D. HANNOUF

BAU 2024

T.C.
BAHCESEHIR UNIVERSITY
GRADUATE SCHOOL
THE DEPARTMENT OF BIOMEDICAL SCIENCE

COMPARING DIFFERENT LASER PATTERNS IN ETCHING ENAMEL FOR CERAMIC BRACKET BONDING

MASTER'S THESIS

DANA HANNOUF

ISTANBUL 2024

T.C.
BAHCESEHIR UNIVERSITY
GRADUATE SCHOOL
THE DEPARTMENT OF BIOMEDICAL SCIENCE

COMPARING DIFFERENT LASER PATTERNS IN ETCHING ENAMEL FOR CERAMIC BRACKET BONDING

MASTER'S THESIS

THESIS ADVISOR
Prof. Dr. AYŞE SENA SARP

ISTANBUL 2024

T.C.

BAHÇEŞEHİR UNIVERSITY

GRADUATE SCHOOL

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

MASTER THESIS APPROVAL FORM

Program Name:	Bioengineering
Student's Name and Surname:	Dana Hannouf
Name of The Thesis:	Comparing Different Laser Patterns in Etching of Enamel for Ceramic Bracket Bonding
Thesis Defense Date	12.01.2024

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

Doç. Dr.Yücel Batu SALMAN

Institute Director

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

	Title, Name	**Signature**
Thesis Advisor:	Dr. Öğretim Üyesi AYŞE SENA SARP	
2. Member (Outside Institution):	Dr. Öğretim Üyesi Seda Nilgün Dumlu	
3. Member:	Dr. Öğretim Üyesi Kübra Sucu	

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

Name, Surname	: Dana Hannouf
Signature	:

ABSTRACT

COMPARING DIFFERENT LASER PATTERNS IN ETCHING ENAMEL FOR CERAMIC BRACKET BONDING

Dana Hannouf

Master's Thesis, Master's Program in Bioengineering

Supervisor: Prof. Dr. AYŞE SENA SARP

January 2024,58 pages

Brackets are small attachments used in orthodontics. Ceramic brackets are more favored because of their resistance to deformation, and their color stability. In contrast to their aesthetic superiority, ceramic brackets are inert and require a higher bonding strength to adhere with tooth. The conventional method is achieved by acid etching roughening which cause carries formation and decalcification. Lasers are being examined as an alternative to this disadvantage.

The main objective of this study was to investigate the consequence of different patterns done by Erbium laser as a safe method for etching enamel before bonding ceramic brackets.

In preliminary experiments the temperature increases in pulp chamber during the irradiation. 100 mj/15 Hz/1.5 W was selected among the other recommended parameters for enamel etching in the main experiments. The importance of scanning pattern was examined and compared in the main part of the experiments. According to the analysis the point-etched group (PIG) showed a significant difference from both the laser-etched and conventionally etched groups. The results of the study also mentioned that there is no statistically significant difference between the acid-etched group and the directionally scanned laser-etched groups, VSG and HSG. Additionally, there was no significant difference between the shear bond strength of the two laser-scanned etched groups, VSG and HSG. Application of pattern showed an adequate bonding force, but there was no significantly difference between the horizantal and vertical patterns.

Key words: Ceramic Brackets, Bonding, Laser Etching, Orthodontics

ÖZ

SERAMİK BRAKET BİRLEŞTİRME İÇİN EMAYE AŞINDIRMADA FARKLI LAZER DESENLERİNİN KARŞILAŞTIRILMASI

Dana Hannouf

Yüksek Lisans Tezi, Biomühendislik Alanında, Yüksek Lisans Programı

Gözetmen: Prof. Dr. AYŞE SENA SARP

Ocak 2024,58 Sayfa

Braketler ortodontide kullanılan küçük apareylerdir ve seramik braketler deformasyona karşı dirençleri ve gelişmiş renk stabiliteleri nedeniyle tercih edilirler. Estetik üstünlüklerinin aksine, seramik braketler inerttir ve bu nedenle dişe tutunmak için daha yüksek bir bağlanma gücü gerektirir. Geleneksel yöntemde bu, dekalsifikasyona neden olan asitle aşındırma pürüzlendirmesi ile sağlanır. Lazerler bu dezavantaja bir alternatif olarak incelenmektedir.

Bu çalışmanın temel amacı, seramik braketlerin yapıştırılmasından önce minenin aşındırılması için güvenli bir yöntem olarak Erbium lazer ile yapılan farklı desenlerin sonuçlarını araştırmaktır.

Ön deneylerde, seçilen parametreler için ışınlama işlemi sırasında pulpa odasındaki sıcaklık artışı ölçülmüştür. Ana deneylerde mine aşındırma için önerilen diğer parametreler arasından 100 mj/15 Hz/1.5 W seçilmiştir. Deneylerin ana bölümünde tarama deseninin önemi incelenmiş ve karşılaştırılmıştır. Analize göre noktasal aşındırma grubu (PIG) hem lazerle aşındırma hem de geleneksel aşındırma gruplarından anlamlı bir

farklılık göstermiştir. Çalışmanın sonuçları ayrıca asitle aşındırılmış grup ile yönlü taranmış lazerle aşındırılmış gruplar olan VSG ve HSG arasında istatistiksel olarak anlamlı bir fark olmadığını belirtmiştir. Ayrıca, iki lazerle taranmış kazıma grubunun (VSG ve HSG) kesme bağlanma dayanımı arasında da anlamlı bir fark bulunmamıştır. Desen uygulaması yeterli bir bağlanma kuvveti gösterdi, ancak horizantal ve vertikal desenler arasında anlamlı bir fark yoktu.

Anahtar kelimeler: Seramik Braketler, Yapıştırma, Lazerle Aşındırma, Ortodontics

This research is wholeheartedly dedicated to my cherished parents Taghrid S, Khodor H, who have continuously given me economic, moral, and spiritual support. They have been my source of motivation and support whenever I was tempted to give up.

To my siblings Mohamad H, Angie H, Abdallah H, Razan H, my best friend Jana D, and my relatives Rawaa S, Sirine A, Rashad A, who have offered guidance and motivation to complete this study.

To my lovely doctor Ayşe Sena Sarp, who has provided me with unwavering support, encouragement, and patience throughout this process, for which I will always be grateful. I will never be able to repay you for all your assistance, the experience you helped me obtain, and the invaluable time you invested in making sure my thesis was completed on time. I hope this little paper brings you some sort of satisfaction. Many thanks for that!

Finally, special thanks to Bahçesehir University Scientific Research Project Department BAU BAP for supporting my thesis study. This study is a part of BAU BAP research project (2021-01.39 NAP).

TABLE OF CONTENTS

LIST OF TABELS

TABELS

LIST OF FIGUERS

FIGURES

LIST OF ABBREVIATION

Nd: YAG	Neodymium-doped Yttrium Aluminum Garnet
CO_2	Carbon Dioxide
Er: YAG	Erbium, Chromium Yttrium Aluminum Garnet
Er/Cr/YSGG	Erbium, Chromium: Yttrium Scandium Gallium Garnet
Nd	Neodymium
Yb	Ytterbium
Er	Erbium
Tm	Thulium
UDMA	Urethane Dimethacrylate
Bis-GMA	Bisphenol A-Glycidyl Methacrylate
TEGDMA	Triethylene Glycol Dimethacrylate
CIM	Ceramic Injection Modeling Technology
AL_2O_3	Aluminum oxide
DNA	Deoxyribonucleic Acid
NIR	Near Infrared
UV	Ultraviolet

FDA	US-Food and Drugs Administration
IPG Laser	Immobilized PH Gradient Laser
GmbH	Company with limited liability
Delta PT	High Polyethylene Cavity Membrane
nm	Nanometer
°C	Degree Celsius
s	Second
W	Watt
$ZOOM_2$	Revolutionary Tooth Whitening Procedure
LED	Light Emitting Diodes
OLED	Organic Light Emitting Diodes
mJ	Microjoules
Hz	Hertz
SEM	Scanning Electron Microscope
MPa	Megapascal

ARI	Adhesive Remnant Index
CAD	Computer Aided Designs Program
K-Type thermocouple	Nickel-chromium/Nickel-Alumel thermocouple
Cw	Continuous Wave
P_2O_5	Phosphorus Pentoxide
Er^{3+}	Erbium ion
Yb^{3+}	Ytterbium ion
SD	Standard Deviation

Chapter 1

Introduction

1.1 Aim and Determination

In science, orthodontics focuses on the alignment of teeth and jaws as well as with tooth movement. The word "Orthodontics" can be branched into two Greek words, orthos and dontics. Orthos implies alignment and dontics signifies teeth. Ameliorating teeth look, looking after teeth health and bringing forth a healthy bite, are the major objectives of orthodontics. Brackets are small attachments used in orthodontics that are fixed on tooth to attach an arch wire; it can be metal or ceramic brackets. Metal braces are the first form of orthodontics therapy, it assists in straightening teeth reliably in a more rapid and effective procedure. However, having a gorgeous smile is the target of the orthodontic treatment but appearance while undergoing therapy is one of their biggest concerns. Therefore, many manufacturers were trying to create "invisible" braces or minimizing metal brackets to meet patient's requests. Ceramic brackets were firstly introduced to orthodontics in the mid-1980s. Monocrystalline sapphire and polycrystalline ceramic braces are used as esthetic tools better than plastic braces due to it's potential in resisting stains and most of the orthodontics forces [5]. Direct bonding is the process of directly attaching brackets to the teeth and ensuring that they are properly attached and positioned. Bonding ceramic brackets mechanisms involve mechanical retention, chemical bonding or incorporating both. Each bonding method have their own benefits and limitations. [6]

The usual plan of action before binding the tooth with ceramic bracket is consist of polishing, acid etching enamel and finally wash and air dry. The usage of acid as an etching agent has many negative aspects on the health of the tooth; it facilitates carries formation and decalcification [7]. Therefore, lasers were introduced to orthodontics as a good alternative to the conventional etching techniques.

From late 1960, various lasers started to be created throughout the years and introduced to many medical fields. “Light amplification by the stimulated emission of radiation” means laser. Firstly, found laser was solid ruby laser made by “*Theodore Maiman*” in 1960 and thereafter, uranium laser in 1960, helium-neon laser in 1961, semiconductor laser in 1962, Nd: YAG laser and CO2 laser in 1964. The employment of laser in the dentistry field confirmed that laser is the efficacious tool that can improve proficiency, particularity, ease and relief of the dental therapy [8]. Tooth whitening, caries management, and debonding ceramic brackets are just some of the procedures that dentists have used dental lasers for. They have also been used to prepare cavities, remove the flings, etch surfaces for micro-retention, remove hard and soft dental tissues, and perform lithotripsy. Infections and bleeding are minimized with laser dentistry. Dental laser procedures may not necessitate the use of stitches and wounds heal more quickly. Anesthesia is not required for some laser dental operations. As of today, the most commonly used dentistry-related lasers include those that use argon and carbon dioxide (CO2), as well as Nd: YAG ,Er: YAG and Er/Cr/YSGG [9]. This research will employ Er: YAG laser (2940 nm) because of the benefits of fiber lasers over other laser types and qualities [10]. "*Elias Snitzer*" built the first fiber laser in 1963. Nd, Yb, Er and Tm are active ions used in fiber lasers to dope an optical fiber as the active medium. Fiber lasers offer several benefits over other sources, which include maximum reliability and brightness, excellent beam quality, and maximum output powers; they can also be conveniently connected with other fibers or equipment. Because of the fiber's waveguiding qualities, which reduce or remove light path thermal aberration, high beam quality of this kind of laser is a key benefit. Nevertheless, the thermal impact of laser radiation on tooth structure might result in negative outcomes. Several research have examined the thermal properties of laser on dental pulp. As said by Zach and Cohen’s research, the highest intrapulpal temperature increase that does not cause any morphologic alterations is 5.5 degrees Celsius. [11]

1.2 Outline

Chapter 2 will generally cover dentistry, orthodontics, and lasers. This chapter also explains the methods used to attach orthodontic brackets.

Chapter 3 describes the materials utilized in the presented research. There are also detailed descriptions of experimental setup and methodology.

Chapter 4 covers the results of the study.

Chapter 5 covers the discussion.

Chapter 6 concludes the study.

Chapter 2
General Content

2.1 Dentistry

Among the medical specialties dentistry focuses on the examination, management and rehabilitation of dental problems, illnesses and disease throughout the mouth, jaw, and oral cavity.

Lips, cheeks, upper and lower gums, under and above tongue area and the little region behind the wisdom teeth comprise the oral cavity. The maxillary teeth get their name from their roots that are implanted in the maxilla's alveolar bone. A mandibular tooth has its roots buried in the alveolar bone of the lower jaw. The incisors (biting teeth), canines (eye teeth), molars (chewing teeth), and premolars all have various purposes. (Figure 1)

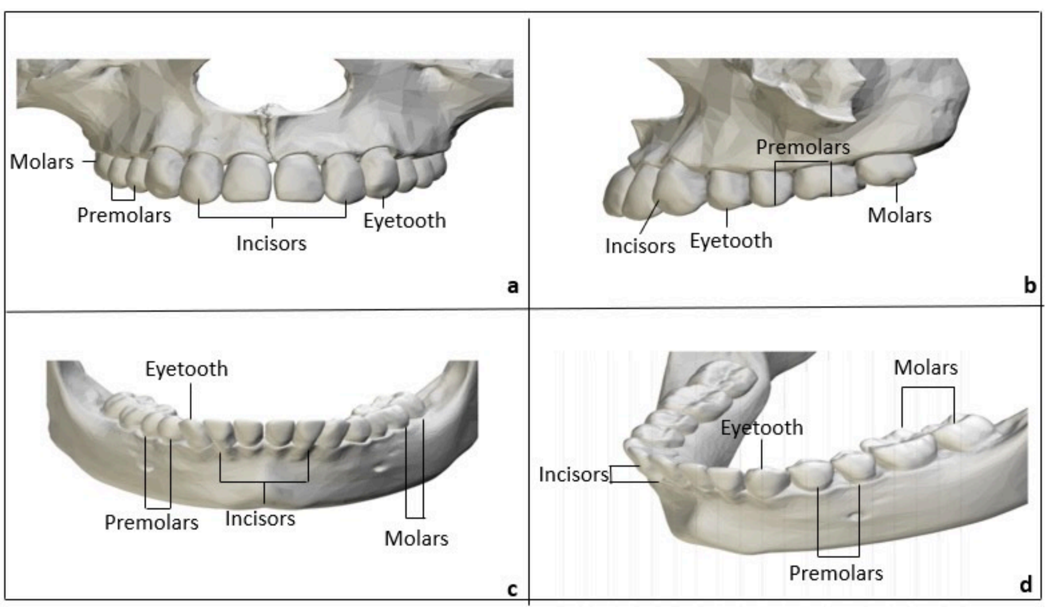

Figure 1: Frontal and Lateral View of Mandibula and Maxilla

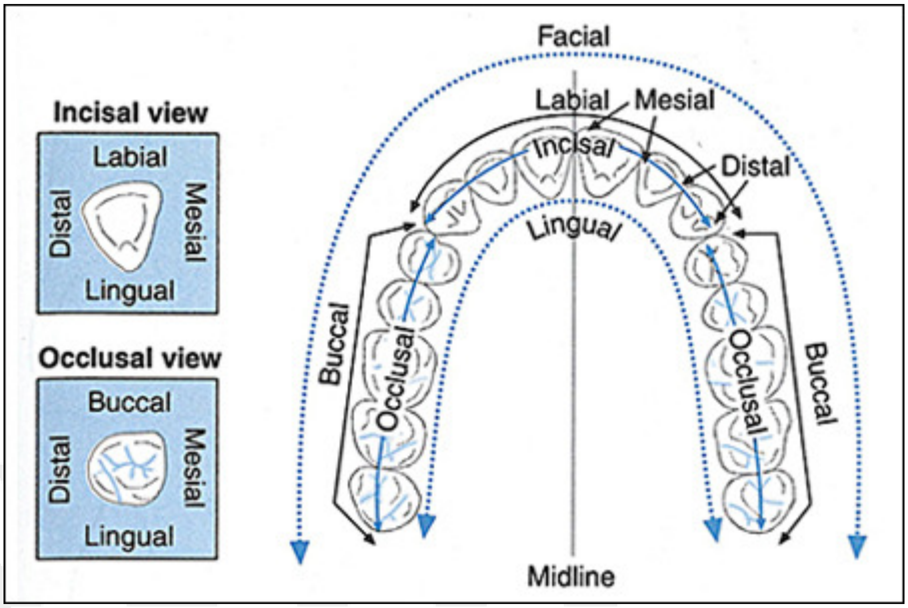

Figure 2: Incisal and Occlusal view of tooth

In total, we have 32 teeth divided into, deciduous, incisors, canines, premolars, and molars. First, milk teeth or also called deciduous teeth are the first to pop out and are subsequently replaced by permanent ones. Second, incisors are known as the cutting teeth. Third, canines are adjacent to the incisors; it aids in breaking and repairing. Finally, premolars and molars that plays the role in chewing and grinding. Each tooth has five surfaces, each of which has a different direction assigned to it. The grinding side of a tooth is known as occlusal surface. The part of the tooth that faces outward is known as the mesial. To find the mesial of the tooth, we must look at the in between surface of two following tooth. The term "Distal" refers to the rear of the teeth. The lingual part of a tooth is the nearest side to the tongue. The Buccal (premolars and molars) side is known as the part facing the cheeks. In addition, the dental arch is the curving framework that supports teeth and comprises the gum and alveolar bone. Its arched design ensures a healthy bite and long-term dental health. This arch is divided into left and right halves by median sagittal plane that gives accurate division of the body into two equal parts. (Figure 1-2)

Four dental tissues make up the structure of the teeth. Enamel, dentin, and cementum are the hard dental tissues. Pulp is the soft, non-calcified tissue that houses nerves, blood vessels and connective tissue. The outside surface of the teeth is covered with a hard material called enamel. The enamel serves as a strong barrier that protects teeth from any kind of physical or chemical damage. Enamel is known to be a very hard material in the human body where it is harder than bones. However, if it is contacted with acid or germs in the mouth, it may degrade. Minerals make up 96% of enamel, whereas organics and water make up 4%. A crystalline calcium phosphate (hydroxyapatite), which is also present in bone, calcified cartilage, dentin, and cementum, is the inorganic composition of enamel. Hence, dentin refers to the portion of the tooth that is located under the enamel and it is comprising microtubules. Tubules in dentin enable heat and cold or acidic foods to activate the nerves and cells within the tooth, resulting in sensitivity when enamel is degraded. The major purpose of dentin is to sustain the enamel's structure. As a result of its thinner structure than enamel, it aids in absorbing the pressure that comes from eating. Finally, cementum is a mineralized tissue that covers the whole root surface and connects it to fibers in the jawbone to maintain tooth's position.

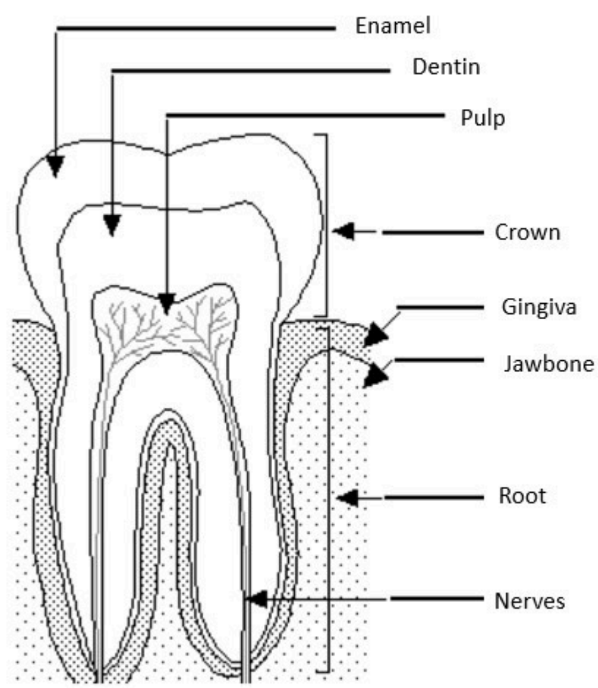

Figure 3: Constitution of a Tooth

Connective tissue, blood vessels, and cells make up the dental pulp, which is in the core of the tooth. The pulp is responsible for two primary functions: the formation of dentin and the supply of nutrients to the tooth. Tooth pulp also provides the dentin layer with hydration and vital nutrients like albumin and fibrinogen, which assist to maintain dentin healthy and strong. [12]

The constitution of teeth is not homogenous. Organic and inorganic components in dentin vary from those in enamel. Tooth enamel, which is the crown's toughest component, is made up of 95 percent hydroxyapatite, 4 percent H_2O, and 1 percent natural material. However, dentin is the layer beneath the enamel. 10 percent water, twenty percent organic materials (mainly collagen) and seventy percent hydroxyapatite make up dentin.

Table 1

Enamel and Dentin Organic and Inorganic Components.

	Enamel	**Dentin**
components	95 % hydroxyapatite 4 % water 1 % organic substances	70 % hydroxyapatite 10 % water 20 % organic substances

There are numerous subfields in dentistry that concentrate on different subjects:

- Modern endodontic therapy focuses on avoiding or curing pulpitis and apical periodontitis to keep a tooth functioning for as long as possible.

- Oral and Maxillofacial pathology that study the causes, symptoms, and treatment of illnesses that may occur orally or in maxillofacial areas.

- Oral and Maxillofacial Radiology study and the use of radiology for examination of oral and maxillofacial illnesses. [13]

- Periodontics that focuses on supporting teeth and its structures like gum, cementum, and alveolar bone.

- Pediatric dentistry is a field in dentistry that is dedicated for toddlers and infants.

- Prosthodontics is involved with the design and construction of dental implant as well as other dental prosthetics.

- Orthodontics

2.2 Dental Orthodontics

Dental orthodontics focuses on the identification, prevention, and repairing the misalignment in teeth and jaws, as well as improper bites. Dentofacial orthopedics may potentially be a part of the treatment plan in case of facial growth disorders. The main goal of orthodontics is to repair these problems by creating an ideal bite and enhancing the aesthetics of the teeth, face, and mouth. Mental and physical health are enhanced because of the treatment. Most orthodontic operations are performed on youngsters, although adults have recently begun to be involved in this type of treatment. At any age, adults may have orthodontic treatment if they are willing to follow the doctor's instructions and wear their braces as prescribed.

In the past several years, orthodontics has benefited greatly from the tremendous technical advancements that have taken place. Clinical processes have always been simplified by research-based results, which have led to the creation of novel materials and methods. Orthodontics use a wide variety of instruments and tools:

- Dental braces: Straightening and repositioning teeth with braces is a common orthodontist treatment. As an added benefit, braces help in maintaining a healthy smile for a very long term. It is also possible to eat more comfortably after treatment. Braces exert pressure on teeth and gradually shift them in the desired direction. The teeth and roots will be able to shift because of the strain on the bones in the jaw.

- Dental arch wire: an arch wire is a part of the braces system. It is a thin wire that runs through each bracket. Arch wires are used to move teeth into their correct positions. It is primarily in charge of most oral motions that take place throughout therapy. Arch wire is usually fabricated using stainless steel, nickel-titanium, and beta-titanium.

- The arch wire is held in place by brackets on each tooth. (Figure 4)

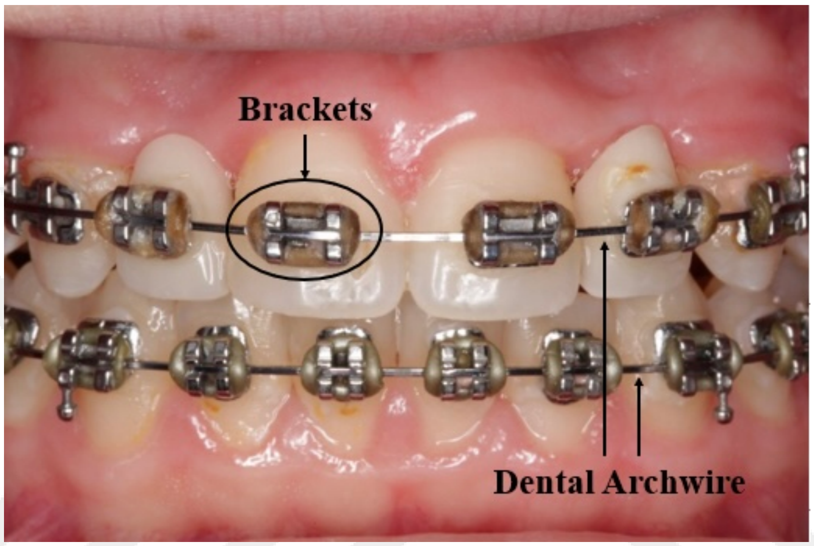

Figure 4: An Illustration of Orthodontic Treatment Using a Bracket and Wire.

2.3 Orthodontic Bracket Bonding

The plan of binding brackets with tooth is called adhesion. Adhesion is a type of force that helps keeping two different materials together when they are in a proximity to one another. Different from the appeal between similar molecules or atoms inside one matter, which is called cohesion. Adhesive refers to the substance that is applied for adhesion and the adherend is the surface that will stick to another surface by adhesion. The surface must be clean and completely dry prior the bonding process, if it is not, the glue (adhesive) will not stick to it. An adhesive's ability to properly adhere to a solid substance is greatly enhanced by applying it to a clean, dry surface. In addition, the presence of contaminants on a surface will hinder adhesive from adhering to substrates. Thermal expansion coefficients vary, causing stress that weakens adhesive bonding. Assembly materials like cement and glue are used in conjunction with teeth and prosthetics to create a strong bond between them. Two primary kinds of adhesion may be found: mechanical and chemical. Interlocking mechanics are the foundation of mechanical adhesion, which is a strong and long-lasting bonding technique. The etching of a surface is altered to create chemical bonding between two different surfaces [14].

Before choosing the best adhesive, we must take into consideration substrate's surface energy and the procedure of adhesion. Adhesion occurs between the adhesive and a substrate, where this relation affects the substrate's surface. Chemical and mechanical can coexist. Mechanical bonding happens when the adhesive penetrates inside the tiny holes created by acid etching. Etching with phosphoric acid showed a very strong bonding between composites and teeth. When an adhesive is applied to a solid surface, the surface is roughened with an acid and thoroughly rinsed to facilitate micromechanical adhesion.

Dental surfaces cannot be adhered to typical resins that are very hydrophobic. This problem may be solved by identifying a coupling agent that will adhere to the dental tissues and an adhesive that has a desirable surface topography for anchoring. The wettability of the adhesive can be improved, the enamel surface can be cleaned, and the substrate's surface energy can be improved by phosphoric acid etching. It is possible to achieve a roughness of up to 50 microns using phosphoric acid etching, allowing resin to penetrate. Enamel etching appears to benefit most from phosphoric acid treatment. Dentin treatment affects the acid that may be used for bonding to enamel and dentin; this means that the dentin must be etched as well. For the dentin adhesion to be as complicated as the enamel's, additional acids, minerals, or chemical compounds have been used to generate new adhesives. However, phosphoric acid seems to be the most efficient of the acids. Phosphoric acid solutions of 10% to 60% appear to have the same adhesive properties. A concentration of 35% is ideal. Because of the lack of the ideal adhesive or restorative materials, this micromechanical bonding process has been widely exploited in dentistry.

The adhesive is primarily made of methacrylate matrix, which is known as an organic polymer. Two methacrylic acid monomers make up the resin matrix. Chemically speaking, polymer is the result of two monomers paired together where this complex is made chemically from big molecules. Monomers with low molecular weights may be transformed into chains of polymers with high molecular weights by polymerization. Thermal and environmental conditions as well as the polymer's molecular weight have an impact on its physical qualities. As the temperature rises, the polymer softens and weakens.

Resin is a substance that has both hydrophilic and hydrophobic qualities. UDMA and BisGMA are two examples of hydrophobic monomers used in resin formation [15]. In addition, other components are added such as TEGDMA that is used as viscosity controller and HEMA used as wetting component. In adhesive systems, HEMA and Bis-GMA are the two most prevalent monomers utilized. HEMA is a polymerizable wetting reagent that is ideal for dental adhesives since it may be entirely dissolved in water. In contrast, Bis-GMA is a lot more water-repellent and when polymerized, only takes up around 3% of its own weight in water. The combination of the two acts as a helpful adhesive for dental hard tissues. Initiators, inhibitors, stabilizers, solvents, and sometimes inorganic fillers are all components of bonding agents (adhesives). This unique bio composite structure, known as the hybrid layer, was initially shown by Nakabayashi in 1982 [16]. In the past, this layer was thought to be the primary method of binding agents. By penetrating in the dentin tubules, binding agents generate a homogeneous amalgam layer by filling nano cavities formed in collagen following acidification [17]. Properly distributing the adhesive all over the surface is an ideal process for primer election and utilization. Bonding agent polymerizes in tandem with the hybrid layer formed following primer application. Resin stamps are formed due to the entrance of resin into dentin tubules. Therefore, the procedure of acid etching and it' ideal distribution prevents the formation of these stamps.

Brackets are tiny attachments used to secure arch wires in orthodontic treatment. When it is time to have your braces adjusted, you may simply remove the arch wire and replace it in the channel. An orthodontic band is fused or bonded to the teeth using these attachments, or they may be placed directly on the teeth. Plastic, ceramic, and metal (stainless steel, gold-coated or titanium) attachments are available for orthodontic bracket bonding. (Figure5)

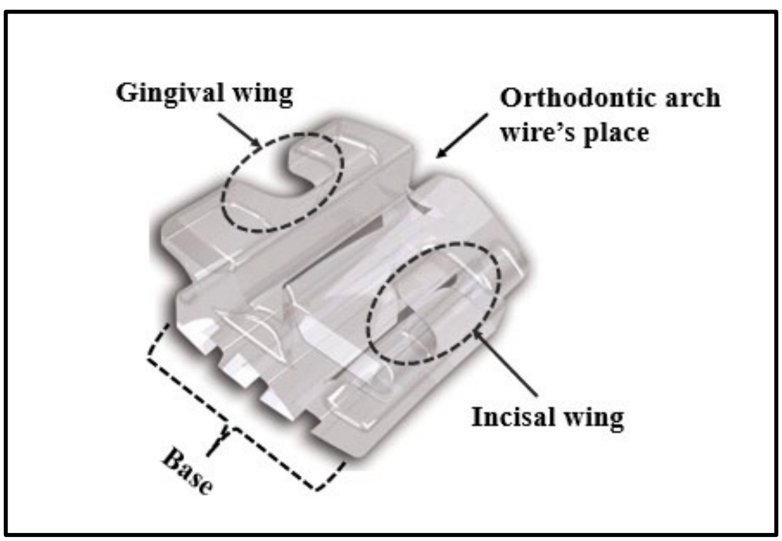

Figure 5: Parts of a Bracket

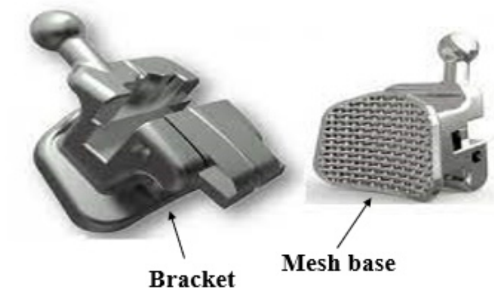

Figure 6: Front and Back View of Brackets Showing The Mesh Base.

Mechanical retention is very important for bonding metal brackets and the well-known way to accomplish this is mesh gauze. (Figure 6). Gingival irritation may be minimized by using tiny, hardly visible metal bases. Most modern orthodontic brackets are composed of stainless steel, and mechanical retention is utilized to hold them in place. This is because stainless steel does not chemically bond with adhesives. In either case, the stainless-steel bracket base is either a built-in component or is produced separately and then brazed or welded to the bracket's main body. There is perforated and mesh bases. In modern orthodontics, mesh-type bases have superseded perforated bases and are the most common form of base.to avoid the possibility of demineralization along brackets perimeter, the bottom of the brackets should not be smaller than its wing.

Most modern braces have evolved from Edward H. Angle's typical edgewise braces [18]. Edgewise brackets were created at a period when stainless steel alloy was still in its infancy and orthodontic brackets soldered to bands were mostly composed of 14 carat or 18 karat gold. For the first time, stainless steel was used in edgewise appliances by Rudolf Schwarz [18]. Brackets made of stainless steel that are resistant to corrosion should be used. A bracket's ability to resist corrosion is more essential than the amount of nickel it contains. Nickel-sensitive patients should avoid using SS brackets. In general, SS brackets with soft bases and hard slots/wings should be used. Brackets with a 17-4 PH MIM flange are a suitable option for expressing torque properly. To minimize corrosion, orthodontists should always choose for a new bracket as the first option.

In addition to stainless steel, orthodontists and patients have been able to use a variety of other materials throughout the years like ceramic and plastic brackets. Plastic brackets were promoted as an aesthetic alternative to metal ones in the early 1970s. For years, dentists have used plastic braces to treat patients who wanted a more attractive result. Plastic brackets, according to new research, performed adequately clinically and aesthetically within the time examined [19]. When arch wires activated to the teeth, the torsional stresses created by the brackets led to significant creep deformation and poor torque capacity in plastic brackets. First-generation plastic brackets were also found to have fractures and concerns about discoloration. Ceramic, fiberglass, and metallic brackets inserts have been produced by suppliers as the best alternative for plastic brackets. In 1980s, ceramic bracket was introduced into orthodontics practice, to remedy the polycarbonate brackets' lack of strength and stiffness. For aesthetic reasons, ceramic braces are favored because of their increased tensile strength, increased resistance to wear and deformation, and improved color stability (figure 7).

Figure 7: The Comparison of Bonded Appliances, Stainless Steel Brackets, and Ceramic Brackets in Terms of their Aesthetics.

To eliminate oxygen dissolved in steel, aluminum must be added to the steel to generate pure alumina, and this is what ceramic brackets are made of. During treatment, ceramic brackets need a higher level of aesthetics due to the optically opaque nature of pure aluminum oxide (alumina).

This material is often found in both polycrystalline and monocrystalline ceramic brackets, which may be used for a wide range of applications. Currently, the most majority of polycrystalline (many crystals) brackets are manufactured using ceramic injection molding technology (CIM). Here is a summary of CIM's structure: A binder is added to the Al2O3 particles. Heat and pressure are used to make this combination flowable, and then it is injected into a bracket mold. Sintering, which is the process of creating a solid mass by heating without melting, follows. CIM has the benefit of being able to produce huge numbers of complicated and accurate products with smooth surfaces at high speeds.

Sapphire brackets are Monocrystalline (single crystal) ceramic brackets, have an entirely separate manufacturing method. The Al2O3 granules are being melted in this picture. A massive, single crystal is formed because of the delayed cooling of the resulting bulk, which allows for controlled crystallization. Using ultrasonic cutting processes and diamond cutting tools, this enormous, single crystal is machined into brackets. Monocrystalline brackets are heat treated after milling to remove surface defects and alleviate stress produced by milling. Compared to the fabrication of polycrystalline brackets, these brackets are more costly to make. It is mostly because of the difficulties of milling, which involves cutting.

Ceramics are significant to orthodontics because of their physical qualities:

- Hardness: Brackets made of ceramic are renowned for their toughness. Harder than enamel, they are more resistant to chipping. As a result, it is imperative that enamel and ceramic brackets be kept apart at all costs. Damage to teeth may occur because of this form of contact. Those patients who have a deep bite or a canine connection class II should be treated with extra caution. To avoid enamel damage, bite opening treatments must be used if necessary.

- Tensile strength: is the maximum amount of stress that any matter can handle before it breaks or fails under a certain amount of strain. Stress redistribution and stress alleviation are almost difficult in ceramic materials because of their rigid atomic structure. Prior to collapse, metals and polymers undergo plastic distortion. Ceramics have a default elongation of less than 1%, whereas stainless steel's default elongation is over 20%. Ceramic brackets, on the other hand, do not sag, as a result. Using the same circumstances, ceramic brackets are much more likely to break than metal brackets.

- Fracture solidity: is a quality that characterizes a material's capacity to withstand fracture in the presence of a crack. Material flaws, like minuscule scratches and pores cannot be totally avoided in the manufacturing of materials. This is a significant feature of the material. There are a variety of elements that determine whether a material's tiny defects are damaging, such as its fracture ruggedness, stress levels on it and its ability to resist crack propagation, as well as its location in nature.

When a matter has a high fracture toughness, cracks are more difficult to spread. In terms of fracture toughness, polycrystalline alumina brackets outperform monocrystalline alumina brackets. This suggests that single-crystal alumina brackets are more susceptible to fracture propagation than polycrystalline alumina brackets. Due of grain boundaries interacting with cracks, polycrystalline brackets are more resistant to crack growth (GBs) (figure 8). If you have a polycrystalline (many crystals) material, a GB is the point where two "grains" meet. At these GBs, cracks cannot form. Ceramic brackets' fracture toughness may be considerably reduced by clinical use that scrape the sides of the brackets.

In a way to avoid damaging ceramic bracket sides, equipment and stainless-steel ligature wires must be used with extreme caution throughout therapy. In addition, while using steel ligature wires, the physician should not use excessive force. The bracket may eventually shatter if this causes a crack to form and spread. A meticulous sequence of arch wires is also required. Resilient full-size arch wires should be used prior to the installation of full-size stainless steel arch wires, according to the manufacturer's instructions.

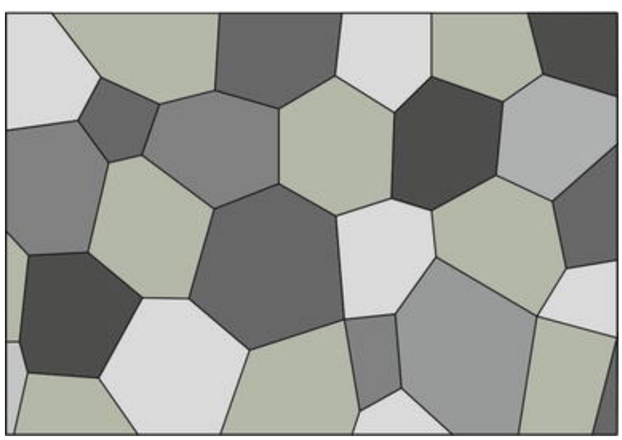

Figure 8: GBs and "grains" are Shown in a Graphical Representation.

- Friction: Polycrystalline ceramics have a greater friction coefficient than monocrystalline ceramics, according to a study. The frictional properties of monocrystalline brackets have really been known for over a decade.

- Optics: Ceramic brackets are appealing to a wide range of patients because of their attractive optical qualities. Crystal GBs are present in the microstructure of polycrystalline ceramic brackets, as previously described. The opacity of this microstructure is due to light reflecting off it. When compared to single-crystal brackets, which do not include GBs, these brackets allow light to flow through, making them virtually transparent.

  Monocrystalline brackets, on the other hand, offer a higher degree of optical clarity than polycrystalline brackets. The orthodontist and the patient must decide whether this difference is crucial from an esthetic standpoint. (Figure 9)

Figure 9: Monocrystalline and Polycrystalline Ceramic Brackets

During the photocuring process, the quantity of light passing through ceramic brackets is affected by their optical qualities in addition to their aesthetics. Curing effectiveness of light-cured adhesive is affected by the quantity of light passed through ceramic brackets. To a larger degree than monocrystalline brackets, polycrystalline brackets and polycrystalline brackets with a polymer mesh base were found to obstruct direct light transmission. The color-coded holders for ceramic brackets meant for identification and handling impede light transmission, it was pointed out. Some have proposed using transparent holders with colorful borders.

- Color stability: Ceramic orthodontic brackets must maintain their color during therapy. Ceramic brackets, both monocrystalline and polycrystalline, are said to switch color while exposed to coffee, black tea, and red wine. These are in vitro discoveries; therefore, it is important to emphasize that up. There is not any research done in humans to determine how long ceramic braces will maintain their color.

- Biocompatibility: If a substance can perform its intended function in the body of a living organism with just a small amount of irritation, it is said to be biocompatible. According to traditional ceramic brackets, the oral environment is chemically stable, and they display great biocompatibility with the oral tissue.

Ceramic brackets offer several benefits, but they also have some drawbacks. Ending fixed appliance therapy, debonding refers to the removal of orthodontic brackets as well as any remaining adhesive residue. Brackets made of ceramic are rigid. Debracketing forces towards the conclusion of treatment may cause stress to build up in the hard ceramic and the enamel, which have limited capacity to disperse it. Debracketing may result in bracket breakage and/or enamel degradation. Ceramic bracket debracketing may have several unpleasant side effects, which can be minimized in many ways. Conventional (mechanical), ultrasonic, electrothermal, and laser methods are all examples of this group of technologies.

In addition, a noticeable contrast in size between ceramic and metal brackets. If your toothbrush cannot get to the enamel and gumline around your brackets, this might cause to sore gums or receding gums.

In comparison to metal braces, ceramic braces are much more prone to shatter or fracture. Debonding, the procedure for removing the adhesive, has been linked to tooth surface damage (enamel).

Different base designs are available from numerous manufacturers for mechanical retention: microcrystalline, mechanical ball, dovetail, dimpled and mechanical buttons are only a few examples. They also claim to have better bonding and debonding properties than typical stainless-steel brackets, which feature a mesh attached to the bracket base to enhance mechanical retention.

In 1960s, bonding orthodontic brackets to enamel was introduced by Newman and Miura in the 1960s. Many new adhesives, complex base designs, new bracket materials, quicker or more efficient curing procedures, self-etching primers, fluoride-releasing agents, and sealants have been developed in the decades afterwards [20]. As Buonocore discovered in 1955, acid etching of enamel alters its surface, which is the basis for the bonding method. There are several phases involved in the bonding of brackets to facial or lingual surfaces:

(a) Polishing
(b) Fastening
(c) Binding

Usually, polishing teeth with pumice helps in removing plaques and pellicles that surfaced teeth. In the second step, completely wash and airdry teeth with compressed air that does not contain any water or oil molecules. Etching agent should be poured onto the mixing pad. Etchant is available in two forms: liquid and gel. For etching, separate the teeth. Apply the etching agent using a cotton pledged or brush to the area to be bonded. Etching agents should not be applied to enamel by rubbing them in. Allocate 30 seconds for the etching process. A soft tissue etching agent is not recommended.

Remove demineralized particles by rinsing teeth with water and make it ready for etching. To properly clean your teeth, you need to thoroughly rinse each one. Clean and dry your teeth completely. Engraved areas should be white and icy in appearance. If not, repeat the etching process for another 20 seconds and see if that helps. Sealant (bonding material) should be applied after etching and making sure that the tooth is fully dried and super white. After that, we can start the installation of brackets after coating all etched teeth with adhesive. To prevent glue from setting, any remaining adhesive must be scraped off using a scaler as soon as possible. (Reliance orthodontic products, inc) [21]

Figure 10: Tooth Preparing Steps for Bonding. (a) Cleaning Tooth with Pumice, (b) Rinsing and Drying Enamel, (c) Preparing S.E.P, (d) Applying S.E.P to Enamel and Scrubbing for 5s.

Figure 11: Tooth Preparing Steps for Bonding. (e) Air Drying Enamel with Compressed Air, (f) Applying Brackets using Light Cure Paste, (g) Light Cure.

2.4 Dental Lasers

Laser is a device that focuses and intensifies a small, strong light beam that is coherent. Theodore H produced the first laser in 1960. Many medical fields began using lasers in the late 1960s. Ophthalmology and dentistry were two of the first fields to report findings. Laser systems may be categorized based on different characteristics. [22]

Table 2

Arrangement of Lasers Based on Different Characteristics

parameter	wavelength	Active material	power	Mode of operation
classification	UV Visible IR	Gas Liquid Solid electronic	Low power High power	Continuous wave Pulse mode

Laser beam's wavelength is a very important factor in determining the depth in which it may enter tissue. Light exposure causes four fundamental reactions in matter: Absorption, Scattering, Refraction, and Reflection (or a combination of these).

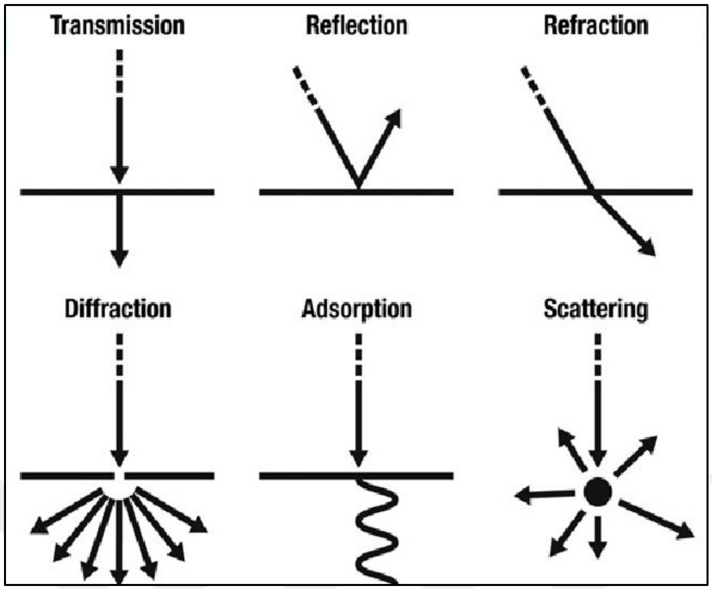

Figure 12: Spectroscopic Measurements of Light's Path Through Matter.

There will be no heat response if light is reflected or passed through the tissue. Light that is absorbed by tissue, on the other hand, gets transformed into heat. Proteins and pigments in biological tissues plays an important role as absorption factors. The phrase "absorption coefficient" refers to the efficiency with which absorption is measured. Water makes up approximately 75% of a tissue's composition, and that is what matters. Water's absorption of UV light is inversely proportional to its wavelength, and as the wavelength becomes less, absorption increases owing to compounds like protein and DNA. Absorption in the infrared range rises with higher wavelength as tissue water content rises. Water molecules absorb the least amount of light in red or NIR. The wavelength helps in determining how light interacts with tissues. (Figure 13)

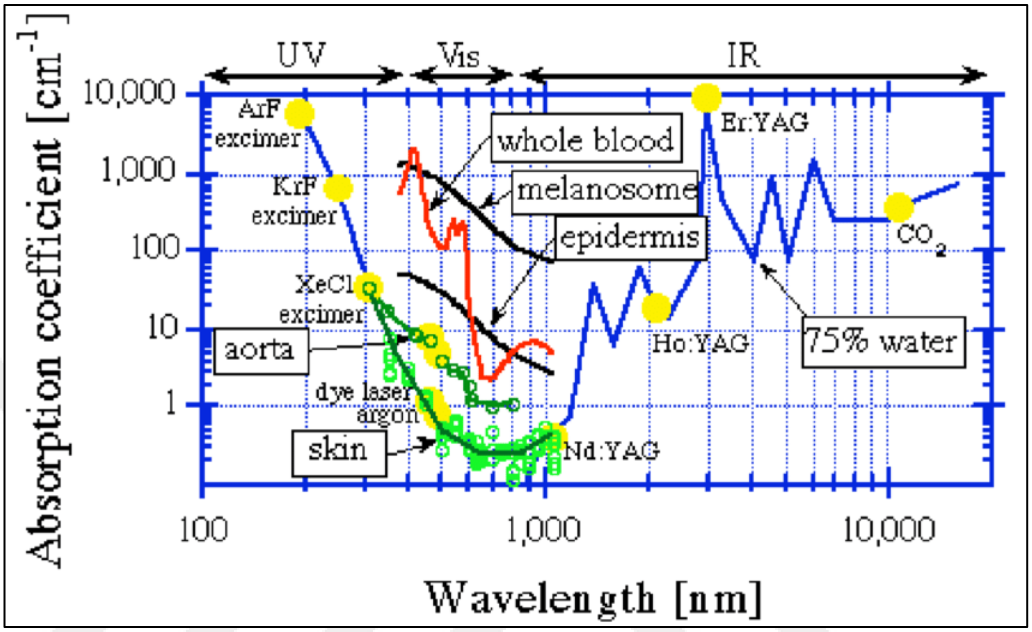

Figure 13: Absorption Level in Biological Tissue and Its Coefficient According to Different Laser Frequencies is Shown Above.

The optic characteristics of a tissue are affected by the allocation, accumulation, and constituent components of chemicals inside the tissue. To put it another way, tooth structure is not made up of the same components all the time. For this reason, the absorption coefficients for enamel and dentin are different. Dentin has lower concentrations of organic and inorganic components than enamel does.

Many dental issues may be treated using lasers, which have been around since 1994. A wide range of lasers have been given the green light by the US FDA. In both experimental and clinical trials, orthodontic lasers are used:

- Tooth decay: Lasers are used to eliminate deterioration from the inside of a tooth and to prepare the enamel around it for the filling.

- Gum infection: During root canal operations, lasers are utilized to restructure the gums and eradicate germs.

- Biopsy and lesion elimination: To check for cancer, a tiny sample of tissue (referred to as a biopsy) may be removed with the use of lasers. Lasers may also be used to treat canker sores and eliminate lesions from the mouth.

- Whitening teeth: teeth whitening is made faster with the use of lasers. Laser radiation "activates" a peroxide bleaching solution given to the teeth, accelerating the whitening process.

- Nerve repair and regeneration: To limit the production of inflammatory mediators from damaged neurons, low-level laser treatment was shown to improve neuronal maturation and regeneration.

- Debonding ceramic brackets

Laser in dentistry provides a broad range of advantages for patients, including decreased or eliminated discomfort during dental operations. These are some examples:

- Some operations may not need the use of anesthetic.

- Laser treatment sanitizes the area being treated, lowering the chance of bacterial infection.

- The requirement for sutures may be reduced in certain treatments.
- Minimal blood loss because of the laser's ability to speed up the clotting process.
- Quick healing time.
- less post-procedure edema and discomfort.
- Reduction in medicine and antibiotic use after therapy.

Er:YAG will be employed in this experiment. There are many rare-earth elements that may be used in fiber lasers, the most common of which are the rare-earth dopants such as ErB2, YB2, Nd, DyB2, and Thulium. Fiber lasers are used in a variety of industries, including manufacturing, telecommunications, spectroscopy, and even medicine. Fiber lasers provide several benefits over other forms of lasers, such as:

- Flexible fiber contains light: due to the presence of the light in a fiber, it can be easily transmitted to a moveable focusing device.
- Powerful yield: As a result of their lengthy active zones, fiber lasers can produce very large optical gains. Fibers can handle continuous output power levels of kilowatts, which facilitates effective cooling.
- Optically excellent: The fiber's waveguiding properties help to keep the optical path from being bent by heat. This usually results in a diffraction-limited, high-quality beam of light.
- Small: They are smaller than other lasers but with the same effectiveness.

- Constancy: they are very stable, have a long life, and do not need any maintenance.

In addition, lasers can cut down on the quantity of tissue that must be cut off to prepare cavity, which means that there will not be any smear layer left behind. This means that bonding and restorative materials can be directly applied to the reduced area, without having to first acid-etch the area.

On the other hand, the photothermal action of the laser works as an adjunctive treatment to cure dentin hypersensitivity. Due to the pulsed application process, a high-intensity laser may obliterate the entrance to dentin tubules, hence reducing liquid mobility among them. Another critical feature of the ablation method is the temperature dissipation that occurs when lasers are applied to dental hard tissues. While the heat generated during the release of laser beat can accumulate to dangerous levels, this effect can be significantly reduced by using wavelengths in optimized absorption bands for enamel and dentin, dosimetry, and energy densities suitable with the optical properties of the irradiated tissue modulated within safe parameters established in scientific literature, in addition to the appropriate cavitation. [23]

According to Khouja and M. Abdelaziz, a temperature increases of 3.5°C was formerly considered to be crucial for pulpal health. After two cycles of irradiation for 30s each using 808 nm diode laser, the results showed a rise in both the surface and subsurface temperatures with all laser settings (delta PT and delta ST). Where no changes were seen on the enamel surface when examined with a digital microscope. Both researchers concluded that, an 808-nm diode laser was safe when it was used for two cycles of 30 seconds each. The laser was used at a constant 1W and a pulsed 5W. [24]

Researchers Zach and Cohen used a hot soldering iron to conduct studies on rhesus monkeys to investigate the impact of thermal irritation on the pulp tissue. Temperature rises of 5.5°C and 11.1°C induced permanent damage to pulp tissue in between 15 and 60 percent of cases, respectively. [25]

In the study of Klaric et al, ZOOM2 was used for 15 minutes, LEDs were used for 30 minutes, OLEDs (organic light emitting diodes) were used for 30 minutes, and a femtosecond laser was used for 30 minutes. ZOOM2 helped in raising the temperature of the pulp from 15.7 degree Celsius to 21.1 degree Celsius without using bleach gel. While on the other hand, using the gel the temperature of the pulp was 15.7 degree Celsius and becomes 8.7 degree Celsius. In this way, it should also be said that the procedure where heat is transmitted in tissues and the wavelength of the light used affects how it works. [26]

According to Sari et. al study [27], A red-colored bleaching agent with 30% water content was applied to the labial surfaces of the teeth. Then, three different laser beams were used to measure the brightness of each tooth. There was a Er: YAG laser (40 mJ,10 HZ,20s), an 810-nm diode laser, and LED as the control. The results showed that, In the diode laser group, the pulp temperature was raised 2.61 °C. The Er: YAG laser group rose 1.86 °C, and the LED group rose 0.02 °C. For one thing, the diode laser group saw the lowest gel temperature rises (6.21 °C). The LED (12.38 °C) and Er: YAG (20.11 °C) groups were next. Sari et. al conclude that, even the temperature is increasing, all lasers can be used safely with the use of a bleaching gel according to certain parameters.

2.5 Dental Lasers in Ceramic Bracket Bonding

Enamel exposed to laser light alters the surface's physical and chemical properties, and these changes show potential for preparing enamel for bonding processes.

Lasers have been used in orthodontics because of the hard tissue studies that were done with lasers in the past. Laser irradiation causes enamel surface changes that are caused by heat. It makes the surface rough and uneven, like acid etching. This is like how acid etching works. There are a lot of small explosions that happen when water in the hydroxyapatite matrix vaporizes. This causes the etching to happen over time. Photon energy is a big factor in how much energy there is.

Laser etching does not hurt and does not use vibration or heat, which makes it very appealing for everyday use. It has also been said that etching enamel or dentin with laser can leave a surface that is broken and uneven, which is good for adhesion and bonding procedure. It would be very important for orthodontics if lasers could make teeth more resistant to decay. [28]

In 1995, Eversole and Rizoiu studied a hydrokinetic laser system using Er,Cr:YSGG. Hard tissue preparation, soft tissue effects, osseous healing, and pulpal responses were all assessed using the same equipment. Hydro kinesis refers to the process in which laser energy interacts with water to cut precisely through hard tissue at the tissue-to-water interface. Using this method, Lin et al. looked at how it sliced through hard tissue. [29-30-31-32]

According to Jun Hui Wang and Kuan Yang study, dentin samples were made from freshly extracted, still-intact primary molars. They were then spontaneously split into four groups based on the surface treatment used. Those in the control and etchant groups didn't get any treatment, while those in the energy and frequency groups got laser surface treatment with different energy and frequency settings. This was done with scanning electron microscopy. The surface-treated dentin slices were glued to resin tablets, then heated in a thermocycle for a long time. The results show that, there was a particular energy and frequency range in which the dentin tubules opened (50-200 mJ; 5-20 Hz).

Cracks and structural breakdown appeared in the intratubular dentin beyond this point. When compared to the control group, the Er:YAG laser pre-treatment considerably enhanced the shear strength ($P \ \ 0.05$). we can conclude that, a pre-treatment with the Er:YAG laser opens up the tubules in the dentin without the formation of a smear layer and it will increase the bonding strength between the primary teeth's dentin and the resin composites. [33]

In 2018, Amir.H and Nasim.Ch did a comparative study between Er,Cr:YSGG and Er:YAG lasers to determine which laser is most effective for etching and affixing composite resins to orthodontic brackets. For the first group, tooth was etched with acid for 10s. The second group was etched with erbium laser at 2W for 10s. The third group was also etched with the same previously used laser but at 3W for 10s. The fourth group was etched using Er:Cr:YSGG laser at 2W for 10s. Finally for the fifth group, we etched using the same used laser previously but at 3 W for 10s. It took 5000 thermal cycles for the metal to bond to the composites, and after 24 hours of water storage, they were tested for shear bond strength. From each group, one specimen was examined under SEM to see how the surface of the composite changed after etching. A stereomicroscope was used to figure out the adhesive remnant index (ARI). Statistical analysis was done on the data. A shear bond's strength was 18.65 MPa on average and 19.68 MPa on average in groups 1-5. The groups didn't have very different shear bond strength. So, they conclude that, using both lasers with these parameters makes it possible to make a strong bond between the bracket and the composite. [35]

Chapter 3
Materials and Methods

3.1 Teeth

2-year-old bovine mandibular incisor teeth were used instead of human teeth because they were easier to find, had better hygiene, and were like human teeth. Reports from the past also found no clinically significant differences in the debonding forces of brackets that were attached to the front teeth or the back teeth. After extraction, the teeth were cleaned and scaled off calculus, soft-tissue, and blood. Then, the teeth were rinsed. Pumice was used to clean and polish the labial surfaces on the teeth of cattle that had been cut. Isotonic sodium-chloride solution was chosen to keep the samples in at room temperature until the experiments.

3.2 Orthodontic Ceramic Bracket

G&H.US made polycrystalline ceramic brackets for maxillary incisors and were used to be bonded onto the bovine incisors.

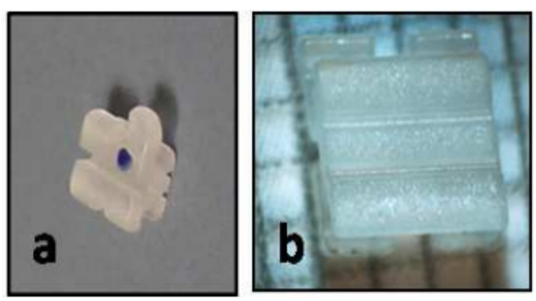

Figure 14: G&H.US made Polycrystalline Ceramic Brackets for maxillar-incisors

(a) Bracket, (b) The bracket's base area

3.3 Experimental Procedure

3.3.1 Preparation of the sample: For each experimental group in the study, all teeth were prepared using those steps. The first step was preparing gypsum mixture for each tooth and embedding the root parts of each tooth but not their crowns in gypsum. The enamel's labial surface was aligned as nearly parallel to the block's vertical axis as feasible. After that, the procedure finished by hardening the gypsum and polishing the gypsum blocks to make them ready for experiments.

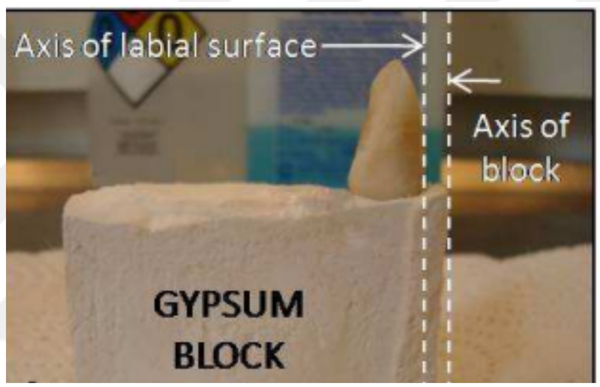

Figure 15: The Side View of the Tooth Specimen Embedded in The Gypsum Block.

There are two types of main experimental groups: irradiated Groups and non-radiated groups. For all samples, irradiated and radiated groups, a hole was opened using a round diamond bur with 1mm diameter on the lingual part of the teeth's crown where also temperature was measured in the pulpal cavity during the laser irradiation in this part of the teeth. (Figure 16). The same procedures were applied to all samples up to this stage. After that, the experimental samples were processed according to etching type that is applied.

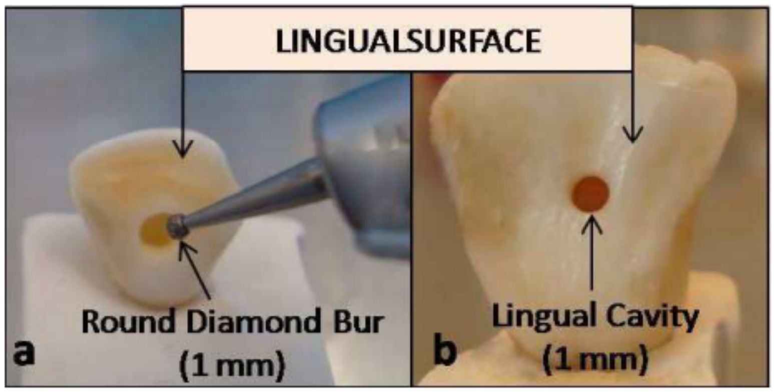

Figure 16: (a) and (b) For each Sample in Irradiated Groups, a Lingual Cavity was Opened.

The experiments in this thesis were conducted in two stages:

- The first stage was the preliminary experiments stage. In this stage, the temperature increases by different parameters that were applied at a selected wavelength in the pulp chamber.

- The second stage was the main experimental stage. A selected type of etching protocol was applied to each experimental group that are divided between irradiated groups and non-irradiated conventional group.

3.3.2 Temperature Measurement. The first stage was the preliminary experiments stage. In this stage, the temperature increases caused by different parameters that were applied at a selected wavelength in the pulp chamber.

In this part of the study, a temperature measurement set-up was prepared. Temperature was measured for each sample. After replacing the sample block in the set-up, the thermocouple was put into the cavity opened at the lingual part of the teeth.

A thermocouple K-type can detect any temperature sensor containing chromel and Alumel conductors, was used for temperature measurements in this study.

We used parameters in this study that are recommended by the laser company in clinical practice for the etching procedure at this wavelength. Based on an earlier preliminary investigation of intrapulpal thermal changes, the yield of energy values employed in this part are chosen from the recommednded parameters as shown in the table below:

Table 3

Er: YAG Laser System was used at 2940 nm at 1.5 w with Different Energy Yield Levels.

Groups	Energy (mJ)	Pulse rate (Hz)	Potential mean (W)	Irradiation time (s)	Energy density (J/cm2)
100 mj/15 Hz Group	100 mj	15	1,5	20	74,0
250 mj/6 Hz Group	250 mj	6	1,5	20	80,2
250 mj/15 Hz Group	250 mj	15	3,25	10	80,2
300 mj/6 Hz Group	300 mj	6	1,8	20	96,2

Perpendicularly, the laser beam was positioned on enamel with 3 mm distance between tooth and the tip of the laser. The fiber waveguide had a 1.6 mm outside diameter. The Laser beam's diameter was maintained at the same length regardless of distance. A total of four groups of samples were created based on the parameters informed.

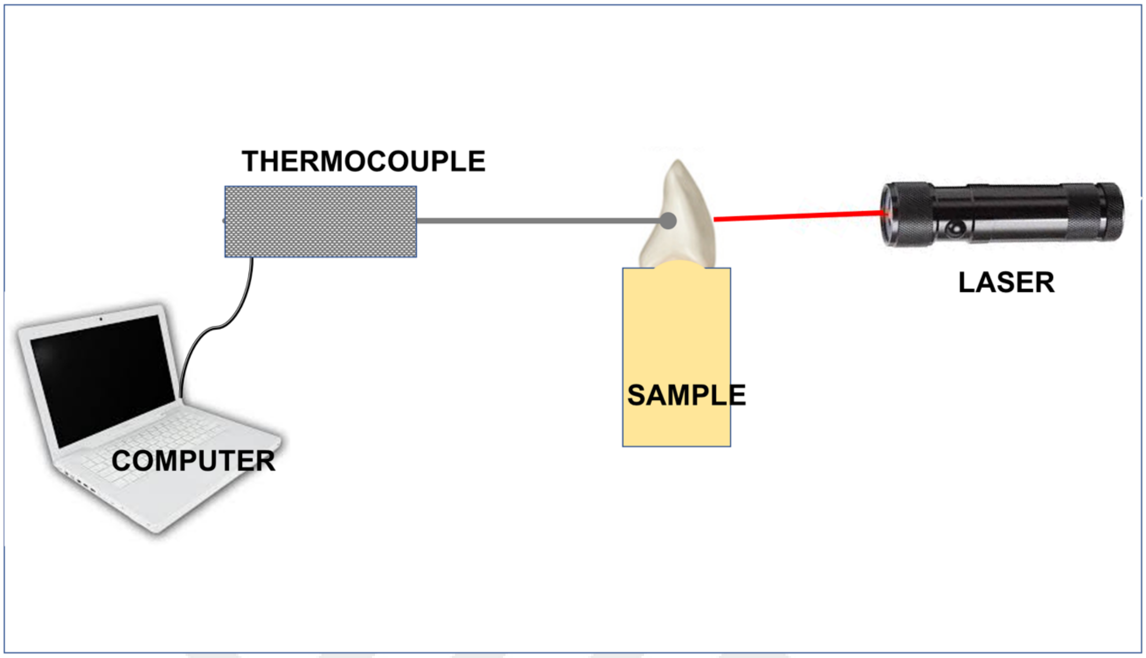

Figure 17: Set-up for Temperature Measurement Inside the Pulp During Lasering.

While the lasing procedure, temperature measurements in the pulp of teeth were monitored via this type of thermocouple. Data was read, collected, and recorded by a computer. Data are shown according to (SD).

3.4 Main Experiments

3.4.1 Etching, Bonding and Debonding Procedure: All brackets were affixed using the selected type of orthodontic adhesive according to the manufacturer's guidelines. The sequential steps in the traditional bonding procedure for directly attaching brackets to the lingual surface are the following: polishing, Etching, fastening, and Binding.

Specimens underwent a preparatory process involving washing and polishing with a pumice paste for 15 seconds prior to the bonding procedure. Subsequently, they were thoroughly rinsed and dried to eliminate any plaque or organic pellicle that may be on the teeth before the etching step. “According to the different etching techniques applied in the clinic, two types of etching methods were applied in this study. The first type of etching group was consisted of samples applied with conventional acid etching method. In this group, 37% phosphoric acid was applied for 30 seconds in the etching step of bracket bonding. The second type of etching method was laser-etching. The samples of the laser groups in this study were created by roughening the enamel surface with the help of laser by applying different parameters.

In conventional method group, teeth were etched using 37% phosphoric acid for 30 seconds. After the limited time, this surface was washed using a syringe filled with distilled water, and then dried. After this process, the enamel had a frosty white look was obtained because of etching the enamel.

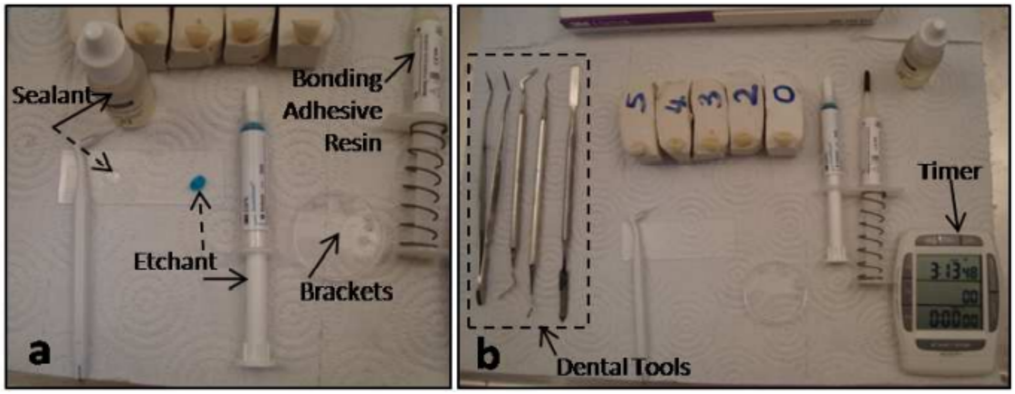

Figure 18: All used Materials During Bonding Period at These Experiments.

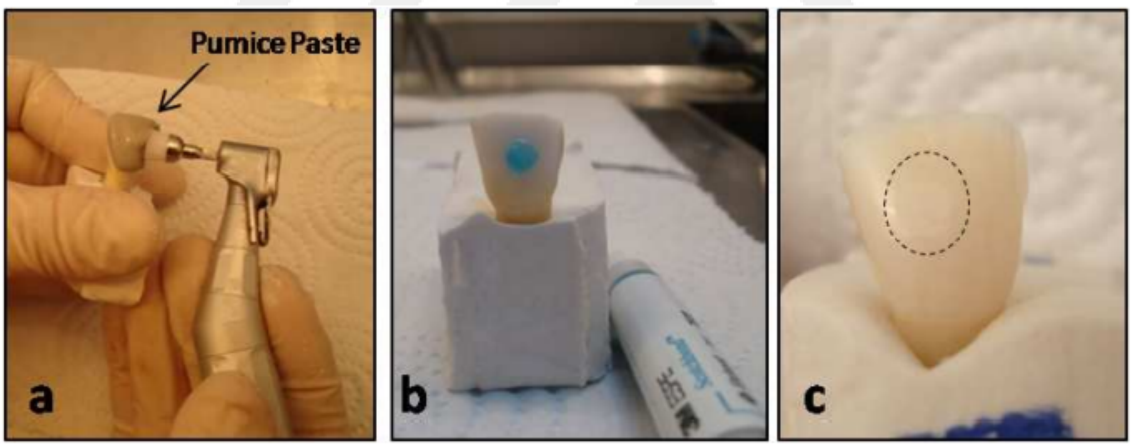

Figure 19: Enamel Cleaning with Pumice

In laser etched groups, the etching on enamel was done by roughening the enamel surface with using the selected parameter in different patterns. Enamel was etched by erbium laser at 2.94µm, 1.5W and 15Hz. After determination of the possible laser parameters in the preliminary experiments, three different irradiation patterns were applied during the experimental study:

- Point Irradiation Group (PG): Laser beam was applied as a single point from 5 cm to the center of the bracket bonding area.
- Vertical Scanned Irradiation Group (VSG): Enamel was scanned at a settled distance, equal to the bracket area, with the laser beam perpendicular to the cutting edge of the tooth. Enamel was etched by Erbium laser at 2.94µm, 1.5W and 15Hz.
- Horizontally Scanned Irradiation Group (HSG): The enamel surface equal to the bracket area was scanned at a fixed distance with the laser beam parallel to the cutting edge of the tooth. Enamel was etched by Erbium laser at 2.94µm, 1.5W and 15Hz.

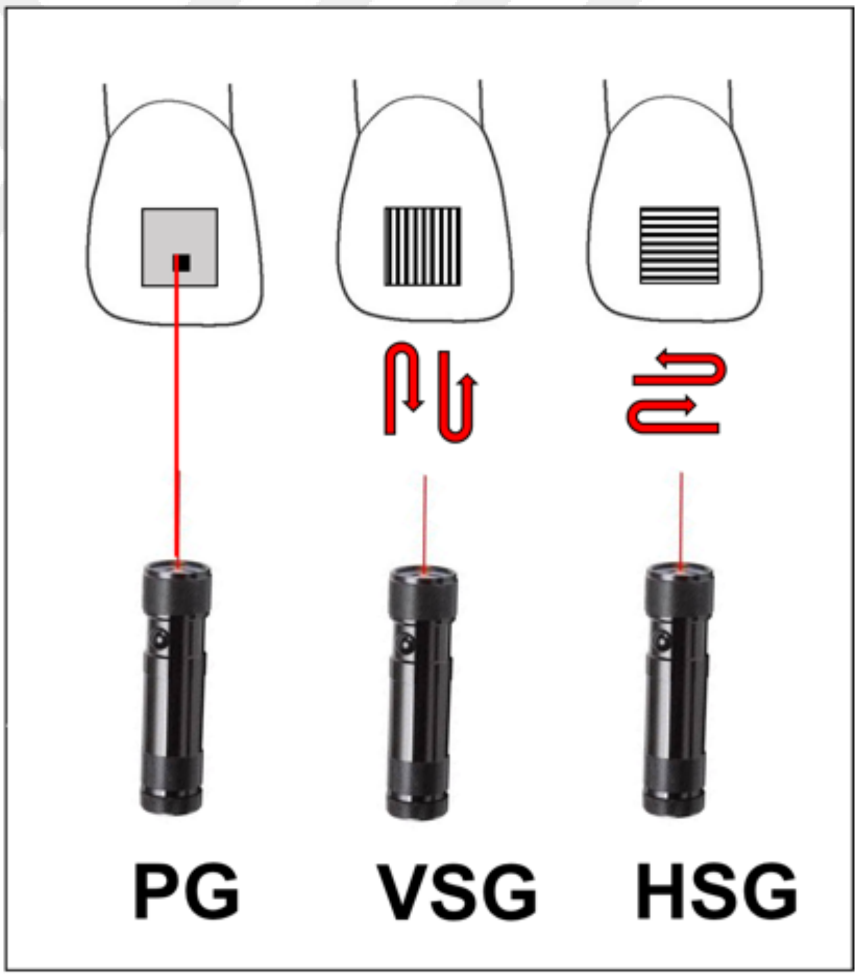

Figure 20: Three Different Irradiation Patterns were Applied During the Experimental Study, PG, VSG and HSG.

Following the application of varying etching techniques, all procedures were applied the same again for each group, both radiated and non-radiated ones. The sealant was applied to the related enamel region and to the base of the bracket. Tweezers were used to replace the bracket after sealant application to the base, the bracket was replaced by using a tweezer in the most optimal position.

The important point was to replace the bracket exactly on the opposite side of the bonding cavity. After ensuring the polymerization, any excess resin was removed using a hand scaler.

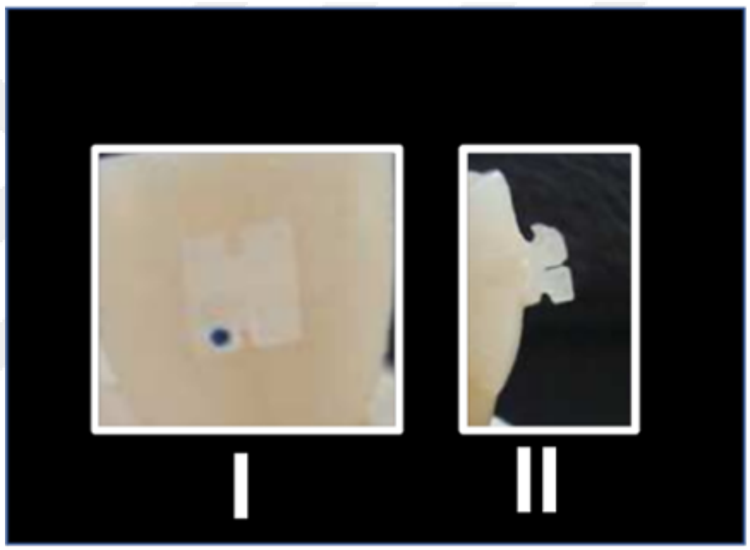

Figure 21: Bonded Ceramic Brackets:
I-Labial View, II Lateral View.

Before shear bond testing after debonding, all samples were incubated at 37 degrees Celsius for 48 hours in distilled water solution. This step was undertaken to ensure thorough composite polymerization.

3.5 Debonding Procedure

At the second phase of our thesis experiments, the bonded ceramic brackets were prepared to be debonded after polymerization. Debonding procedure was done by using a universal testing machine (Lloyd, LF Plus, UK) and aim was to measure the shear-bond-strength (SBS) force in newtons during debonding. The universal testing machine set up consists of a universal testing machine and a computer for recording the data. This testing machine features a dual-jaw design, where one jaw serves as a stable support with a testing frame for accommodating gypsum blocks, while the other incorporates a mobile component and a debonding mechanism equipped with a shearing blade. This configuration facilitates the controlled debonding of ceramic brackets with precision and efficiency. As the shear bond strength was assessed using a universal testing machine to de-bond the ceramic brackets, all data was captured, collected, and recorded using computer.

Four different groups were examined in this the experimental study:

- Conventional Acid Etching Group: The Samples were etched using 37% phosphoric acid for 30 seconds as it is done in the conventional method in clinic.
- Point Irradiation Group (PG): The samples were etched via laser light using selected parameter. Laser beam was applied as a single point from 5 cm to the center of the bracket bonding area.
- Vertical Scanned Irradiation Group (VSG): The samples were etched via laser light using selected parameter. Enamel was scanned at a settled distance, equal to the bracket area, with the laser beam was at a perpendicular position to the cutting edge of the tooth.
- Horizontally Scanned Irradiation Group (HSG): The samples were etched via laser light using selected parameter. The enamel surface equal to the bracket area was scanned at a fixed distance with the laser beam was in a parallel position to the cutting edge of the tooth.

All ceramic bracket of the sample was inserted in the prepared space in the machine blade and then a vertical inciso-gingival force was applied at a cross head speed of 1 mm/min. The measured bond strength was directly recorded in Newton unit.

After debonding process all debonding forces were recorded. Data were presented as mean and standard deviation (SD) and thus analyzed to compare the varying methods using statistical tests. A student t-test was used to compare between the etching techniques. A p-value≤0.05 was considered significant.

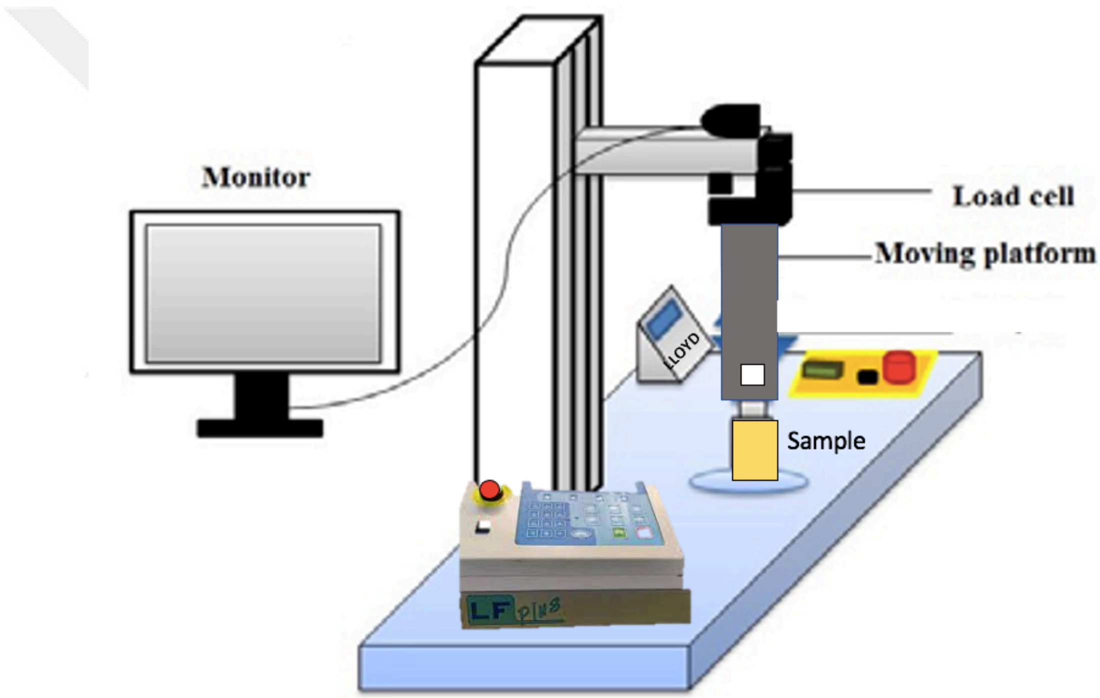

Figure 22: The universal testing machine set up consists of a universal testing machine and a computer for recording the data. This testing machine features a dual-jaw design, where one jaw serves as a stable support with a testing frame for accommodating gypsum blocks, while the other incorporates a mobile component and a debonding mechanism equipped with a shearing blade.

Chapter 4

Results

4.1Preliminary Experiments

4.1.1 Tempretaure Measurments: K-type thermocouple was used to take the measurments of the temperature inside the pulp chamber. Data was recorded by a computer which was connected to the thermocouple. Intrapulpal temperature change is the temperature difference in the pulp between the first measured temperature at the beginnning, and the final temperature after irradiation.

Table 4

Table Shows Mean Temperature Rise, Standard Deviations for the Experimental.

Groups	Energy (mJ)	Pulse rate (Hz)	Potential mean (W)	Irradiation time (s)	Energy density (J/cm2)	Temperature rise (°C) and means (±SD)
100 mj/15 Hz Group	100 mj	15	1,5	20	74,0	1,08 ± 0.66
250 mj/6 Hz Group	250 mj	6	1,5	20	80,2	3,17 ±1.21
250 mj/15 Hz Group	250 mj	15	3,25	10	80,2	8,05 ± 2,18
300 mj/6 Hz Group	300 mj	6	1,8	20	96,2	4,06 ±1,94

Irradiation parameters on enamel surface was applied with the constant power for a determined time range. Parameters are choosed in these according to the laser company in clinical practice for the etching procedure at this wavelength. Mean temperature rise data and standard deviations were calculated for each experimental group.

In this study, experiments were completed and tested according to the rates between 74,0 and 96,2 J laser energy magnitude.

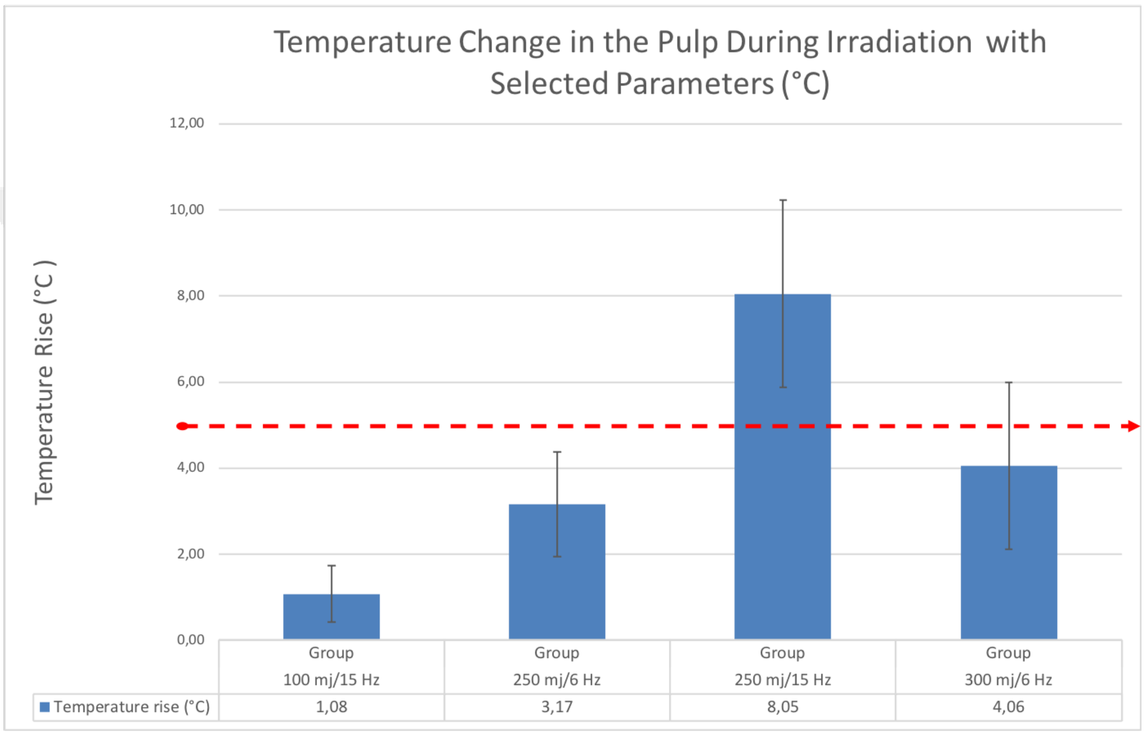

Figure 23: Temperature Change in the Pulp During Irradiation with Selected Parameters in Degree Celsius

The collected data was analyzed and each experimental group was compared. The student *t-test* was used to compare between the laser irradaition groups. A *p*-value≤0.05 was considered significant. Group 100mj/15 Hz was significantly different and had a lower value than all other groups ($p < 0.05$, student t-test). No significant difference is shown in Group 250mj/6 Hz and Group 300mj/6 Hz.

In our thesis study, 5.5°C is the optimum temperature to intercept pulpal destruction during lasering as Zach and Cohen's declared in their study. According to this information, calculated mean values show that Group 100mj/15 Hz, Group 250mj/ 6 Hz, and Group 300mj/ 6 Hz showed a very low temperature value that is equal to the safe value 5.5 ± °C. On the other hand, Group 250mj/ 15 Hz was above the acceptable safe limit which is not in the safe range.

According to the results of the preliminary results parameters of Group 100mj/15 Hz had the safest limits. using the lowest power so it was selected as the optimum parameter for the main part of the thesis study.

4.2 Main Experimental Study

4.2.1 Debonding Forces: According to the laser parameters obtained from the preliminary expeirments, samples were divided into 4 different groups were one of them is the control group, which has samples etched by conventional acid etching method:

- Group I: Conventional Acid Etching Group (AEG) : The Samples were etched using 37% phosphoric acid for 30 seconds as it is done in the conventional method.
- Group II: Point Irradiation Group (PIG) : The samples were etched fom a point via laser light using selected parameter.
- Group III: Vertical Scanned Irradiation Group (VSG) :. The enamel surface was scanned via laser light at a fixed distance, with the laser beam perpendicular to the cutting edge of the tooth.
- Group IV: Horizontally Scanned Irradiation Group (HSG):. The enamel surface was scanned at a fixed distance with the laser beam parallel to the cutting edge of the tooth.

Table 5

Mean Debonding Force and Standard Deviations for Each Group

ETCHING GROUP NAME	ABBREVIATION	MEAN VALUE (N)	STD
Conventional Acid Etching Group	AEG	44,47	± 17,07
Point Irradiation Group	PIG	25,55	± 13,70
Vertical Scanned Irradiation Group	VSG	38,37	± 14,77
Horizontally Scanned Irradiation Group	HSG	48,68	± 23,91

Basal area of polycrystalline ceramic brackets was measured, and average value was calculated with the standard deviation as 10.35 ± 0.41 mm^2

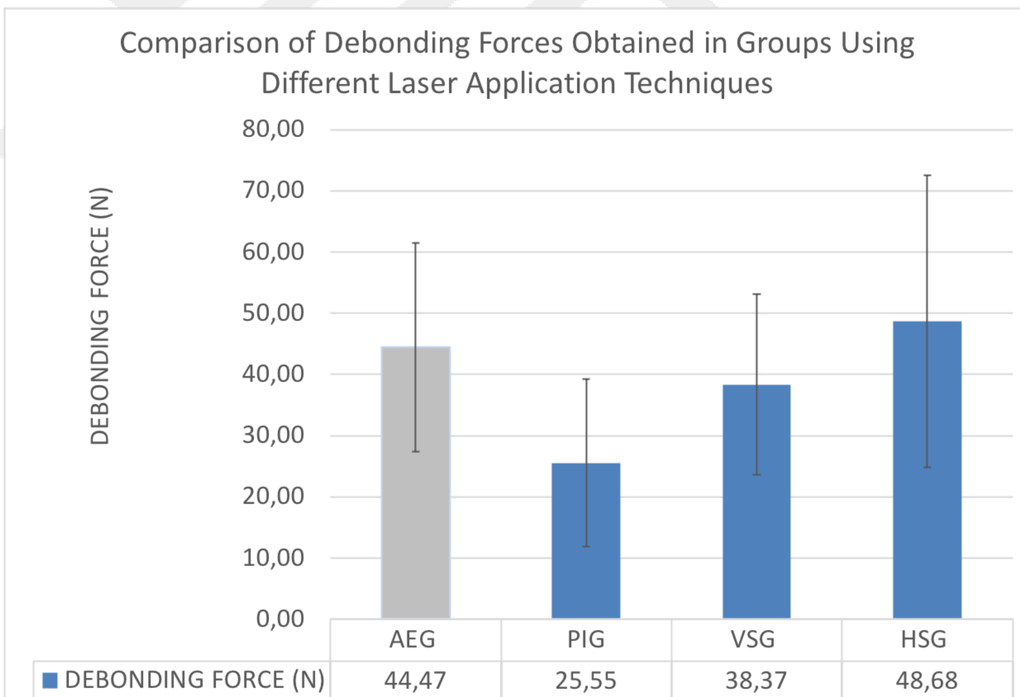

Figure 24: Comparison of Debonding Forces Obtained in Groups using Different Laser Application Techniques

Analysis using student's t-test was used to compare between each group. A significant level was set at $p \leq 0.05$. Our results indicated no statistically significant difference between the acid-etched (44,47±17,07 N) and directionally scanned laser-etched groups, VSG and HSG.. Only point etched group, (PIG), was significantly different from the other laser etched and coneventioanally etched group. Additionally, there was no-significant difference between both laser scanned etched groups, VSG and HSG.

All Erbium Laser Etching imparts clinically acceptable shear bond strength. There was no statistically significant difference between the shear bond strength of the two different laser etched groups and acid-etched group and there is no significant difference between the etching pattern direction.

Chapter 5

Discussion

The usual protocol for bonding an orthodontic bracket to a tooth is to condition the enamel with 37% phosphoric acid before applying adhesive. However, the application of etchant causes a roughly 10-to 15-micrometer loss of mineralized surface, which leads to an unintentional demineralization of the enamel. In addition, the potential for discoloration from resin tags and decalcification, which makes the enamel layer vulnerable to caries attacks.

Any process that helps in protecting enamel and surrounding tissues before bonding ceramic brackets, will serve in protecting the health of the tooth, satisfaction of clients and limit the risk of the formation of caries that leads to tooth damage.

Even if the alteration of these surfaces is very minimal but it is irreversible. Therefore, other etching techniques that minimize enamel loss were found such as laser application (Er:YAG, Er,Cr:YAG, Nd:YAG,CO_2) [38]. In previous bonding studies, Er: YAG showed that this wavelength could be used as an alternative to acid etching technique on enamel surfaces. It may produce an uneven, fractured surface as that are excellent for adhesion and have a reduced chance of developing cavities. Hard dental tissues exposed to laser radiation change in mineral composition, contain less water and organic matter, and form more stable, less acid-soluble compounds [39].

Besides all advantages and disadvantages, Er:YAG (2940 nm) laser was used in many applications in dentistry including, labial frenectomy. A study of Isa et al. shows tha Er:YAG (2940 nm) can highly absorb water and mineral apatite which makes 2940 nm wavelength very safe and needed in the removal of hard tissue. [43]

The experiments were done in two parts in this thesis. In the first stage, preliminary experiments, the temperature increases in the pulp chamber were measured during the application of three different recommended parameters of the selected wavelength for enamel etching. A thermocouple K-type used to measure the temperature increase in pulp chamber during irradiation on the enamel.

As mentioned before researchers Zach and Cohen used a hot soldering iron to conduct studies on rhesus monkeys to investigate the impact of thermal irritation on the pulp tissue. Temperature rises above 5.5°C induced permanent damage to pulp tissue so they concluded that 5.5 degree Celsius is the safest value for temperature raise to keep the enamel away from distortion [25]. In this thesis study, 5.5˚C was also accepted as the optimum temperature to intercept pulpal destruction. Four different laser parameters were compared in the preliminary experiments: Group 100mj/15 Hz, Group 250mj/ 6 Hz, Group 250mj/ 15 Hz, and Group 300mj/ 6 Hz. According to this information, calculated mean values show that Group 100mj/15 Hz, Group 250mj/ 6 Hz, and Group 300mj/ 6 Hz showed a very low temperature value that is equal to the safe value 5.5 ± ˚C. Specially group 100mj/15 Hz that showed the lowest and safest value (1.08 degree celsius).

In addition to this, it was discovered that laser etching at 100mj is sufficient to preserve enamel from distortion. In this study varying parameters were compared using this wavelength and 100 mj/15 Hz/1.5 W parameters was selected among the other recommended parameters. for enamel etching. So the parameters for Group 100mj/15 Hz was selected for the main experimental study.

In the main experimental stage, using the laser parameter obtained from the preliminary expeirments, the importance of scanning pattern was examined and compared in this part. Taking into consideration the numerous benefits of Er:YAG usage on enamel, there were three different lasering patterns examined in this study. point irradiation group (PIG), vertical scanned irradiation group (VSG) and horizontally scanned irradiated group (HSG). All groups examined in this part were:

- Group I: Conventional Acid Etching Group (AEG) : The Samples were etched using 37% phosphoric acid for 30 seconds as it is done in the conventional method.
- Group II: Point Irradiation Group (PIG) : The samples were etched fom a point via laser light using selected parameter.

- Group III: Vertical Scanned Irradiation Group (VSG) :. The enamel surface was scanned via laser light at a fixed distance, with the laser beam perpendicular to the cutting edge of the tooth.
- Group IV: Horizontally Scanned Irradiation Group (HSG):. The enamel surface was scanned at a fixed distance with the laser beam parallel to the cutting edge of the tooth.

The results for group AEG, PIG, VSG and HSG were found as 44,47 ±17,07; 25,55 ±13,70; 38,37 ± 14,77; 48,68 ±23,91 respectively. The analysis utilized the student's t-test to compare each group, with a set significance level of $p \leq 0.05$. The point-etched group (PIG) showed a significant difference from both the laser-etched and conventionally etched groups. Since the results obtained in this group were significantly less than with the conventional method group, regardless of its numerical value, this type of application accepted as it had non-show sufficient adhesion during the treatment with a ceramic bracket.The results of the study also mentioned that there is no statistically significant difference between the acid-etched group and the directionally scanned laser-etched groups, VSG and HSG. Additionally, there was no significant difference between the shear bond strength of the two laser-scanned etched groups, VSG and HSG. The ceramic brackets are bonded as strong as necessary on the tooth surface in log term orthodontics therapy, but they are not significantly different from each other due to the difference in pattern.

As in this study, Salam et al. used t same parameter to etch enamel at 1.5W and 15Hz and found that using Er:YAG (1.5W/15 Hz) laser for etching enamel showed optimum bond strength. As said, parallel to that study, in this thesis study, Er:YAG was used to etch enamel at 1.5W and 15Hz. Our results indicated no statistically significant difference between the acid-etched (44,47±17,07 N) and directionally scanned laser-etched groups. So we can conclude that etching at a certain point on tooth (PIG) with the same parameteres of laser indicated above leads to an acceptable bond strength.[41]

In summary, Erbium Laser Etching demonstrated shear bond strength within clinically acceptable limits. No statistically significant difference was observed between the shear bond strength of the two laser-etched groups, acid-etched group, and there was no significant distinction between the etching pattern directions.

Using near parameters Jing et. All. Found comparably different results. The study of Jing et al, tested the effect of binding laser and acid etching methods together. Both etching methods were used for etching ceramic specimens but in different parameters. Groups were divided into two: acid etching group and acid plus laser etched group with specific parameters. Both groups were etched according to the following parameters respectively: 250 mj/20Hz and 300mj/20 Hz for each group. In conclusion, they found out that groups with combined etching methods (Er:YAG and Hf acid) at 250mj/20 Hz obtain satisfying bond strength and a high reduction rate of fracture while bonding procedure. In contrast, in our study we used only Er:YAG laser as an etching technique with optimum parameter 100mj/15Hz that showed acceptable results on shear bond strength.[44]

The study done by Hosseini et al, tested different Er:YAG laser power in the preparation of enamel to make it ready for bonding process. 45 human premolars were randomly divided into groups according to the etching technique and the power used. The first group was acid etched with 37 % phosphoric acid. The second group was etched using erbium laser at 1W power. Finally, the last group was also lased with erbium laser but at 1.5W. The results shows that both used powers (1W and 1.5W) and acid etching technique showed same results. But laser etched samples showed high bond strength. In our study we used 1.5W and it was a sufficient value.[45]

Chapter 6

Conclusion

As a conclusion, erbium laser showed many clinical benefits through many studies in literature and in this study. There was no significant difference between acid etched and laser etched these experimental groups, so this study mentions that using this wavelength with determined parameters is a properly working etching technique that leads to an adequate shear bond strength. Point Irradiated Group has the least debonding force values used in laser etching groups, in comparison with Horizontally Scanned Group and Vertically Scanned Group. This value is lower than the acid etched group.

Er: YAG 2940 nm, 1.5 W, 15 HZ, 100mj showed to be a well-chosen parameter in this study because it leaded to an optimum value of intrapulpal temperature, shear bond strength and low debonding force.

For further works, combining two etching techniques (acid and laser) with different laser patterns can be studied for further knowledge on enamel health and to find the best bonding and etching techniques.

REFERENCES

Adhesion of Teeth Zhilong Zhao[1†], Qihui Wang[1†], Jing Zhao[2], Bo Zhao[1], Zhangyu Ma[3] and Congxiao Zhang[1*]

Alves JCC, Borges GA, Versluis A, Soares CJ, Veríssimo C. Effect of Orthodontic Bracket Type and Mouthguard Presence on the Stress and Strain during a Frontal Impact. Braz Dent J. 2020.

Alzainal AH, Majud AS, Al-Ani AM, Mageet AO. Orthodontic Bonding: Review of the Literature. Int J Dent. 2020.

Elekdag-Türk, Selma, (née, Hüdanur. "Ceramic Brackets Revisited". Current Approaches in Orthodontics, edited by Belma Aslan, Fatma Uzuner, IntechOpen, 2018.

Eversole LR, Rizoiu IM, Kimmel AI. Osseous repair subsequent to surgery with an erbium hydrokinetic laser system. International Laser Congress; 1996.

Eversole LR, Rizoiu IM, Kimmel AI. Pulpal response to cavity preparation by an erbium, chromium:YSGG laser-powered hydrokinetic system. J Am Dent Assoc 1997.

Eversole LR, Rizoiu IM. Preliminary investigations on the utility of an erbium, chromium YSGG laser. J Can Dent Assoc 1995.

Fleming PS. Timing orthodontic treatment: early or late? Aust Dent J. 2017.

Fornaini, Carlo et al. "Use of 1070 nm fiber lasers in oral surgery: preliminary ex vivo study with FBG temperature monitoring." Laser therapy vol. 26,4 (2017).

Francisco I, Travassos R, Nunes C, Ribeiro M, Marques F, Pereira F, Marto CM, Carrilho E, Oliveiros B, Paula AB, Vale F. What Is the Most Effective Technique for Bonding Brackets on Ceramic-A Systematic Review and Meta-Analysis. Bioengineering (Basel). 2022.

Francisco I, Travassos R, Nunes C, Ribeiro M, Marques F, Pereira F, Marto CM, Carrilho E, Oliveiros B, Paula AB, Vale F. What Is the Most Effective Technique for Bonding Brackets on Ceramic-A Systematic Review and Meta-Analysis. Bioengineering (Basel). 2022.

Francisco I, Travassos R, Nunes C, Ribeiro M, Marques F, Pereira F, Marto CM, Carrilho E, Oliveiros B, Paula AB, Vale F. What Is the Most Effective Technique for Bonding Brackets on Ceramic-A Systematic Review and Meta-Analysis. Bioengineering (Basel). 2022.

Fuhrmann R, Gutknecht N, Magunski A, Lampert F, Diedrich P. Conditioning of enamel with Nd:YAG and CO2 dental laser systems and with phosphoric acid. An in-vitro comparison of the tensile bond strength and the morphology of the enamel surface. J Orofac Orthop. 2001.

Ghannam MG, Alameddine H, Bordoni B. Anatomy, Head and Neck, Pulp (Tooth) [Updated 2021 Aug 11]. In: StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing; 2022.

Gontijo, Isa et al. "The applications of diode and Er:YAG lasers in labial frenectomy in infant patients." Journal of dentistry for children (Chicago, Ill.) vol. 72,1 (2005).

Haruyama A, Kameyama A, Kato J, et al. Resin Bonding of Self-Etch Adhesives to Bovine Dentin Bleached from Pulp Chamber. Biomed Res Int. 2016.

Heo MS, Kim JE, Hwang JJ, et al. Artificial intelligence in oral and maxillofacial radiology: what is currently possible? Dentomaxillofac Radiol. 2021.

Hosseini MH, Namvar F, Chalipa J, et al. Comparison of Shear Bond Strength of Orthodontic Brackets Bonded to Enamel Prepared By Er:YAG Laser and Conventional Acid-Etching. J Dent (Tehran). 2012.

Juntavee N, Juntavee A, Wongnara K, Klomklorm P, Khechonnan R. Shear bond strength of ceramic bracket bonded to different surface-treated ceramic materials. J Clin Exp Dent. 2018.

Kamak, Hasan. "Orthodontic brackets selection, placement and debonding." Journal of Orthodontic Research, vol. 3, no. 3, Sept.-Dec. 2015, p. 208. Gale Academic OneFile.

Kazak, Magrur and Nazmiye Dönmez. "Development of Dentin Bonding Systems from Past to Present." Bezmialem Science (2019).

Khouja F, Abdelaziz M, Bortolotto T, Krejci I. Intra-pulpal and subsurface temperature rise during tooth irradiation with 808 nm diode laser: an in vitro study. Eur J Paediatr Dent. 2017.

Klaric E., Rakic M., Sever I., Tarle Z. Temperature rise during experimental light-activated bleaching. Lasers in Medical Science. 2013

Labunet A, Tonea A, Kui A, Sava S. The Use of Laser Energy for Etching Enamel Surfaces in Dentistry-A Scoping Review. Materials (Basel). 2022.

Labunet A, Tonea A, Kui A, Sava S. The Use of Laser Energy for Etching Enamel Surfaces in Dentistry-A Scoping Review. Materials (Basel). 2022.

Lasmar M, Reher V, Lalloo R, Reher P. Enamel demineralization and bracket bond strength when etching with acid and/or Er: YAG laser. Aust Dent J. 2012.

Lima DM, Tonetto MR, de Mendonça AAM, Elossais AA, Saad JRC, de Andrade MF, Pinto SCS, Bandéca MC. Human Dental Enamel and Dentin Structural Effects after Er:yag Laser Irradiation. J Contemp Dent Pract 2014.

M. Iijima, ... T. Eliades, in Orthodontic Applications of Biomaterials, 2017.

Mirhashemi AH, Chiniforush N, Sharifi N, Hosseini AM. Comparative efficacy of Er,Cr:YSGG and Er:YAG lasers for etching of composite for orthodontic bracket bonding. Lasers Med Sci. 2018.

Nahas P, Nammour S, Gerges E, Zeinoun T. Comparison between Shear Bond Strength of Er:YAG and Er,Cr:YSGG Lasers-Assisted Dentinal Adhesion of Self-Adhering Resin Composite: An Ex Vivo Study. Dent J (Basel). 2020;8(3):66. Published 2020.

Nakabayashi N, Kojima K, Masuhara E. The promotion of adhesion by the infiltration of monomers into tooth substrates. J Biomed Mater Res 1982.

Nojima, Lincoln Issamu et al. "Indirect orthodontic bonding--a modified technique for improved efficiency and precision." Dental press journal of orthodontics vol. 20,3 (2015)

Parker, S. Introduction, history of lasers and laser light production. Br Dent J **202,** 21–31 (2007).

Rizoiu IM, Eversole LR, Kimmel AI. Effects of an erbium, chromium, yttrium, scandium, gallium, garnet laser on mucocutanous soft tissue. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 1996.

Sallam RA, Arnout EA. Effect of Er: YAG laser etching on shear bond strength of orthodontic bracket. Saudi Med J. 2018.

Sari T, Celik G, Usumez A. Temperature rise in pulp and gel during laser-activated bleaching: in vitro. Lasers Med Sci. 2015

Sfondrini MF, Calderoni G, Vitale MC, Gandini P, Scribante A. Is laser conditioning a valid alternative to conventional etching for aesthetic brackets? Eur J Paediatr Dent. 2018.

Subramanian SK, Anbarasu P, Joushua RS, Jeyaraj Y, Iyer SR, Bhaskar N. Effect of Er, Cr:YSGG laser enamel etching with varying power output and irradiation time on the shear bond strength. J Orthod Sci. 2022.

Uşümez S, Orhan M, Uşümez A. Laser etching of enamel for direct bonding with an Er,Cr:YSGG hydrokinetic laser system. Am J Orthod Dentofacial Orthop. 2002;122(6):649-656

Verma, Sanjeev Kumar et al. "Laser in dentistry: An innovative tool in modern dental practice." National journal of maxillofacial surgery vol. 3,2 (2012).

Verma, Sanjeev Kumar et al. "Laser in dentistry: An innovative tool in modern dental practice." National journal of maxillofacial surgery vol. 3,2 (2012).

Wang JH, Yang K, Zhang BZ, et al. Effects of Er:YAG laser pre-treatment on dentin structure and bonding strength of primary teeth: an in vitro study. BMC Oral Health. 2020.

Xu Z, Li J, Fan X, Huang X. Bonding Strength of Orthodontic Brackets on Porcelain Surfaces Etched by Er:YAG Laser. Photomed Laser Surg. 2018.

Youngson CC, Gray NJ. An in vitro comparative analysis: Scanning electron microscopy of dentin/restoration interfaces. Dent Mater 1992.

Zach, L., C. G., Pulp response to externally applied heat.,Oral Surg Oral Med Oral Path, Vol. 19, pp. 51530, 1965.