

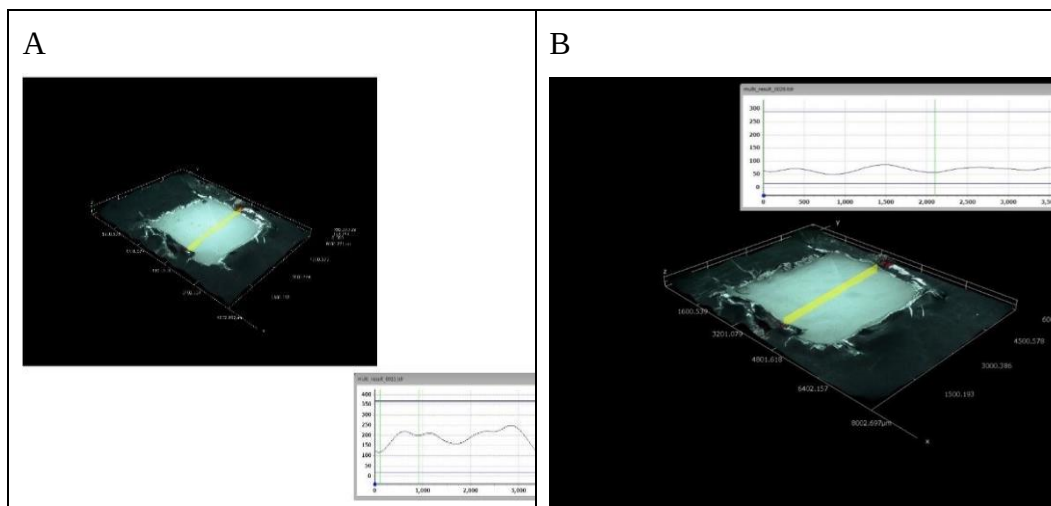


Figure 30. The difference between (A) 0.75_4s_s2_pre and (B) 0.75_4s_s2_after.

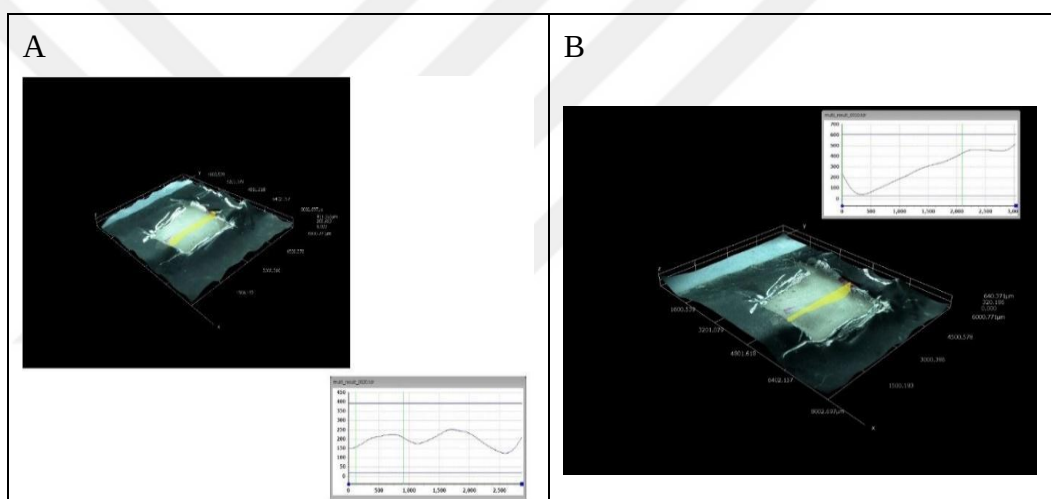


Figure 31. The difference between (A) 0.75_4s_s3_pre and (B) 0.75_4s_s3_after.

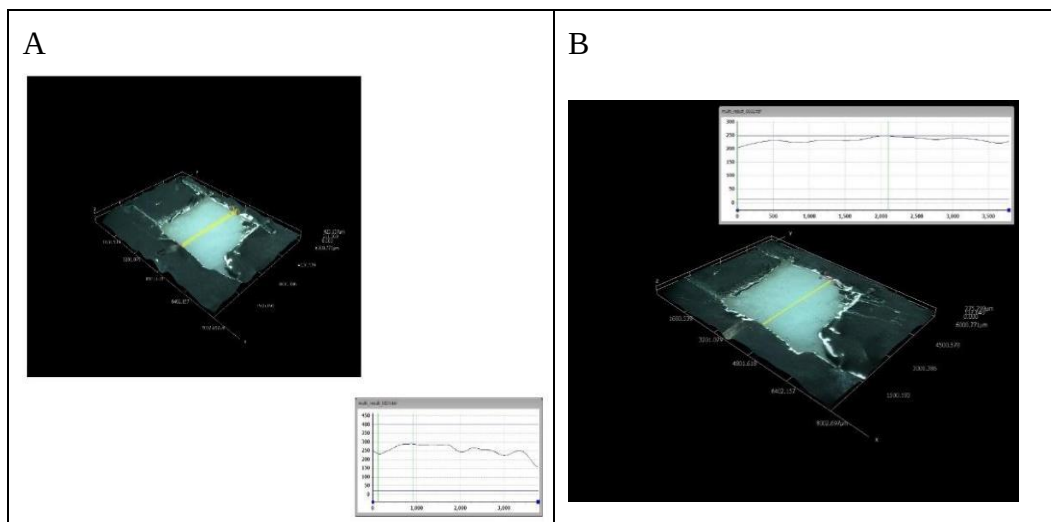


Figure 32. The difference between (A) 1.0_3s_s1_pre and (B) 1.0_3s_s1_after.

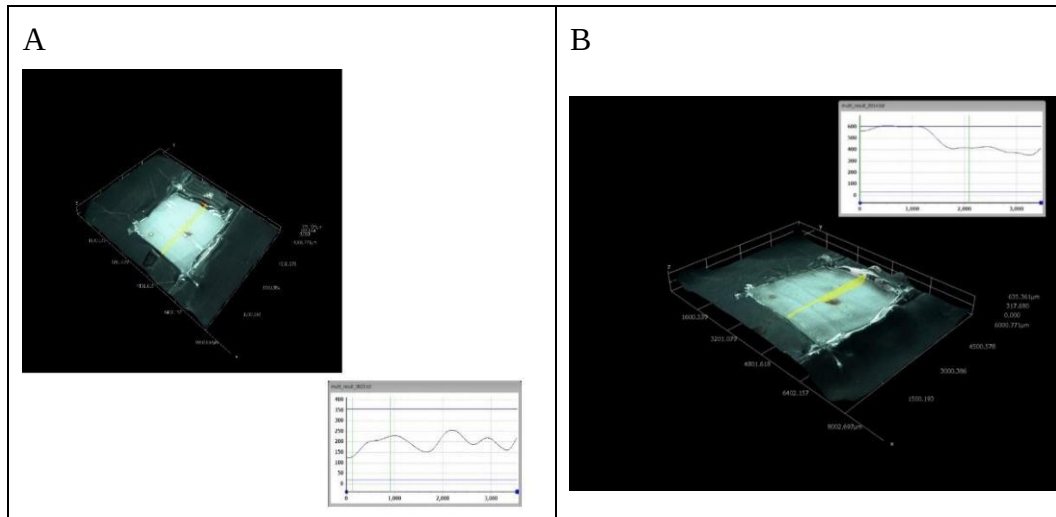


Figure 33. The difference between (A) 1.0_3s_s2_pre and (B) 1.0_3s_s2_after.

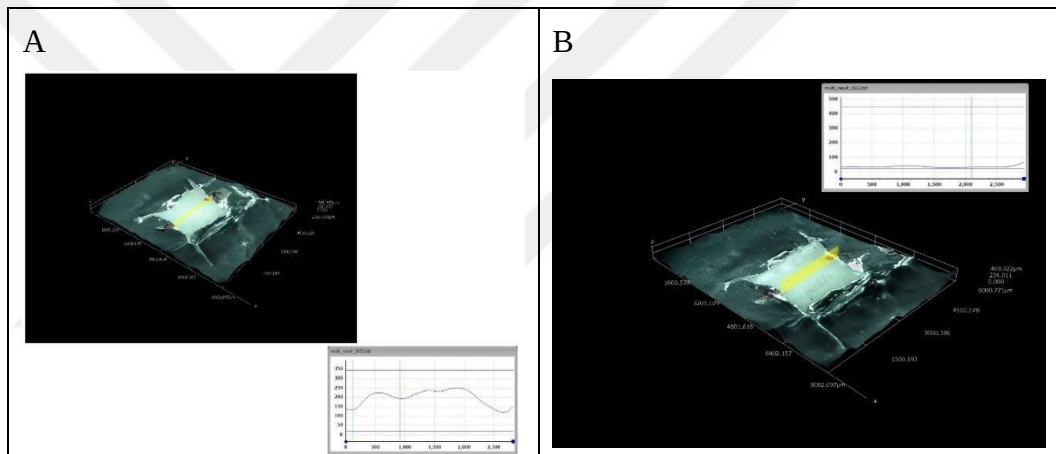


Figure 34. The difference between (A) 1.0_3s_s3_pre and (B) 1.0_3s_s3_after.

The comparison areas under the curves were calculated using MATLAB for all pre-lasing and post-lasing samples as shown in (Table 11). The difference of areas was calculated, and the results were analyzed. Statistical analysis showed that there is no significant difference between the data after and before lasing.

Table 11.

The areas of pre-lasing and post-lasing samples and calculated differences between them.

NO.	PRE SAMPLE NAME	AREA UNDER THE CURVE	AFTER SAMPLE NAME	AREA UNDER THE CURVE	DIFFERENCE
1	025_12s_1s_pre1	1.00E+06	025-12s-s1-aft1	1.01E+06	-4.70E+03
2	025_12s_1s_pre2	1.12E+06	025-12s-s1-aft2	1.12E+06	-2.70E+03
3	025_12s_1s_pre3	8.09E+05	025-12s-s1-aft3	1.15E+06	-3.36E+05
4	025_12s_s2_pre1	3.75E+05	025-12s-s2-aft1	8.15E+05	-4.40E+05
5	025_12s_s2_pre2	4.90E+05	025-12s-s2-aft2	8.16E+05	-3.26E+05
6	025_12s_s2_pre3	6.25E+05	025-12s-s2-aft3	8.11E+05	-1.86E+05
7	025_12s_s3_pre1	6.67E+05	025-12s-s3-aft1	9.08E+05	-2.41E+05
8	025_12s_s3_pre2	7.56E+05	025-12s-s3-aft2	8.97E+05	-1.41E+05
9	025_12s_s3_pre3	7.66E+05	025-12s-s3-aft3	9.45E+05	-1.79E+05
10	075_4s_1s_pre1	5.48E+05	075-4s-s1-aft1	9.01E+05	-3.54E+05
11	075_4s_s1_pre2	6.10E+05	075-4s-s1-aft2	9.55E+05	-3.45E+05
12	075_4s_1s_pre3	6.28E+05	075-4s-s1-aft3	8.16E+05	-1.88E+05
13	075_4s_s2_pre1	7.44E+05	075-4s-s2-aft1	3.37E+05	4.08E+05
14	075_4s_s2_pre2	8.17E+05	075-4s-s2-aft2	1.33E+06	-5.12E+05
15	075_4s_s2_pre3	1.19E+06	075-4s-s2-aft3	2.95E+05	8.93E+05
16	075_4s-s3_pre1	5.52E+05	075-4s-s3-aft1	1.12E+05	4.40E+05
17	075_4s_s3_pre2	5.62E+05	075-4s-s3-aft2	2.60E+05	3.02E+05
18	075_4s_s3_pre3	5.67E+05	075-4s-s3-aft3	2.66E+05	3.01E+05
19	1_3s_s1_pre1	3.45E+05	1-3s-s1-aft1	9.45E+05	-6.00E+05
20	1_3s_s1_pre2	9.39E+05	1-3s-s1-aft2	9.02E+05	3.78E+04
21	1_3s_s1_pre3	9.84E+05	1-3s-s1-aft3	8.77E+05	1.07E+05
22	1_3s_s2_pre1	7.92E+05	1-3s-s2-aft1	1.28E+06	-4.84E+05
23	1_3s_s2_pre2	7.98E+05	1-3s-s2-aft2	1.10E+06	-3.04E+05
24	1_3s_s2_pre3	7.26E+05	1-3s-s2-aft3	1.28E+06	-5.54E+05
25	1_3s_s3_pre1	5.58E+05	1-3s-s3-aft1	4.61E+05	9.68E+04
26	1_3s_s3_pre2	4.76E+05	1-3s-s3-aft2	1.80E+05	2.96E+05
27	1_3s_s3_pre3	5.07E+05	1-3s-s3-aft3	4.84E+05	2.31E+04

MATLAB also draws the graphs from the points calculated from the FP graph reader as shown in the (Figures 16-17).

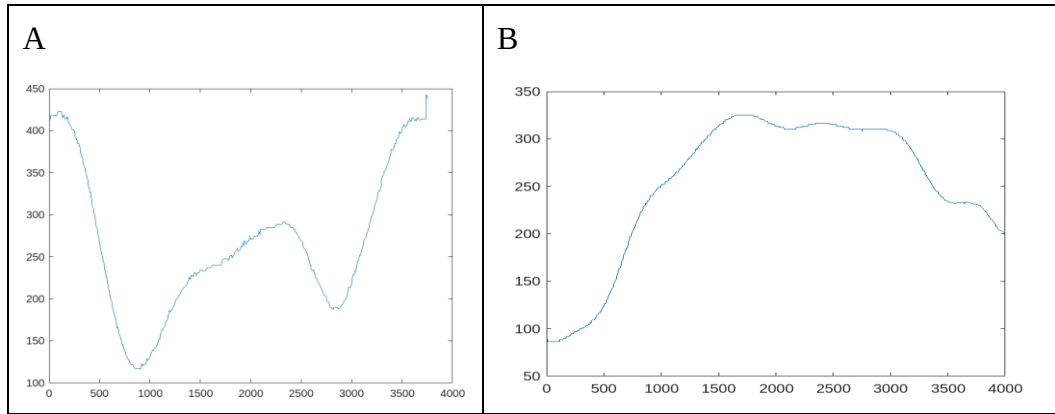


Figure 35. Curves drawn by MATLAB for (A) 0.25_12s_s1_pre and (B) 0.25_12s_s1_aft.

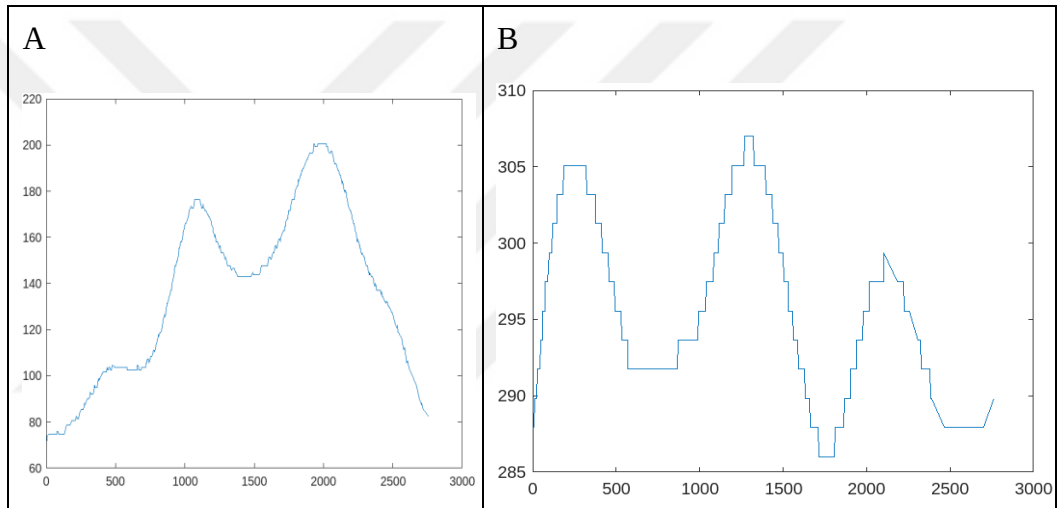


Figure 36. Curves drawn by MATLAB for (A) 0.25_12s_s2_pre and (B) 0.25_12s_s2_aft.

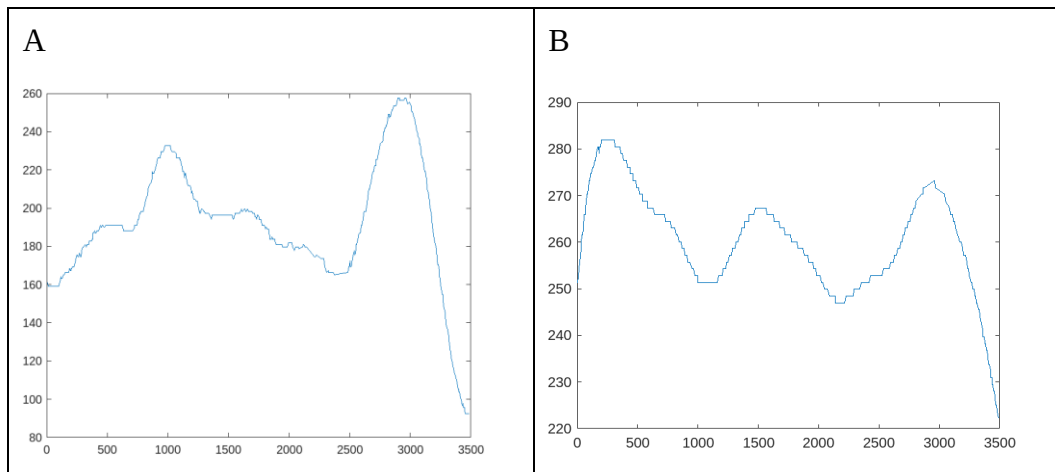


Figure 37. Curves drawn by MATLAB for (A) 0.25_12s_s3_pre and (B) 0.25_12s_s3_aft.

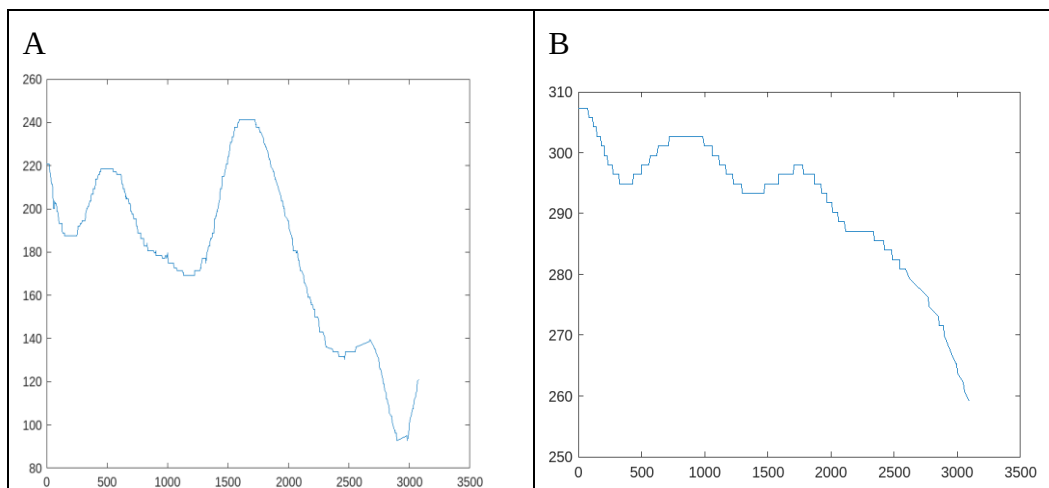


Figure 38. Curves drawn by MATLAB for (A) 0.75_12s_s1_pre and (A) 0.75_12s_s1_aft.

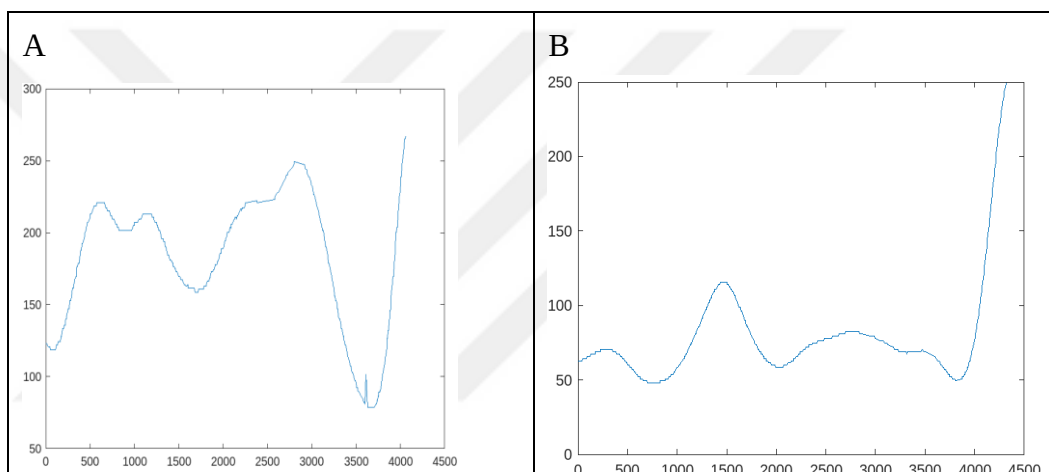


Figure 39. Curves drawn by MATLAB for (A) 0.75_12s_s2_pre and (B) 0.75_12s_s2_aft.

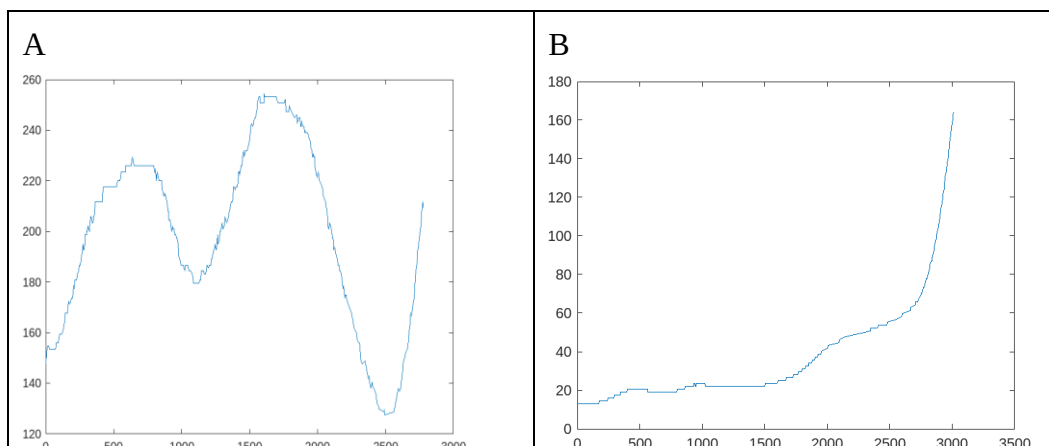


Figure 40. Curves drawn by MATLAB for (A) 0.75_12s_s3_pre and (B) 0.75_12s_s3_aft.

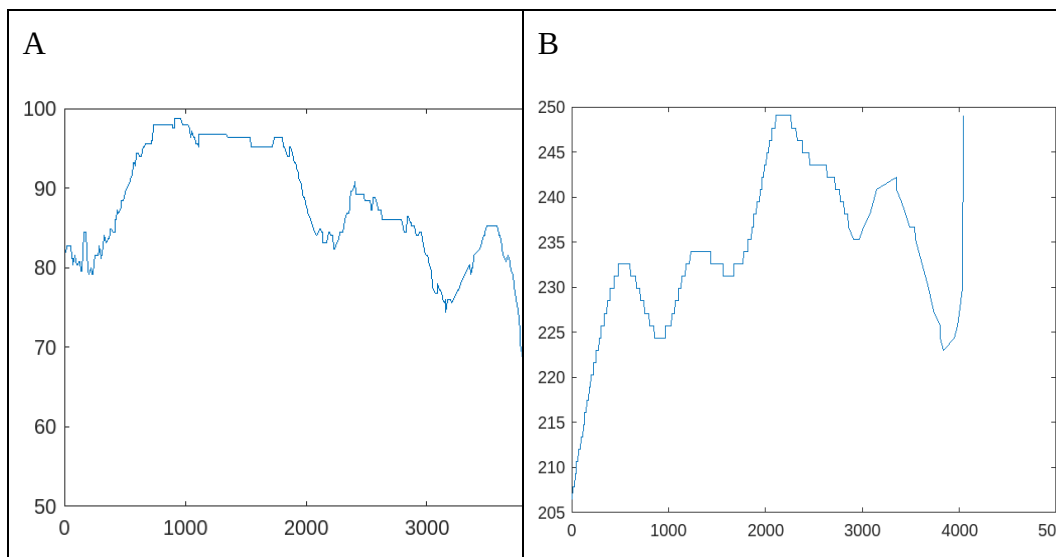


Figure 41. Curves drawn by MATLAB for(A) 1_3s_s1_pre and (B)1-3s-s1-aft.

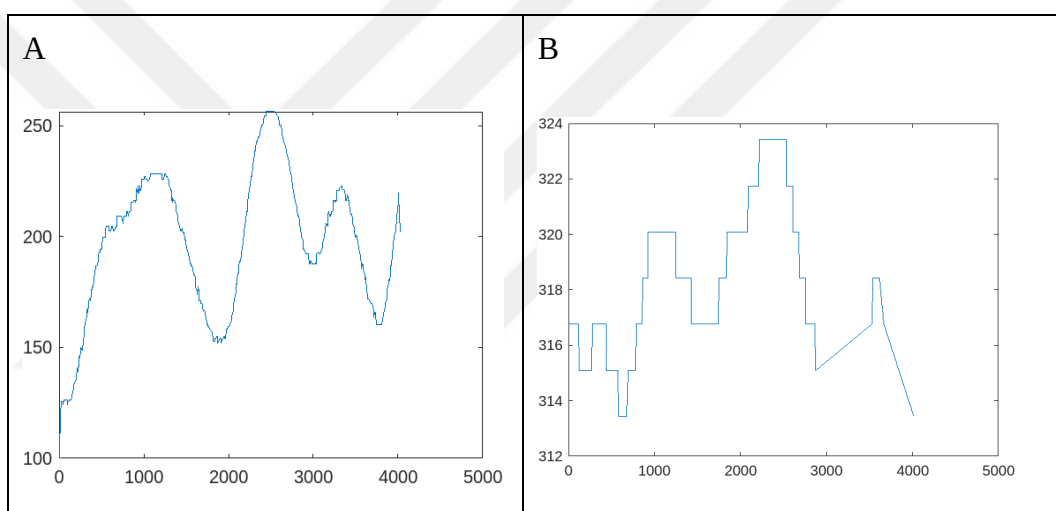


Figure 42. Curves drawn by MATLAB for (A)1_3s_s2_pre and (B)1-3s-s2-aft.

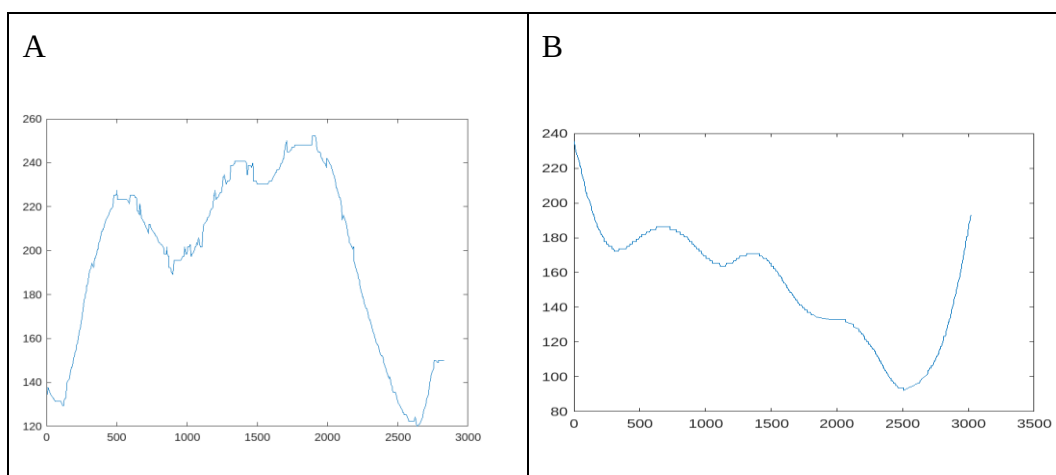


Figure 43. Curves drawn by MATLAB for (A) 1_3s_s3_pre and (B) 1-3s-s3-aft.

The points selected using FPGraph tracer were defined to calculate the curve of each sample before and after laser irradiation in MATLAB. Additionally, using these points, the approximated graphs were drawn in MATLAB for each sample before and after lasing as shown in (Figure 35-43) in order to verify the correctness of the graph approximations.

The averages and standard deviations of the sample areas of pre-lasing & post-lasing application for each group of laser energy are shown on the Table 12. After statistical analysis, it is observed that there is no significant difference between the post-lasing & pre-lasing sample areas for all irradiation groups ($p \leq 0.05$, *student t-test*) as shown in Figure 44.

Table 12.

The average and standard deviations for the both pre-lasing and post-lasing stages of the same sample areas were calculated.

Average	BEFORE	AFTER
0.25 Watt 12 Seconds	734518.8889 $\pm$ 240603	940838.8889 $\pm$ 140748
0.75 Watt 4 Seconds	690774.4444 $\pm$ 196133	585704.4444 $\pm$ 344091
1 Watt 3 Seconds	680773.3333 $\pm$ 144850	834227.7778 $\pm$ 427068

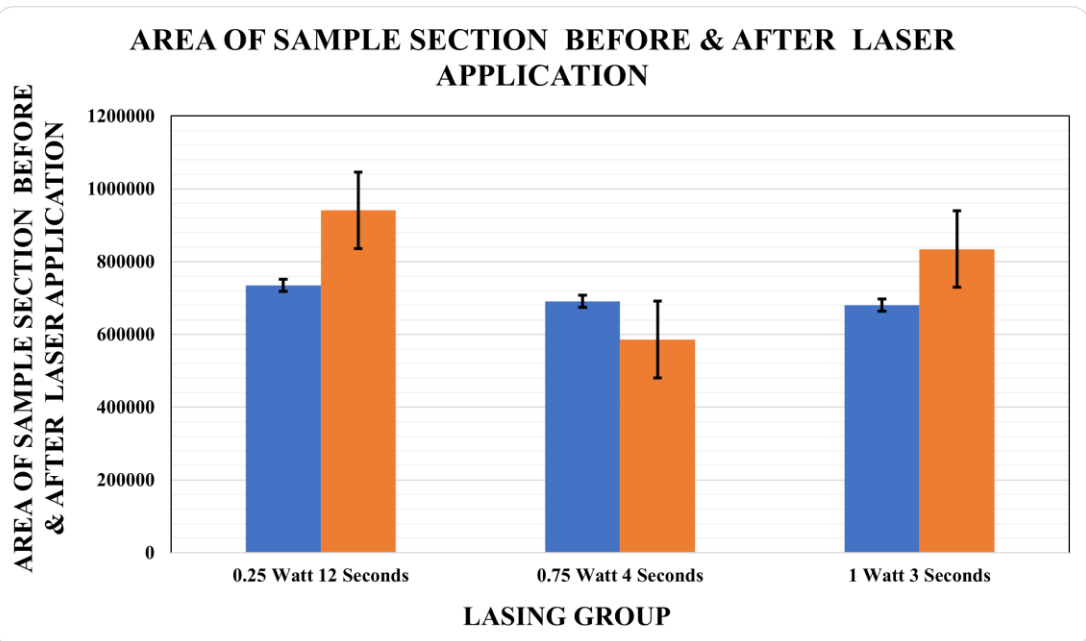


Figure 44. This graph illustrates the comparison of the areas of sample section before and after laser application. Statistical analyses show that there is no significant difference between the post-lasing & pre-lasing area samples section of all the powers ($p \leq 0.05$, student *t*-test)

After analyzing all data for pre-lasing and post-lasing stages for each sample, one by one, it is examined to see that there is no significant difference between the post-lasing & pre-lasing area samples section for all laser groups ($p \leq 0.05$, student *t*-test).

Chapter 5

Discussion & Conclusion

5.1 Discussion

Dentistry is a branch of medicine that involves preventing, detecting, and oral disease treatment, including fixing abnormalities of the jaws, teeth, and oral cavity. In oral health, there is a growing need for reconstruction components that are becoming more like real teeth in terms of both their visual qualities and biomechanical and chemical properties. The roughness of the enamel is an important parameter for tooth-health in the long term. Smooth surfaces give teeth a glossy, lustrous appearance and prevent bacteria adhesion and biofilm formation (Daniel and Harfst., 2004). Polishing techniques comes from the variation of terms:

1. Therapeutic polishing refers to polishing of the exposed root to disinfect it during surgery,
2. Cosmetic or coronal polishing refers to removing the plaque and stains,
3. The tooth crown polishing is a term of polishing which tagged by the name superficial polishing,
4. Selective polishing is when the dentist uses polishing for hygienic reasons after some procedures or for removing stains that could affect the health of tooth. (Felton *et al.*, 2011)

In many medical fields, lasers were first used in the late 1960s. Due to a lack of research discussing the process of polishing with lasers, which uses specific lasers like (neodymium: YAG (Nd: YAG), Erbium: YAG), a new laser wavelength in this era, 1940-nm Thulium Fiber Laser (TLR-5-1940; IPG Laser GmbH, Germany), was tested to find the most effective parameter when dealing with enamel of the tooth.

Lasers have some advantages like eliminating stitches needed that may reduce the amount of tissue damage. Moreover, no anesthetic is needed during the procedure. Furthermore, the tissue renews, and wound healing happens faster. Finally, the procedure reduces the risk of bacterial infection.

Also, some disadvantages may be observed during the procedure, the temperature increase is the most important disadvantage of lasers. Temperature increase on the enamel surface during lasing may cause cracks on the enamel surface. thus, transferred heat can cause irreversible damage to the pulp. Several studies mentioned the damage caused by a temperature increase after heating to 275°C, also an increase of 11°C can cause irreversible damage to the pulp. (Zach, and Cohen., 1965) As Zach and Cohen, many other researchers mentioned pulp temperature and the threshold value of the pulp of the tooth which is about 5.5°C (De Alencar Mollo *et al.*, 2011).

The purpose of the preliminary experiments in this study was to find the optimum parameters using the threshold point set where the pulp can safely survive without getting any damage. In the first part of our experiment, varying lasing times and different power values were applied to the enamel of the samples in order to find the optimal working ranges.

The new wavelength was applied to the teeth with 0.25 W with 5 different lasing times. The results showed that the temperature increase between 2 second and 3 second groups were significantly different ($p \leq 0.05$, *student t-test*). The samples which were lased by 0.50 W were irradiated for 1, 2, 3 and 4 seconds. The 0.50 W irradiated groups showed that the temperature increase was significantly different for each of the lasing times. 0.75 W of laser power was applied to the sample teeth for 1, 2 and 4 seconds. The lased groups showed a significant difference in temperature measurements within all the lasing times applied. Like 0.75 W irradiated group, applying 1.0 W for 1 and 3 seconds, showed no significant difference in temperature measurements of all lasing times applied to the teeth. For 2.5 W, the results showed a significant difference between the two lasing times, for 2 and 4 seconds were significantly different from each other. Finally, for 5.0 W lased groups, three lasing times, 1, 2 and 3 seconds were applied and the temperature differences for group (1 second) of lasing-time was significantly different from 2 sec and 3 seconds of lasing time. These results showed that increasing power had an significant effect on each time value, but this difference was more noticeable between 0.25 and 5 watts. The guide studies done before the preliminary experiments showed when values are below 0.25 and higher than 5.0-watt irradiation, the effect of lasing power was less and the difference between the groups were less appreciable.

A diode laser measurement with irradiation power (1-2 W) assumed that the increase in the pulp chamber temperature is below 5.5°C which is the critical temperature before the irreversible damage in the pulp, at the same time this study mentioned that the increase in the surface of the teeth when irradiated with (1 W) was 37 °C (M Sulieman *et al.*, 2006).

In this study each applied power and lasing time for the definition of energy produced by the laser. It is mentioned that the temperature measurements that 3 joules produced by the power ranges (0.25 W, 0.75 W, 1.0 W) and lasing time ranges (12 sec, 4 sec, 3 sec) respectively is a significant difference in temperature production, the temperature produced can be described as it is near the safe range of enamel capacity which described as an increase with 5.5°C on the pulp of the tooth which considered higher and more effective in comparison with (1 J, and 1.5 J), and significantly lower than (5 J, 10 J, and 15 J). Additionally, the differentiation of this energy may generate a better understanding about this wavelength and the parameters to work on in this study. according to (M Sulieman *et al.* 2006) the temperature measurement done in this study the best parameters are 3 joules of lasing energy which has a different temperature increase between lasing powers of this group which is between (24 °C and 42 °C).

In literature, the studies about some IR lasers, such as the Nd: YAG or CO₂ laser, showed comparable effects of carbonization and melting, as well as detrimental heat harmful to the pulp. Additionally, Carbonization can be observed by brown or dark colors on the enamel or dentin (Hossain *et al.*, 1999). Furthermore, other studies mentioned that dentin showed an irregular structure with numerous micro holes and cavities that resembled molten magma, although the use of water mist counterworked to carbonization when the enamel surface was lased, the surface examinations in this study showed no carbonization for each irradiated sample (Hossain *et al.*, 1999). In our study, applying laser powers from 0.25 Watts to 5.0 Watts showed no carbonization effect under microscope.

Human dental enamel has an amount of roughness, which is present even on the most carefully finished surface of any material on a microscopic level. A study in literature calculated under the profilometer in earlier studies using the CO₂ and Nd: YAG lasers, the roughness values was also, determined by the color 3D microscopy and they were high and deferent from the results calculate by

profilometer. It was unclear why the roughness numbers vary in this way. However, a number of factors might be taken into mind. First, it's possible that readings were impacted by variations in the laser instruments and energy densities used. Second, variations in the assessment method might account for the disparity, as mentioned in Hossain's study that the surface roughness is higher than previous studies which was calculated by using profilometer (Hossain *et al.*, 2001). Parallel to this study, it was mentioned that the surface temperature rose during irradiation, there was no indication of denaturing or disturbance of the enamel structure (Cecchini *et al.*, 2005). Additionally, in their morphological analysis, they demonstrated that the various energies used resulted in visible enamel prisms, a rough surface, and various divot diameters.

In the main experiment, the parameters defined by the preliminary experiment have been used to measure the surface depth of the enamel surface by using a hirox 3D microscope which describes the effect of the energy chosen. From 3D microscope pictures and the redrawn graphs shown that all the before lasing groups gained changes in there shapes as shown in (Figures 26-43).

The average and standard deviation calculated by MATLAB shows an increase in the area under the curve of enamel surface sample groups for the powers (0.25 W, 1.0 W), nonetheless, the power (0.75 W) sample group showed a decrease in the area under the curve of the enamel surface as mentioned in (Table 12).

For the record, 0.75 Watt of lasing power with 4 second of laser irradiation parameters, it was different from (0.25Watt and 1.0 Watt) parameters, in those parameters the surface area measurement showed an increase with the area under the curve whereas 0.75 Watt showed that the roughness of enamel surface decreased.

5.2 Conclusion

In conclusion, this study finds out the parameters of temperature produced from the tested powers and lasing-times in the preliminary experiment. In the main experiment, 3 joules energy was irradiating the enamel surface of the teeth sample which finds out an increase and decrease in the surface area of enamel teeth samples. But the difference between the area under the curve of before-lasing and after-lasing enamel surface area wasn't significantly different.

On the record, 0.75 Watt is the best among the parameters calculated in this study which resulted in a decrease in the surface area while other parameters showed an increase in enamel surface roughness.

In this study, applying laser powers from 0.25 Watts to 5.0 Watts showed no carbonization effect or observable cracks under microscope. In our further studies, the effect of air spray during application of selected parameters will be examined under SEM examinations.



References

- Alencar Mollo, Márcio de, Lucio Frigo, Giovani Marino Favero, Rodrigo Álvaro Brandão Lopes-Martins, and Aldo Brugnera Junior. 2011. "In Vitro Analysis of Human Tooth Pulp Chamber Temperature after Low-Intensity Laser Therapy at Different Power Outputs." *Lasers in Medical Science* 26 (2): 143–47.
- Anić, I, D Vidović, M Luić, and M Tudja. 1992. "Laser Induced Molar Tooth Pulp Chamber Temperature Changes." *Caries Research* 26 (3): 165–69.
- Boyde, A. 1984. "Airpolishing Effects on Enamel, Dentine, Cement and Bone." *British Dental Journal* 156 (8): 287–91.
- Braun, Andreas, Felix Krause, Matthias Frentzen, and Søren Jepsen. 2005. "Removal of Root Substance with the VectorTM-system Compared with Conventional Debridement in Vitro." *Journal of Clinical Periodontology* 32 (2): 153–57.
- Cecchini, Renata Cristina M., Denise Maria Zezell, Elisabeth De Oliveira, Patricia M. De Freitas, and Carlos De P. Eduardo. 2005. "Effect of Er:YAG Laser on Enamel Acid Resistance: Morphological and Atomic Spectrometry Analysis." *Lasers in Surgery and Medicine* 37 (5): 366–72. <https://doi.org/10.1002/lsm.20247>.
- Christensen, R P, and V W Bangerter. 1984. "Clinical Science Determination of Rpm, Time, and Load Used in Oral Prophylaxis Polishing in Vivo." *Journal of Dental Research* 63 (12): 1376–82.
- Coluzzi, Donald J. 2002. "Lasers and Soft Tissue Curettage: An Update." *Compendium of Continuing Education in Dentistry (Jamesburg, NJ: 1995)* 23 (11A): 1104–11.
- Daniel, Susan J, and Sherry A Harfst. 2004. *Mosby's Dental Hygiene: Concepts, Cases, and Competencies*. Vol. 1. Mosby Incorporated.
- Darling, Cynthia L, and Daniel Fried. 2008. "Real-Time near IR (1310 Nm) Imaging of CO₂ Laser Ablation of Enamel." *Optics Express* 16 (4): 2685–93.
- David, Chaya M, and Pankaj Gupta. 2015. "Lasers in Dentistry: A Review." *Int J Adv Health Sci* 2 (8): 7–13.
- Felton, David, Lyndon Cooper, Ibrahim Duqum, Glenn Minsley, Albert Guckes, Steven Haug, Patricia Meredith, Caryn Solie, David Avery, and Nancy Deal Chandler. 2011. "Evidence-based Guidelines for the Care and Maintenance of Complete Dentures: A Publication of the American College of Prosthodontists." *Journal of Prosthodontics: Implant, Esthetic and Reconstructive Dentistry* 20: S1–12.

- Fraunhofer, J A Von, and D J Allen. 1993. "Thermal Effects Associated with the Nd/YAG Dental Laser." *The Angle Orthodontist* 63 (4): 299–304.
- Frentzen, M, and H J Koort. 1990. "Lasers in Dentistry: New Possibilities with Advancing Laser Technology?" *International Dental Journal* 40 (6): 323–32.
- Galloway, S E, and David Henry Pashley. 1987. "Rate of Removal of Root Structure by the Use of the Prophy-Jet Device." *Journal of Periodontology* 58 (7): 464–69.
- Garcia-Godoy, F. 1988. "An SEM Study of the Effects of Air-Polishing on Fissure Surfaces." *Quintessence Int* 19: 465–67.
- Harashima, Tomomi, Jun-Ichiro Kinoshita, Yuichi Kimura, Aldo Brugnera Jr, Fatima Zanin, Jose D Pecora, and Koukichi Matsumoto. 2005. "Morphological Comparative Study on Ablation of Dental Hard Tissues at Cavity Preparation by Er: YAG and Er, Cr: YSGG Lasers." *Photomedicine and Laser Therapy* 23 (1): 52–55.
- Hedge, M N, Payal Garg, and N D Hedge. 2018. "Lasers in Dentistry: An Unceasing Evolution." *J Otolaryngol Ent Res* 10 (6): 422–48.
- Hegde, Mithra N, Nidarsh D Hegde, and S C Nagesh. 2011. "Lasers in Management of Endo-Perio Lesion-A Case Report." *Archives of Oral Sciences & Research* 1 (4): 215–18.
- Hodges, Kathleen O. 1998. *Concepts in Nonsurgical Periodontal Therapy*. Cengage Learning.
- Hossain, Mozammal, Yukio Nakamura, Yoshishige Yamada, Yuichi Kimura, Naoto Matsumoto, and Koukichi Matsumoto. 1999. "Effects of Er, Cr: YSGG Laser Irradiation in Human Enamel and Dentin: Ablation and Morphological Studies." *Journal of Clinical Laser Medicine & Surgery* 17 (4): 155–59. <https://doi.org/doi.org/10.1089/clm.1999.17.155>.
- Hossain, M., Y. Nakamura, Y. Yamada, N. Suzuki, Y. Murakami, and K. Matsumoto. 2001. "Analysis of Surface Roughness of Enamel and Dentin after Er,Cr:YSGG Laser Irradiation." *Journal of Clinical Laser Medicine and Surgery* 19 (6): 297–303. <https://doi.org/10.1089/104454701753342749>.
- Jelínková, H, J Šulc, T Dostálová, P Koranda, M Němec, and P Hofmanova. 2008. "Bracket Debonding by Mid-Infrared Laser Radiation." *Laser Physics Letters* 6 (3): 222.
- Khouja, Firas, Marwa Abdelaziz, Tissiana Bortolotto Ibarra, and Ivo Krejci. 2017. "Intra-Pulpal and Subsurface Temperature Rise during Tooth Irradiation with 808

- Nm Diode Laser: An in Vitro Study.” *European Journal of Paediatric Dentistry* 18 (1): 56–60.
- Martínez-Insua, Arturo, Luis Da Silva Dominguez, Francisco Guitián Rivera, and Urbano A. Santana-Penín. 2000. “Differences in Bonding to Acid-Etched or Er:YAG-Laser-Treated Enamel and Dentin Surfaces.” *Journal of Prosthetic Dentistry* 84 (3): 280–88. <https://doi.org/10.1067/mpr.2000.108600>.
- Moritz, A, N Gutknecht, O Doertbudak, K Goharkhay, U Schoop, P Schauer, and W Sperr. 1997. “Bacterial Reduction in Periodontal Pockets through Irradiation with a Diode Laser: A Pilot Study.” *Journal of Clinical Laser Medicine & Surgery* 15 (1): 33–37.
- Morsi, Asmaa, Darya Haidary, René Franzen, and Norbert Gutknecht. 2020. “Intra-Pulpal Temperature Evaluation during Diode Laser (445 Nm) Irradiation for Treatment of Dentine Hypersensitivity: In Vitro a Pilot Study.” *Lasers in Dental Science* 4 (3): 139–44.
- Nambiar, K R. 2006. *Lasers: Principles, Types and Applications*. New Age International.
- Oliveira, Cleide Regina Alves Carrara de, Fátima Zanin, Alessandra Cassoni, José Augusto Rodrigues, Landulfo Silveira Jr, Marcos Tadeu Pacheco, and Aldo Brugnera. 2017. “Analysis of Human Tooth Pulp Chamber Temperature after 670 Nm Laser Irradiation: In Vitro Study.” *Photomedicine and Laser Surgery* 35 (10): 515–19.
- Pandey, Divya, Pooja Chaturvedi, and Vinayak Shuklai. 2016. “Recent Diagnostic Aids in Endodontics.” *International Journal of Pharmaceutical and Clinical Research* 8(8): 1159-1162
- Petersilka, Gregor, Clovis Mariano Faggion Jr, Udo Stratmann, Joachim Gerss, Benjamin Ehmke, Ingo Haeberlein, and Thomas F Flemmig. 2008. “Effect of Glycine Powder Air-polishing on the Gingiva.” *Journal of Clinical Periodontology* 35 (4): 324–32.
- Petersilka, Gregor J, M Bell, Ingo Häberlein, A Mehl, Reinhard Hickel, and Thomas Frank Flemmig. 2003. “In Vitro Evaluation of Novel Low Abrasive Air Polishing Powders.” *Journal of Clinical Periodontology* 30 (1): 9–13.
- Putt, M S, C J Kleber, and J C Muhler. 1982. “Enamel Polish and Abrasion by Prophylaxis Pastes.” *Dental Hygiene* 56 (9): 38–40.

- Badwal R, Deborah A, and S M Hashim Nainar. 2002. "Assessment of Evidence-Based Dental Prophylaxis Education in Postdoctoral Pediatric Dentistry Programs." *Journal of Dental Education* 66 (9): 1044–48.
- Rethman, J. 2009. "Polishing Angles, Cups and Pastes. Pract Hyg 1997; 1: 32-3. Retraction in: Madan C, Bains R, Bains VK. Tooth Polishing: Relevance in Present Day Periodontal Practice." *J Indian Soc Periodontol* 13: 58–59.
- Ring, Malvin E. 1967. "History of Dental Prophylaxis." *The Journal of the American Dental Association* 75 (4): 892–95.
- Sarp, Ayşe S Kabaş, and Murat Gülsoy. 2011. "Etching of Enamel for Direct Bonding with a Thulium Fiber Laser." In *Lasers in Dentistry XVII*, 7884:127–32. SPIE.
- Sawai, Madhuri Alankar, Ashu Bhardwaj, Zeba Jafri, Nishat Sultan, and Anika Daing. 2015. "Tooth Polishing: The Current Status." *Journal of Indian Society of Periodontology* 19 (4): 375.
- Spain, B De, and R Nobis. 1988. "Comparison of Rubber Cup Polishing and Air Polishing on Stain, Plaque, Calculus, and Gingiva." *Dent Hyg* 62 (55): 55.
- Srimaneepong, V, J E A Palamara, and P R Wilson. 2002. "Pulpal Space Pressure and Temperature Changes from Nd: YAG Laser Irradiation of Dentin." *Journal of Dentistry* 30 (7–8): 291–96.
- Verma, Sanjeev Kumar, Sandhya Maheshwari, Raj Kumar Singh, and Prabhat Kumar Chaudhari. 2012. "Laser in Dentistry: An Innovative Tool in Modern Dental Practice." *National Journal of Maxillofacial Surgery* 3 (2): 124.
- Walsh, L J. 2003. "The Current Status of Laser Applications in Dentistry." *Australian Dental Journal* 48 (3): 146–55.
- Wigdor, Harvey A, Joseph T Walsh Jr, John D B Featherstone, Steven R Visuri, Daniel Fried, and Joseph L Waldvogel. 1995. "Lasers in Dentistry." *Lasers in Surgery and Medicine* 16 (2): 103–33.
- Wilkins, Esther M, and Wilkins. 1976. *Clinical Practice of the Dental Hygienist*. Lea & Febiger Philadelphia.
- Zach, Leo. 1965. "Pulp Response to Externally Applied Heat." *Oral Surg Oral Med Oral Pathol* 19: 515–30.
- (https://www.tuxedodental.ca/dental_library/the-anatomy-and-structure-of-a-tooth/ , 2018)

- Al-Sanabani J, Madfa A, Al-Sanabani F, Application of Calcium Phosphate Materials in Dentistry, 2013, International Journal of biomaterials, Doi - 10.1155/2013/876132
- Lasers in medicine - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Wavelengths-of-common-medical-lasers-courtesy-of-Dr-Albert-Poet-Shore-Laser-Center_fig1_231009441 [accessed 21 Dec 2022]
- Jim Stewart, <https://www.eeweb.com/wtf-wireless-technology-fundamentals-wave-mechanics-ii/>, Wednesday, August 8, 201
- Nguyen, Van Phuc, Paulus, Yannis, Photoacoustic Ophthalmoscopy: Principle, Application, and Future Directions, 2018, Journal of Imaging, doi - 10.3390/jimaging4120149
- Rodrigo S. Lacruz, Stefan Habelitz, J. Timothy Wright, Michael L. Paine, ‘‘dental enamel formation and implications for oral health and disease’’, 2017, the American Physiological Society, doi: [10.1152/physrev.00030.2016](https://doi.org/10.1152/physrev.00030.2016).
- M. Sulieman, J. S. Rees, M. Addy Surface and pulp chamber temperature rises during tooth bleaching using a diode laser: a study in vitro, 2006, British Dental Journal, DOI: 10.1038/sj.bdj.4813644.