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MASTER THESIS

SHEAR/PEEL BOND STRENGTH OF REBONDED ORTHODONTIC BRACKETS : AN IN VITRO STUDY

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ARI:	Adhesive Remnant Index
CPQ:	Camphorquinone
GIC:	Glass-ionomer cement
HS:	Henry Schein
LED:	Ligth emitting diod
MBT:	McLauglin, Bennet, Trevisi
RPM:	Round per minute
SB:	Sandblasting
SBS:	Shear Bond Strength
SEM:	Scanning electron microscope
STR:	Strength
SWA:	Straight wire appliance
TC:	Tungsten carbide
US:	Ultrasonic
µm:	Micrometer

1.ABSTRACT

SHEAR/PEEL BOND STRENGTH OF REBONDED ORTHODONTIC BRACKETS: AN IN VITRO STUDY

The aim of this study is to examine the success of various bracket base and tooth surface preparation methods before rebonding. Brackets were bonded on 96 specimens with Transbond XT. 12 specimens were randomly selected to form the control group. Brackets were removed and teeth were randomly divided into two equal groups according to the enamel surface preperation procedure. Enamel surface cleaning performed with Henry Schein silicone polishing kit (h.s.) and low-speed tungsten carbide bur (t.c.). Brackets were randomly divided into 4 equal groups and adhesive material was removed with; sandblasting, low-speed tungsten carbide bur, direct torch flame and ultrasonic scaler (u.s.) A total of 8 groups were formed by cross matching the tooth and bracket groups. Total of 9 groups were obtained with control group. Brackets rebonded with the initial procedure, the shear-peel bond strength was measured with a Universal testing machine. Adhesive Remnant Index (ARI) scores were recorded after second debonding. Rebond strength of control group was higher than all rebonding groups. T.c.-sanblasting group showed highest rebond strength. Higher rebond strength were obtained when the enamel surface was cleaned with h.s.. Amongst bracket cleaning methods, sandblasting was most succesful method. Most common failure site was ARI score 2. Lowest rebonding bond strength was recorded in t.c.-u.s. group. There was no statistically significant difference between the enamel cleaning methods, and most successful bracket base cleaning method was sandblasting and least successful was direct flame.

Keywords: Debonding**,** rebonding, sandblasting, shear-peel bond strength, silicone bur.

2.ÖZET

TEKRAR YAPIŞTIRILMIŞ ORTODONTİK BRAKETLERİN SIYIRMA/AYIRMA BAĞLANTI KUVVETİ : BİR IN VİTRO ÇALIŞMA

Bu çalışmanın amacı, çeşitli braket tabanı ve diş yüzeyi temizleme yöntemlerinin tekrar yapıştırma sonrası başarısını incelemektir. İlk aşamada braketler 96 dişe Transbond XT ile yapıştırıldı. Kontrol grubunu oluşturmak için rastgele 12 örnek seçildi. Kontrol grubundaki örnekler evrensel test cihazı ile , diğer braketler braket söküm pensi yardımıyla dişlerden ayrıldıktan sonra dişler, mine yüzey hazırlama prosedürüne göre rastgele iki eşit gruba ayrıldı. Mine yüzey temizliği, Henry Schein silikon polisaj kiti (h.s.) ve düşük hızlı tungsten karbid frez (t.c.) ile gerçekleştirildi. Braketler rastgele 4 eşit gruba ayrıldıktan sonra ve artık adeziv; kumlama, düşük hızlı tungsten karbid frez, direkt torç alevi ve ultrasonik temizleyici (u.s.) Diş ve braket grupları çapraz eşlenerek toplam 8 grup oluşturuldu. Kontrol grubu ile toplam 9 grup elde edildi. Braketler ilk prosedürle yeniden yapıştırıldıktan sonra, sıyırma/ayırma bağlantı kuvveti bir evrensel test cihazı ile ölçüldü. Adhesive Remnant Index (ARI) skorları, ikinci braket koparma işleminden sonra kaydedildi. Kontrol grubunun yeniden bağlanma kuvveti, tüm yeniden bağlanma gruplarından daha yüksek çıktı. T.c.-kumlama grubu en yüksek yeniden bağlanma kuvvetini gösterdi. Mine yüzeyi h.s. ile temizlendiğinde daha yüksek bağlantı kuvveti elde edildi ama aralarında istatistiksel olarak anlamlı bir fark bulunmadı. Braket temizleme yöntemleri arasında kumlama en başarılı yöntemdi. En yaygın başarısızlık bölgesi ARI skor 2 oldu. En düşük yeniden bağlanma bağlanma kuvveti t.c.-u.s. grubunda kaydedildi. ve en başarılı braket tabanı temizleme yöntemi kumlama, en az başarılı olan ise doğrudan alev çıktı.

Anahtar Kelimeler: Debonding, rebonding, sandblasting, shear-peel bond strength, silicone bur.

3.BACKGROUND

Rebonding of the failed brackets or brackets that require intentional repositioning is a process that we frequently do during orthodontic treatment. The preperations to be made on the tooth and bracket surface must be carefully selected in order to be successful. Although there are various recycling methods, some of these methods are impractical or costly.

In this study, different cost effective rebonding methods which can be easily carried out will be utilized. Each method's bonding strength and success will be investigated and compared.

This study will examine shear/peel bond strengths of brackets rebonded according to selected modalities. Results will be compared and contrasted with those of similar studies. Rebonded brackets or freshly bonded brackets are exposed to various intraoral forces during chewing. These forces can come from any angle, the effect and moment of the force will change according to its geometric relationship to the bracket tooth interface.

A simulation of rectangular wire and rectangular slot relationship under shear/peel force application is the focus of this experimental study. Direct forces and moments acting on the bracket bases will be considered.

Aim of this study is creating a mechanism that will mimic mentioned scenario and transmit both shear and peel force types to the bracket, the effectiveness of the procedures applied to debonded brackets and teeth and their comparison with each other will be put forth.

The null hypothesis of this study is that the adhesive cleaning methods applied to the bracket and enamel surface before rebonding have no significant effect on the bond strength of the bracket to the tooth.

4.INTRODUCTION

4.1.Development Of Orthodontics

Orthodontics is a specialty of dentistry mainly focused on the growth and development of the facial structures and occlusion, and centered around the prevention and treatment of occlusal and dentofacial anomalies and abnormalities. The term “orthodontics” roots from Ancient Greek words “orthos” and “odontos” , which respectively mean correct and tooth (1).

A significant portion of the population has struggled with crowded, crooked, and protruding teeth since ancient times. Attempts to solve this issue date back at least a thousand years around 1000 B.C. Primitive orthodontic devices have been discovered in both Greek and Etruscan remains. As dentistry evolved in the 18th and 19th centuries, various authors described a variety of devices for the regulation of the teeth.

After 1850, the first systematic descriptions of orthodontics appeared, the most notable of which was Oral Deformities by Norman Kingsley. Kingsley, who had a significant impact on American dentistry in the second half of the 19th century, was one of the first to use extraoral force to fix bulging teeth. In addition, he was a pioneer in the treatment of cleft palate and associated symptoms. As it was common practice to extract teeth for a variety of dental issues, extractions due to crowding and misalignment were common.

During a time when complete dentition was uncommon, occlusal relationships were not regarded as an important issue. Late in the 19th century, a notion of occlusion was formed in order to create an effective prosthetic replacement teeth. A s the concepts of prosthetic occlusion progressed and improved, implementing them to natural dentition was inevitable.

Edward H. Angle, whose significance began to be apparent around 1890, is largely responsible for the emergence of the natural dental occlusion concept. His growing interest in occlusion and the requisite application to achieve normal occlusion ultimately led to the creation of orthodontics as a specialization, and himself as the "father of contemporary orthodontics" (2).

4.2.Development Of Fixed Orthodontic Mechanics

4.2.1.Work of Edward H. Angle

Edward H. Angle produced countless designs and developed numerous fixed orthodontic mechanics, from the first appliance he labeled as "Angle System" in 1887 to the "Edgewise" technique he presented two years prior to his passing away in 1928.

4.2.1.1.Angle system

In his first system called the Angle System, he attached the bands to the teeth by soldering them to the screws he invented, and he produced the first fixed orthodontic attachment capable of applying rotational force to the teeth. The rotational force was delivered by passing Coffin's wire through the precise metal tubes fixed to the bands.

4.2.1.2.E arch system

By 1907, the use of screws for tooth movement was obsolete. Meanwhile a new appliance arose. This appliance consisted a thick, rigid arch connected to the molar bands and passing through the vestibule of the teeth, with copper wires ligating the archwire to the teeth. This appliance was based on the principle of three-dimensional expansion. It was named and introduced as "E arch" to the scientific community.

4.2.1.3.Pin and tube system

The inadequacy of existing appliances, their inability to correct axial disorders, and their inability to cause bodily movement of the teeth paved the way for the creation of new ones. In this circumstances, Angle developed the "Pin and Tube" appliance to overcome the teeth's axial tilt correction issues. The appliance was made of vertical tubes that the pins placed on the teeth will enter and pins that are precisely soldered to an archwire. And hence, the first fixed orthodontic appliance that can move roots has been created, despite being extremely challenging to use.

4.2.1.4.Ribbon arch technique

In 1915, Angle developed the "Ribbon Arch," which is incredibly simple and applicable, to address these issues. However, this device was also unable to provide root movements or induce bodily movement.

4.2.1.5.Edgewise technique

Two years prior his death, Angle introduced the Edgewise technique, which drew on his prior experience with the appliances he had initially made. This new setup combines the simplicity to use of the Ribbon Arch appliance with a significant amount of root movement. With the Edgewise technique, controlled tooth movement is possible in all three dimensions. Due to its ability to make root movements in the vestibulo-lingual direction, the Edgewise technique has been a widely used system and has influenced the fundamental principles of all orthodontic bracket systems used to date (3).

4.2.2.Work of Begg

Paul Raymond Begg collaborated with Angle on his new edgewise appliance. Upon his return to Australia, he created his own bracket, a modified version of Angle's previous ribbon arch. In the 1940s, he collaborated with a Melbourne metallurgist to produce a highly resilient, stainless steel "Australian" wire. 1965 saw the publication of his book, Begg Orthodontic Theory and Technique, in which he describes the multiloop light-wire Begg technique (4).

4.2.3.Work of Andrews

4.2.3.1.Straight wire appliance (SWA) system

Lawrence Andrews developed and introduced the straight wire appliance (SWA) in 1970 with the intention of creating an orthodontic fixed appliance that would enable the orthodontist to attain the "six keys" of normal occlusion in the vast majority of cases in an effective and consistent manner. Even though Andrews believed that his appliance could be used to treat a wide range of cases, he developed a series of additional brackets with varying degrees of overcorrection to compensate for undesirable tooth movement that would happen specifically while sliding teeth in extraction cases. Then, Andrews introduced a series of overcorrected brackets, initially referred to as extraction brackets and later as translation brackets. Andrews' complete bracket system turned out less commercially successful than anticipated, in part because his treatment mechanics required a large bracket inventory. Midway through the 1970s, however, Ronald H. Roth drove the Andrews' SWA and combined the standard bracket prescription with some of the overcorrected bracket prescription values. And thus created the "Roth setup". Following Roth prescription, a large number of clinicians introduced minor modifications to both the Andrews and Roth prescriptions (5).

4.2.3.2.Work of McLaughlin, Bennett and Trevisi (MBT)

From 1975 to 1993, McLaughlin and Bennett favored primarily utilizing the standard SWA bracket system. Then, McLaughlin and Bennett collaborated with Trevisi to redesign the whole bracket system to accommodate their established treatment philosophy and overcome the perceived shortcomings of the original SWA. This third generation bracket system, retained the greatest features of the original design while incorporating a number of enhancements and changes to specifications to address the clinical inadequacies based on a combination of fundamental scientific principles and years of clinical experience. MBT is a variation of the pre-adjusted bracket system that was developed particularly for use with light, continuous forces, lacebacks, and bendbacks. Additionally, it was intended to function in conjunction with sliding mechanics in the most efficient manner possible (6).

4.3.Bonded Components In Fixed Orthodontic Treatment

Chemical or micromechanical attachments, depending on the choice of the clinician, are used to attach fixed orthodontic appliances to teeth. Because of this, the clinician is able to accomplish a far wider variety of tooth movements than is possible with removable appliances. The use of an orthodontic archwire in conjunction with the tooth attachments, which is often either a bracket or a tube, may result in movements of the teeth in all three dimensions of space.

4.3.1.Components of fixed appliances

4.3.1.1.Bands

An orthodontic band is a metal ring that surrounds the teeth and where an orthodontic attachment is welded or soldered onto and bonded to teeth in order to hold an orthodontic attachment in place. However, with the introduction of contemporary bonding procedures some forty years ago, orthodontic bands have mainly been replaced by bonded attachments. Bonded attachments are more aesthetically pleasing and simpler to maintain a clean environment than orthodontic bands.Bands are not commonly used except on molars in some cases anymore unless the bond strength of direct attachments is inadequate for the loads that are intended to be applied, or if extra custom laboratory-made components are required.

4.3.1.2.Components which can be directly bonded to teeth

These are orthodontic components that make use of acid-etch adhesive technology in order to adhere directly to the surface of the tooth. The typical components are typically brackets or tubes, both of which come with an integrated prescription and are designed to facilitate the majority of the tooth movements that are required. Buttons, cleats, and gold chains are some of the other components that may be used in as auxiliary function with the primary components. The mechanical interlocking was what created the necessary adhesion to the metal basis. When compared to prior methods, in which brackets were soldered onto metal bands, the ability to add bonded attachments directly onto the enamel surface enables a more aesthetically pleasing look as well as greater positional precision (7).

4.4.Ortodontic Brackets

4.4.1. Structure of brackets

In orthodontic treatment, the brackets are the most essential force transmitters that are used. In today's market, there is a wide variety of brackets created by a variety of firms. These brackets may be found in a wide range of structures, sizes, and forms, and are made from a variety of materials The components that make up a bracket are the bracket base, the tie wings, and the bracket slot, which may be thought of as a canal that lays between the tie wings.

4.4.1.1.Base of brackets

The construction of the bracket base is the main critical component that determines the bond strength of brackets(8). A mechanical undercut gives the orthodontic adhesive a location to spread before it becomes polymerized (9). Metal brackets are fixed in place with the assistance of a fine brazed mesh (10,11). The bases of some other brackets have been milled to have an undercut, while others have been sandblasted, chemically etched, or sintered with porous metal powder (9,12).

Today most commonly used bracket base designs are 80-mesh, 100-mesh, double mesh, Master Series, Dynalock, Mini Twin. For this study 80-gauge mesh design, rhomboid shaped metal premolar brackets (AZDENT Orthodontics, P.R.C.) were selected.

4.4.1.2.Bracket slot

Currently, brackets with a slot width of 0.018 or 0.022 inches are generally used for fixed orthodontic treatment. Current brackets have two types of torque force transmission methods, torque-in-face and torque-in-base. In torque-in-face brackets, the canal base is angled and the force is transmitted to the tooth by the rectangular wire that sits in the canal. In torque-in-base brackets, the canal base is flat and the bracket base is inclined.

In pre-adjusted brackets, the arch wire that fits into the bracket channel provides transmission of tooth-type rotational forces. The higher the bracket base width in the horizontal dimension, the arch wire projects greater the control over the tipping and rotational tooth movements.

4.4.1.3.Tie-wings

Extensions of the regular bracket, tie-wings are an example of this. Their undercuts are what make them useful for the purpose of securing ligatures made of elastic or stainless steel, which in turn keep the archwires in place. Additionally, tie-wings may be used to attach wire hooks, such as Kobayashi tie hooks for elastic traction, in the event that this is necessary and the design of the bracket did not include built-in hook (13).

Conventional brackets and aesthetic brackets are the two primary classifications that can be applied to braces. This categorization was based on the components that braces were constructed from as well as the way they seem to the patient.

4.4.2.Types of brackets

4.4.2.1.Metal brackets

Although they are not as aesthetic as the later produced counterparts, original stainless steel brackets are the most used metal bracket type for years because they are durable, hygienic and inexpensive. These brackets were made of austenite stainless steel containing 18% chromium and 8% nickel.

4.4.2.2.Aesthetic brackets

The cosmetic demands of patients who are receiving orthodontic treatment have been steadily growing over the last several years. Since the 1970s, a wide variety of aesthetic brackets have been developed in order to fulfill the ever-increasing demands placed upon dental professionals by patients. In spite of the fact that these transparent brackets are superior than their metallic counterparts in terms of aesthetics and attractiveness, they do have a few drawbacks, including brittleness, structural wear, discoloration, friction forces, and stickiness. Ceramic or plastic may be used in the production of aesthetically pleasing brackets (14).

4.4.3.Bracket Systems

4.4.3.1.Pre-adjusted appliances

Because of the in-built prescription of these appliances, which takes into account the first order, second order, and third order bends this type of appliance has become the mainstay of contemporary orthodontic treatment. In the past these would have had to be individually placed in the archwire for each tooth. However, in order to attain the best possible tooth position, it is often necessary to make some additional changes to the archwire. This was due to the fact that the prescription is based on average values and will not be able to consider individual variances such as differences in tooth size or an underlying skeletal discrepancy. As a result of this, the prescription will not be able to accommodate certain patients. On the market today, you may choose from a wide variety of pre-adjusted systems, each of which comes with its own set of personalized prescription settings. The Andrew's prescription, the Roth system, and the MBT are perhaps the ones that are most well recognized.

4.4.3.2.The Tip-Edge appliance

In the 1930s, Australian orthodontist Raymond Begg came up with the idea for what would become known as the Begg appliance. This appliance has a slot that runs vertically. The Tip-Edge system was developed in an effort to combine the perceived merits of the Begg and pre-adjusted edgewise appliances in an effort to achieve a treatment that is quicker, less anchorage-demanding, while still having the ability to finish the case to the optimal level.

4.4.3.3.Self-ligating systems

It is not a novel idea to use a bracket that has a built-in mechanism to secure the archwire instead of one that requires an elastomeric or wire ligature in order to hold the archwire in place. This reduces the amount of friction that occurs between the bracket and the archwire. Stolzenberg, writing in 1935, first described a variant he termed the Russell Lock. However, the early versions did not have commercial success, which was often attributable to the vulnerability of the mechanism or the high expenses associated in the production process. The 1990s and 2000s saw the development of a variety of different bracket production technologies, which brought about this transformation. These newly produced systems included the Damon, Innovation, and SmartClip appliances, all of which made a variety of claims about the superiority of these appliance types, particularly in relation to a reduction in the total treatment time and a reduction in the need to undergo orthodontic-related extractions.

4.4.3.4.Lingual appliances

These have been designed to enhance aesthetics during treatment by putting the attachments on the lingual surfaces of the teeth, hence diminishing the visual appearance of orthodontic treatment. This has been done in order to make the teeth seem more natural. This appliance design will always result in an increase in the difficulties experienced by the clinician as a result of less accessibility to the appliance as well as increased complexity in the production of components and wire (7).

4.5.Bonding Agents

Bonding and adhesion are two different terms that refer to the same complicated set of physical, chemical, and mechanical principles that enable one material to connect to and bind to another. A dental bonding system serves three primary purposes, which are as follows:

1. Prevents an adherend substrate (such as enamel, dentin, metal, composite, or ceramic) from detaching from a restorative or cementing substance by acting as a glue holding materials together against to the separation process.

2. Is responsible for the distribution of stress along the bonded surfaces.

3. Seals the interface between the bonded material and the dentin or enamel using adhesive bonding, which increases resistance to microleakage and decreases the likelihood of postoperative discomfort, marginal discoloration, and secondary caries.

Dental bonding agents are formulated to produce a contact between restorative composites and tooth structure that is adequately resilient to resist the effects of mechanical forces as well as the stress caused by shrinking.

4.5.1.Classification of bonding agents

This categorization is further differentiated into the number of phases in the procedure, and it is based on the two main techniques to etching, priming, and applying the bonding resin to the surfaces of dentin and enamel. As a result, the two primary classifications of bonding systems are referred to as "etch-and-rinse" and "self-etch" systems, with two subclasses for each, according on the number of clinical procedures required (15).

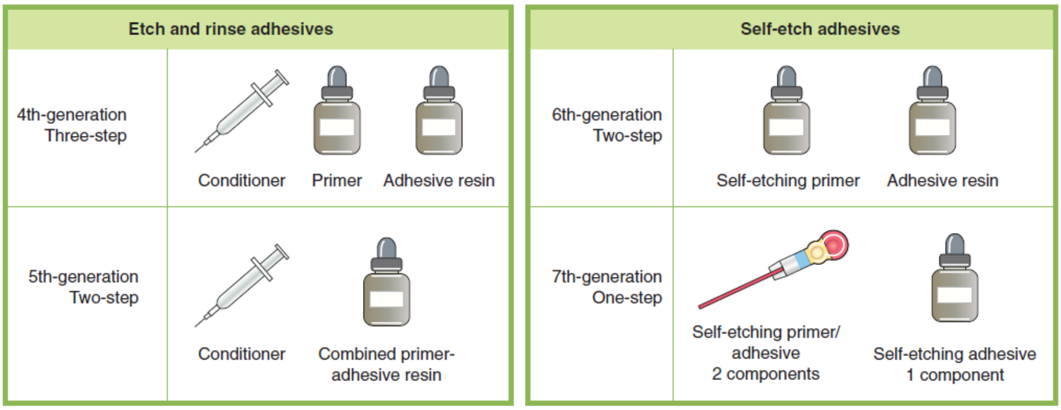

Figure 4.1: Classification of current adhesive systems (16).

4.5.1.1.Etch-and-rinse adhesives

4.5.1.1.1.Three-step (fourth generation)

This procedure has three stages: the first stage involves involves applying an acid etchant, the second stage involves applying the primer, and the third stage involves applying the bonding agent or bonding resin. There is hydrophilic functional monomer in the primer which dissolved in an organic solvent such as acetone, ethanol, or water. The application of a hydrophobic resin is the third phase in the process.

4.5.1.1.2.Two-step (fifth generation)

Using this approach will just need one application of both the primer and the adhesive resin at once. This etch-and-rinse approach is the most effective method for achieving efficient and stable bonding to enamel since it removes surface contaminants. Etching, which typically involves the use of a phosphoric gel with a concentration of between 30 and 40 percent and that is then removed, encourages the dissolution of enamel rods. This results in the formation of pores, which are then filled with bonding agents via capillary action and then followed by the polymerization of resin (17).

4.5.1.2.Self-etch adhesives

4.5.1.2.1.Two-step (sixth generation)

With this method, there is no need for a separate etching step to be taken. In this method, the tooth is conditioned and primed simultaneously with the assistance of an acidic monomer that is not rinsed off. Because self-etching adhesives only dissolve the dentin surface in a partial manner, there is still a sizeable quantity of hydroxyapatite present within the hybrid layer. After that, specific carboxyl or phosphate groups found in functional monomers are able to engage in chemical interaction with the residual hydroxyapatite. The bond to dentin achieved by these adhesives is superior to that achieved by etch-and-rinse adhesives due to the presence of minerals in this layer.

4.5.1.2.2.One-step (seventh generation)

With this approach, the actions of conditioner, primer, and bonding resin are all performed in a single step. In comparison to multistep etch-and-rinse adhesives, one-step, self-etching adhesives offer clinicians the benefit of requiring a smaller number of clinical steps that are also simpler to perform. This makes these adhesives an appealing option for use in clinical practice. Due to the fact that there is not an etch step, the tooth structure does not require any additional steps such as rinsing or drying.

When compared with the two-step self-etch and etchand-rinse products, the products that fall into the category of "one-step self-etch" have less clinical understanding, and as a result, less is known about their performance and bond durability under long-term clinical conditions (18).

4.5.1.3.Historical classification

This classification consists of first, second and third generation dentin adhesive systems that are no longer in use. The first and second generation systems are adhesive systems that applied on smear layer. The third generation system however, works as it modifies the smear layer.

4.5.1.3.1.First generation adhesive systems

Buonocore revealed in 1955 that glycerophosphoric acid dimethacrylate could connect to the surface of roughened enamel with hydrochloric acid (19). Bowen and Rodriguez suggested that NPG-GMA (N-phenyl glycine glycidyl methacrylate) develops a chemical bond with dentin (20). As a consequence of many such studies, industries began producing NPG-GMA origin dentin bonding agents, also known as first generation dentin adhesives, in 1962. However, because these bonds had a hydrophobic structure, their bonding strength to tooth surface was low (2-6 MPa) (21).

4.5.1.3.2. Second generation adhesive systems

These halophosphate esters of resin monomers were created in the early 1980s. The second generation adhesive systems lacked the necessary binding power to withstand the polymerization shrinkage of composite resin (1-10 MPa). Despite the fact that the first and second generation adhesive systems were designed to bind to the inorganic structure of the dentin, clinical success was not achieved (21).

4.5.1.3.3.Third generation adhesive systems

The smear layer is preserved and modified instead of removal in this system, and the resin monomer penetrates to the dentine (22). Fusayama et al. proposed roughening dentin tissue with phosphoric acid before applying this bonding agent containing phosphonate ester. However, due to the bonding agent's hydrophobic nature, the preferred effectiveness in terms of binding power was not achieved again (23).

4.6.Adhesive Materials

Resin adhesive and dental cements are typically used in the process of bonding orthodontic appliances to a patient's teeth. The level of success achieved by the treatment has substantially effected by the bond's strength. Failures in the connection between the bracket and the enamel caused the work that needed to be done to produce an ideal adhesive happen much more quickly. An ideal adhesive should not shrink during polymerization, it should have sufficient fluidity, the bond strength should be at an optimal level, it should be easy to use clinically, and it should be able to penetrate the pores formed on the tooth surface (2).

There are 2 main adhesives used in orthodontic bracket bonding. These are glass ionomer cements and composites.

4.6.1.Glass-ionomer cements

Glass ionomer cements were first developed in 1972 with the primary purpose of acting as luting agents and as a direct restorative material. These cements have the distinctive ability to chemically bond to enamel, dentin, and stainless steel, in addition to the capacity to release fluoride ions that protect against caries. The water-hardening cements of the second generation contain the same acids in freeze-dried form or in an alternative powdered copolymer of acrylic and maleic acids. Both of these forms are available. Modifications were made to glass ionomer cements in order to create dual-cure or hybrid cements (5). When in contact with acids, fluoride ions are released, which is an important step in the prevention of dental caries. In addition to this, there is a hydrogel that facilitates the movement of ions within GICs, including calcium, strontium, and others. After the curing process is finished, the hydrogel continues to exist, which makes it possible for ion exchange to take place not only within the cement but also between the cement and its surroundings. Therefore, it gives back the fluoride ions that were taken from the applications of topical flüor (19). However, there are a number of significant drawbacks associated with this material. Glass ionomer cements are highly reactive to moisture, can take on the color of their surroundings readily, and mostly have poor physical properties (20).

4.6.2.Resin-modified glass ionomer cement (compomer)

Because conventional glass ionomer cements have lower bond strengths than resin adhesives, hybrid materials containing glass ionomer and composite components have been developed, offering improved bracket bonding potential (25). Polyacid modified composites, or compomers, are one type of hybrid cement (25), formed by combining composite resin and fluoride silicate glass into a single component composite resin. Compomers are also capable of fluoride release and uptake, but to a lesser degree than that of conventional glass ionomer cements, and they may therefore confer some protection against development of decalcification around bonded attachments (26,27).

Compomers have the advantage of being structurally stronger and bonding to dentin more effectively than traditional glass ionomer cements. In spite of these benefits, it is stated that GICs still possess undesirable properties such as low moisture tolerance and brittleness during the bonding-hardening reaction (28).

4.6.3.Composites

Dental composites are widely used. All are silane-coated inorganic filler particles with bisglycidil methacrylate (BISGMA) or urethane dimethacrylate resin (UDMA). Triethyleneglycol dimethacrylate (TEGDMA) is sometimes added to reduce viscosity. Filler particles are barium silicate glass, quartz, or zirconium silicate, combined with 5% to 10% microscopic (0.04-m) colloidal silica. Modern dental composites consist of glass or ceramic particles in a photopolymerizable syntheticorganic resin matrix. Polymer materials are blended with finely divided inorganic material, such as barium aluminosilicate glass or other glass composition, containing an effective amount of radiopaque oxide to make the glass radiopaque to x-rays (29,30). Most modern composite resin systems are based on bisGMA (31). Resin-based adhesives are classified depending on filler's particle size (32).

Table 4.1. Resin types by filler particle size.

Resin	**Filler particle size**
Microfilled	0.1 µm
Minifilled	0.1 – 1 µm
Mid-sized	1 – 10 µm
Macrofilled	10 -100 µm

4.6.3.1.Composites by type of activation

Polymerization of composite resins can be initiated chemically or by light exposure.

4.6.3.1.1.Chemically activated composites

These adhesives set when one paste is pressed lightly onto etched enamel and bracket backing or when another paste is bonded to a tooth. Compared to a 2008 survey, only 5% of orthodontists in the US routinely use these adhesives (33).

4.6.3.1.2.Light-polymerized composites

Not only did the development of light-cure adhesives make it possible to skip a step in the bonding process, but it also gave dental professionals the ability to decide when in the process they wanted to begin the curing cycle for the adhesive after bracket placement. In the 1970s, light-curing resin composites were made available to consumers on the market. The activation of a photoinitiator is what sets in motion the curing process in adhesives that are cured with light. Camphoroquinone is utilized as the diketone absorber in the vast majority of dental photoinitiator systems. Camphoroquinone's maximum absorption occurs in the blue region of the visible light spectrum at a wavelength of 470 nanometers(nm) (34,35). The lightcured adhesives are routinely used today by more than 80% of orthodontists (33).

Transbond XT (3M Unitek, Monrovia, USA) is a traditional 4th generation two-step light-cure resin cement for orthodontic bracket bonding. Transbond XT is a widely used an one of the most succesful adhesives (36,37). In this study Transbond XT used for initial bonding and rebonding stages.

4.7.Light Sources

During the polymerization reaction, a dental resin composite should convert all of its monomer to its corresponding amount of polymer as this is the desired outcome. For resin composite restorative materials, adequate polymerization is one of the most important factors in achieving optimal levels of both their physical properties and their clinical performance (38). As a result of the fact that the degree to which the resin composite has cured can have an impact on nearly every physical property, including its mechanical properties, solubility, dimensional stability, color change, and biocompatibility. In order to achieve adequate polymerization, light-cured resin composites require a level of light intensity that is sufficient. The majority of dental photoinitiator systems make use of camphoroquinone as the diketone absorber. Camphoroquinone's absorption is at its maximum in the blue region of the visible light spectrum at a wavelength of 470 nanometers(nm) (39).

4.7.1.Halogen systems

Halogen-based light-curing units have been one of the most popular means of delivering blue light. The majority of the energy input in the halogen system is converted to heat, while only a small portion is emitted as light. The wavelengths are screened by selective filters so that only blue light is released. This technique's basic light conversion principle is inherently inefficient. Halogen light bulbs have a lifespan of approximately 100 hours (40). Approximately fifty percent of the time, the irradiance of the halogen system is less than 300 mW/cm2 (41), which is the minimum value required to properly cure resin composite (42).

4.7.2.Argon laser

The combined bandwidth of the argon laser covers 42 nm (between 454 nm and 488 nm) of the visible light spectrum (43), with an intensity that approaches 800 mW/cm2. It has been demonstrated that the wavelength precision of the argon laser, coupled with its ability to emit visible light with substantial energy density and no wasted or unusable emissions, improves the physical attributes of composite resins by achieving a more extensive cure with up to 75 percent less exposure time than conventional light-curing units (44).

4.7.3.Xenon plasma arc

In the latter half of the 1990s, a lamp that employed a xenon plasma arc bulb was made available to the public. It promised very short exposure times, comparable to those of the argon laser, but with a lower price. The majority of reports stated that the exposure times were between 3 and 5 seconds, with ceramic brackets having significantly shorter times (45). The xenon plasma arc light source is able to produce light of an intensity that is significantly higher than that of the traditional tungsten-quartz halogen light, and the light can be screened to a bandwidth accumulation of 450 to 500 nm for peak absorption of the photoinitiator systems that are most frequently utilized (46). The cost of xenon light is higher than that of regular light, despite the fact that it is not as expensive as a laser.

4.7.4.Light emitting diod (LED)

Mills et al. proposed the utilization of solid-state light-emitting diode (LED) technology for the polymerization of light-activated dental materials in 1995 as a way to overcome the shortcomings of halogen visible light-curing units (47). This was done in order to polymerize light-activated dental materials.

LEDs have a lifespan of over 10,000 hours and their output degrades very little over the course of this time. LEDs also have a very low power consumption (48). When compared to the technology that uses halogen bulbs, the LEDs' longer life spans and more consistent light output make them a promising option for use in dental applications. In addition, LEDs do not need to use any filters in order to generate blue light.

LEDs made of gallium nitride produce a narrow spectrum of light (400 to 500 nm) that is very close to the absorption range of camphorquinones, which are the compounds that start the polymerization of resin monomers (40). When compared to the technology that uses halogen bulbs, the LEDs' longer life spans and more consistent light output make them a promising option for use in dental applications.

In this study Optilux 501 by Kerr is the selected device for curing. Optilux 501 is a premier halogen curing light designed by Demetron and is engineered to polymerize adhesives and composite materials.

4.8.Enamel Structure And Orthodontic Bonding Application

4.8.1.Enamel

The composition of enamel is distinguished by a high percentage of minerals (96 wt%), a low percentage of organic matter (0.4-0.8 wt%), and a high percentage of water (3.2-3.6 wt%). The mineral part is commonly referred to as calcium hydroxyapatite, which is a compound that is part of an isomorphous series of apatites. Enamel is made up of modules, which are hexagonal crystallites of hydroxyapatite that are tightly packed together and have a needlelike shape. These crystallites are arranged into prisms. And this prisms are the main unit of the enamel. Variations in the crystallites' orientation contribute to the appearance of "keyhole" shaped prisms radiating from the dentinoenamel junction toward the outer surface. These prisms can be found radiating outward from the junction. Because the crystallites in the interprismatic area are less tightly packed and more randomly oriented, this region has a higher concentration of water and organic matter in comparison to the regions that are contained within the prisms. The majority of the water that is firmly bound can be found in the form of hydration shells surrounding the crystallites (49).

4.8.2.Orthodontic bonding application

Attachments in orthodontics are typically bonded for a specific amount of time. In orthodontics, it is therefore essential to meet the requirements of sufficient bond strength, ease of debonding, and a limited risk of permanently damaging the enamel surface (50). The acid-etching method, which Newman et al.(51) and Retief et al.(52) adapted specifically for orthodontic use, has been the foundation of the orthodontic bonding system that has enjoyed the greatest level of success over the course of several decades.

In most cases, pumicing the enamel surface prior to conditioning is considered to be necessary in order to achieve maximum bond strength. Pumicing is done because organic material, such as plaque and acquired pellicle, can prevent optimal etching from occurring. This is the rationale behind pumicing.

4.8.2.1.Conventional acid etching

Micromechanical retention is the foundation of today's modern bonding systems for resin-based materials. In order to accomplish this goal, an acid, most commonly an orthophosphoric acid with a concentration of 37% is utilized to cleanse the surface and dissolve the minerals. It is critical for the retention of the bond that the bonding material successfully reaches the etched areas and polymerizes there. The low-energy, hydrophobic surface of the enamel can be altered into a high-energy, hydrophilic surface by using acid etching. In order for the bonding material to be able to wet the surface, either the surface must have a higher energy than the bonding material or the material must be sufficiently "soluble" in the components of the surface (53,54).

In general, the manufacturers of various adhesive systems recommend applying a 37% concentration of ortophosphoric acid and leaving it on the surface for 15–30 seconds. It is the opening of the interprismatic areas that occurs during the etching process that is responsible for the mechanical retention of the attachment. At the conclusion of the etching phase, the etchant is removed from the teeth by spraying them with a substantial amount of water. It is strongly recommended that a high-speed evacuator be used because it will increase the efficiency of collecting the etchant-water rinse and will reduce the amount of moisture contamination that occurs on the teeth. It is to apply a thin layer of bonding agent to the surface of the etched enamel after the teeth have been allowed to thoroughly dry and become matted white. A gentle air burst that lasts between one and two seconds can be used to reduce the thickness of the coating. It's possible that a thick layer will cause drifting before the curing process is even started, which could impede the precise adaptation of the bracket base. After finishing coating each of the etched surfaces, you should get right to work on installing the brackets.

4.8.2.2.Self-etching primers

Due to the fact that these bonding systems incorporate the conditioning and priming agents together into a single acidic primer solution, it is possible to use it on both enamel and dentin simultaneously. Because of this, it is not necessary to perform a separate acid etching of the enamel, followed by a subsequent rinsing with water and air spray. The fact that these bonding systems combine the priming and conditioning agents is the defining characteristic of these systems. Both the etching and the monomer penetration to the exposed crystallites happen at the same time.

Additionally, the depth of both the etching and the primer penetration are the same. There has been a great deal of research conducted on the application of self-etching primers in orthodontics, and the results suggest that clinical bond strengths may be lower than those obtained through conventional etching and priming (55,56).

In spite of the fact that the use of self-etch primers has increased due to the ease with which they can be applied, these primers only save a marginal amount of time, approximately 8 minutes for full mouth bonding (57).

4.8.3.Bonding procedure

4.8.3.1.Direct bonding

The direct bracket bonding procedure includes the steps outlined below. The bracket is first secured in place using tweezers with a reverse-action grip, and then an adhesive is added to the the bracket base. After that, the bracket will be attached to the tooth as soon as possible. Using either a scaler or a round probe, the bracket is positioned on the surface of the tooth so that it faces in the appropriate directions. Locating the center of the clinical crown or measuring the distance from the incisal edge may be used to direct the placement of orthodontic brackets. With a handpiece such as a scaler or probe, the bracket is then pressed against the enamel surface. It is essential that the base of the bracket conforms to the shape of the tooth.

Undesirable tooth movement, typically in the form of rotation, results from improper base fitting. A scaler is used to remove any excess material expressed around the bracket before the material hardens or the light polymerizes it. After bracketing has been completed, the position of each bracket must be carefully examined. Immediately remove and reattach any attachment that is not in the correct position (58).

4.8.3.2.Indirect bonding

Indirect bonding was initially presented as a concept in its entirety for the first time by Silverman and Cohen (59) in the year 1972. Indirect bonding has many advantages, some of which are that it is more cost-effective, that it improves patient comfort, that it eliminates the need for separators and bands, that it makes it easier to rebond brackets and establish overcorrections, that it provides better in/out and vertical control, and that it improves oral hygiene due to typically smaller attachments (60,61). There are a few different approaches to employ when indirect bonding is desired. Composite resin is used to provide a temporary bond between the brackets and the teeth on the stone models. The brackets are then transferred to the mouth with some type of tray into which they become incorporated into the tray, and an intermediate sealant is used to provide a permanent bond between the brackets and the teeth (60,62,63).

4.9.Debonding Of Brackets

During the course of routine orthodontic treatment, patients frequently experience a complication known as bracket debonding. Due to the fact that the bonding procedure is technique-sensitive (64), even a trace amount of salivary contamination or improper application of composite primer can result in a weaker bond strength between the enamel and the bracket (65). Other causes are excessive mechanical forces, occlusal interferences and hard sticky diet during treatment (65,66). In addition in orthodontic practice, it is common to remove a bracket on purpose with the intention of repositioning it (67).

There is an increased risk of treatment failure associated with longer treatment duration, with an additional bracket failure occurring every 10 months. For every additional failed bracket, the length of treatment is prolonged by an additional 18 days (95 percent confidence interval = 0.21–1.05; P =.004) in the average case (68).

Most studies indicates a high incidence of brackets detachment during orthodontic treatment (69). In a retrospective study on orthodontic patients (71), it was found that 32 percent of the patients and 3.3 percent of the total brackets had experienced bracket failure at some point during the course of their treatment. According to the findings of the same study, there is a higher risk of unsuccessful bracket bonding occurring in the mandibular dentition during treatment compared to the maxillary dentition. In spite of the fact that these values shift from study to study, bracket debonding remains a significant issue in the orthodontic treatment of today (70).

4.10.Rebonding Of Brackets

Rebonding an orthodontic bracket, following elements should be considered:

1. Reconditioning the tooth surface,
2. Using the original debonded brackets or use of new ones,
3. The bonding system to be used.

It has been reported that the bond strength of a rebonded bracket should be greater than the minimum force requirement of 6-8 MPa (72). Nevertheless, there isn't a general agreement on how the rebonding strength compares to the original bonding strength. It has been reported by some authors that the rebond strength is lower(73)(74), while others have reported that it is either comparable (72,75) to or greater (76,77) than that of the original bond. The differences may be attributable to variations in the bonding systems and bracket types that were utilized, as well as the technique that was utilized to recondition the enamel surface and the bracket base.

The type of failure is very important clinically. When the fracture occurs primarily at the interface between the resin and the enamel, it makes it possible to easily remove any excess resin. This is preferable from the standpoint of the practitioner because the ideal bonding system is one that produces sufficient bond strength to retain the bracket during active orthodontic tooth movement while simultaneously allowing for the speedy removal of brackets and the complete removal of residual resin from tooth surfaces at the conclusion of treatment. This is the case with the optimal bonding system (68).

4.10.1.Reconditioning of the enamel

The first step in the reconditioning process is to remove any remaining adhesives in the appropriate manner. Hand instruments (such as pliers and scalers), various burs, soflex discs, ultrasonic devices, and air abrasion units are some examples of the various modalities that have been used for this purpose. It has been demonstrated in several studies that tungsten carbide burs, whether used in low or high speed handpieces, produce the most satisfying results (78–80).

4.10.1.1.Tungsten-carbide (t.c.) burs

It is possible to damage the enamel surface when using rotary finishing instruments to completely remove the adhesive resin. This is because, without the assistance of powerful magnification, it is nearly impossible to stop the removal process exactly at the enamel–resin interface. When removing adhesive resin, it is impossible to complete the process without causing iatrogenic damage to the enamel of the tooth. This is true regardless of the method used. For the most effective removal of any remaining orthodontic bonding materials, a tungsten carbide finishing bur operating at a low speed is currently the method of choice (81,82).

It has been hypothesized that the low speed technique, in comparison to the high speed tungsten carbid bur, facilitates the simple and speedy elimination of the bonding material, results in the production of satisfactory surfaces, and does so without causing significant harm to the enamel. Tüfekci et al. n.d., on the other hand, demonstrated that debonded enamel samples exhibited a greater enamel loss when polished with a slow-speed tungsten carbide bur in comparison to an abrasive disk system(Sof-Lex) (83). On the other hand, in this study, a low-speed t.c. bur was selected for a safer approach because the majority of studies suggests that low-speed t.c. burs are less damaging against enamel. In addition, a comparison will be made between the Henry Schein universal silicone polishing kit and the low speed t.c.

4.10.1.2.Silicone based polishing systems

It is common practice for clinicians to use silicon carbide coated abrasive discs, silicone impregnated rubber or discs and wheels, and other types of finishing and polishing devices to finish and polish dental restorative materials such as bracket bonding adhesives. These devices are among the wide variety of finishing and polishing devices that are available on the market to clinicians. The surface of the various restorative materials are left with varying degrees of surface roughness as a result of the use of each of these instruments or devices (84).

Henry Schein Universal Silicone Polishing system is a silicone is a finishing kit for resin-based materials such as composites, compomers, enamel, and porcelain. It features a medium grit right angle format and a silicone polishing pad. It is utilized at speeds ranging from 5000 to 12000 revolutions per minute. There have been no previous studies conducted on this topic using this material.

4.10.2.Use of new brackets or reconditioning original brackets

Recycling brackets in order to rebond them brings down the overall cost of orthodontic treatment for both the patient and the orthodontist (85). Also recycling may result in surfaces that are smoother and more resistant to corrosion (86). In most cases, it has been reported that the shear bond strength of a rebonded bracket is similar to that of the original bracket (88,89). When the bracket has been removed, the first step is to check it for any deformation that may have occurred as a result of the breakage. It is recommended that any brackets that appear to have been deformed be replaced with new brackets.

Several different approaches for recycling have been proposed, all with the end goal of removing the adhesive and establishing sufficient shear bonding strength(SBS) levels. Sandblasting is the most popular and efficient method for removing bond material, and it is used extensively (89). For recycling brackets with sandblasting there are various particle sizes available such as 25, 50, 75, 110 μ , etc. There is not a statistically significant difference in the bond strength of recycled brackets when comparing different particle sizes of aluminum (90). In addition to this, it is a simple method that can be carried out in the clinic with relative ease in order to clean brackets (91). Sandblasting or air abrasion removes adhesives and contaminants, improves surface roughness, and as a result, increases surface energy and the amount of area that is available for bonding. These processes use alumina particles (92,93). Furthermore Mui et al. 1999 and Sharma-Sayal et al. 2003 suggests that sandblasting does not damage the bracket base (68,95).

Thermal recycling is an additional method that can be used in the clinic for debonded brackets. In order to achieve desirable outcomes from orthodontic treatment, reconditioned brackets via thermal recycling will have a bond strength that is sufficient enough to withstand the size and scope of forces produced in the mouth throughout the entirety of the treatment process, despite the fact that there is a significant reduction in bond strength when compared to sandblasting with aluminum oxide particles (96).

It is not very common, but cleaning bracket bases with high or low speed tungsten carbide burs is a simple practice that can be done in clinics. T.C. burs alone results in a significant reduction in shear bond strength, despite the fact that it requires significantly less time than most other methods and that recycling can be done in a cost-effective manner (97).

It is also possible to recycle debonded brackets in an indirect manner by delivering them to specialized reconditioning services located outside the clinic. This practice is known as industrial recycling. In industrial recycling, the two methods that are used the most frequently are either the use of heating to burn the bond agent, preceded by electrolytic polishing to remove any residual oxide, or the application of chemical agents to dissolve the bond agent, combined with high-frequency vibration and electrochemical polishing (98,99).

Wheeler et al.(100) have observed a reduction in shear bond strength after industrial bracket recycling of 6%–20% and Mascia et al.(101) found that it can reach 35% for finer mesh-type brackets. However, Cacciafesta et al.(102) compared the clinical behavior of industrially recycled brackets and new brackets with a 12-month follow-up but found no significant differences in bond failure percentages.

Montero et al.(103) have reported among commercially recycled brackets, there was some metal loss in certain parts of the bracket as well as a reduction in the diameter of the mesh wires. This was true regardless of whether the brackets were reconditioned with heat or chemicals. Nevertheless according to Postlethwaite 1992, these changes did not seem to affect bond strength (104).

5.MATERIALS AND METHOD

This study was carried out after obtaining the ethics committee approval dated 22/06/2021 and numbered E-10840098-772.02-2950 from the Non-Interventional Clinical Research Ethics Committee of Istanbul Medipol University (Appendix 1. Ethics Committee Approval).

5.1.Materials

5.1.1.Obtaining the teeth

In this study, 96 lower and upper premolar teeth obtained from patients who applied to Istanbul Medipol University Faculty of Dentistry, Department of Orthodontics for treatment, were used. In order to determine the number of teeth to be included in the study, power analysis was performed using the GPower 3.1.0 package program. As a result of the calculations, the sample volume to provide the power of the test (1-β) = 0.80 was determined as 12 in each group. Therefore, the study was carried out on 96 extracted permanent premolars.

The determined inclusion criteria of teeth in the study are as follows:

1. Extracted for orthodontic or periodontal reasons.

2. Having a smooth buccal surface.

3. Absence of caries on the buccal surface.

4. Has not been treated with any chemical agent.

5. The enamel of the teeth is not damaged.

6. Absence of any developmental disorders, decalcifications.

The collected teeth were kept in glass containers containing physiological saline (0.9% NaCl) at room temperature. The solution was changed every five days to prevent bacterial growth.

Figure 5.1.A sample of obtained teeth.

5.1.2.Brackets

In this study, standard metal brackets (AZDENT Orthodontics, P.R.C.) standard metal brackets were used in a 0.022" slot MBT system. AZDENT brackets have 80-gauge mesh base and low profile, and their rhomboid shaped base is specially designed to ensure accurate and easy bracket placement. In total 96 upper premolar brackets used for 96 teeth. Brackets used in this study has 13,44mm^2 base area.

5.1.3.Materials used for bonding

In this study for enamlel surface roughnening a blue colored 37% orthophosphoric acid (FGM Dental Group, Condac37, LOT:460139, Brazil) was used in 2.5ml syringes.

Transbond XT (3M Unitek, Monrovia, USA) primer and adhesive agents were used for bonding the brackets. Transbond XT is a light-curing composite adhesive consisting of a liquid primer and a paste that does not release fluoride. Both components of the adhesive contain camphoroquinone (CPQ) as a light-curing initiator. The liquid primer consists of 100% organic Bis-GMA without filler. The paste component of Transbond XT is 23% organic and 77% inorganic. The inorganic part contains silicated quartz as filler particles and silica in powder form. The organic part consists of 14% Bis-GMA and 9% Bis-EMA.

Figure 5.2. Materials used in bonding procedure.

The polymerization of the primer and adhesive was achieved with an Optilux 501 halogen light source from Kerr. It has 850-1000mW/cm2 power output and a wavelenght range of 400-501 nm. Various features of the Optilux 501 includes , a self diagnostic system, 4 radiometer selections, volume control, ramp and boost modes as well as a count-up timer.

Figure 5.3. Optilux 501 Light Curing Unit.

5.1.4.Test setup

For this study a test setup prepared to use with universal testing machine (Instron, 3345, U.S.A.). A stainless steel plate manufactured in 0,43x1,25x1 mm dimensions. The plate ligated tightly to brackets via 0,01” wires until no movement between plate and bracket can occur.

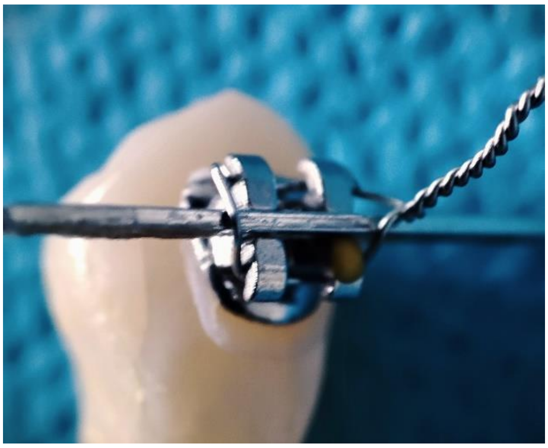

Figure 5.4. Illustration of stainless steel plate ligated to a bracket.

5.2.Method

5.2.1.Obtaining debonded brackets

In order to prepare the debonded brackets to be used in this study, 96 upper premolar brackets were bonded according to the standart test procedure to 96 human premolar teeth, which were first kept in physiological saline. Twelve of them were randomly selected and put into the test as a control group. The remaining brackets were removed from the teeth with the help of bracket removal forceps gently without any damage to the teeth or the brackets. After checking whether there was any defect in the brackets that were tested and removed from the other teeth as the control group, they were randomly divided into 8 groups and stored.

5.2.2.Bonding Procedure

In the first stage of the study, 96 new upper premolar brackets were bonded to the untreated teeth, without forming any groups. Upper premolar brackets were chosen because otherwise they would affect the results due to the different surface areas and torque values of the upper and lower premolar brackets in the bracket set supplied by the manufacturer.

Since there should be no residue on the enamel surface before bonding brackets, after the teeth were removed from the physiological saline, vestibule surface of the teeth cleaned for 10 seconds at low speed with a soft polishing brush attached to the contra-angle handpiece. Thus, it is ensured that no residue is left on the tooth surface.

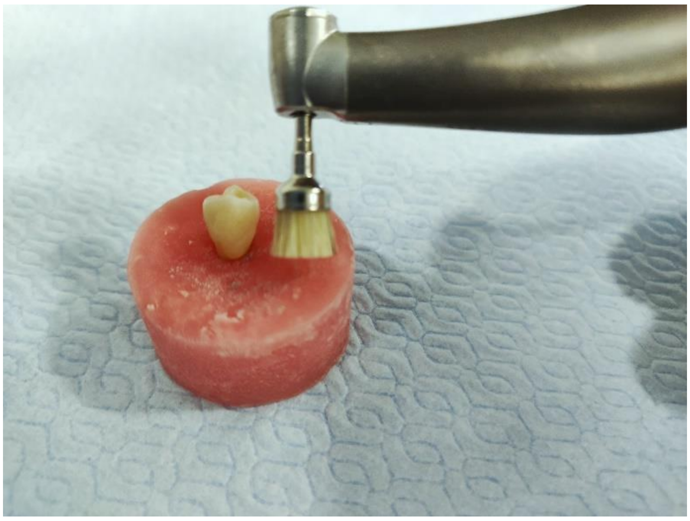

Figure 5.5. Cleaning tooth surface with soft brush bur.

After brushing, the tooth was washed with air-water spray for 20 seconds so that no pumice or similar material remained on the surface. After that, the teeth were dried with oil-free air freshener for 20 seconds. After the teeth surfaces were dry, acid was applied to the entire buccal surface of the teeth with the help of an injector. After a waiting time of 20 seconds, the acid on the surface was washed away for 20 seconds with air-water spray. After washing, it was dried with air spray for 15 seconds and a chalky mat appearance was obtained on the enamel surface.

Light-cured adhesive primer was applied as a layer on the matted tooth surface. After thinning the wet adhesive layer with slight air pressure, it was cured with halogen lighting unit (Kerr, Optilux 501, Germany) for 20 seconds. After placing the light-cured adhesive paste on the base of the bracket to be adhered to the tooth, the bracket was placed on the tooth with a bracket holding forceps. The bracket was pressed lightly with the help of forceps, and the adhesive overflowing from the edges was removed with a probe. After checking the position of the bracket, it was cured. Curing application was performed for 20 seconds for each mesial and distal edges of the bracket from a distance of 5-6 mm, with the head of the light source perpendicular to that area of the tooth.

Figure 5.6. Primer application materials.

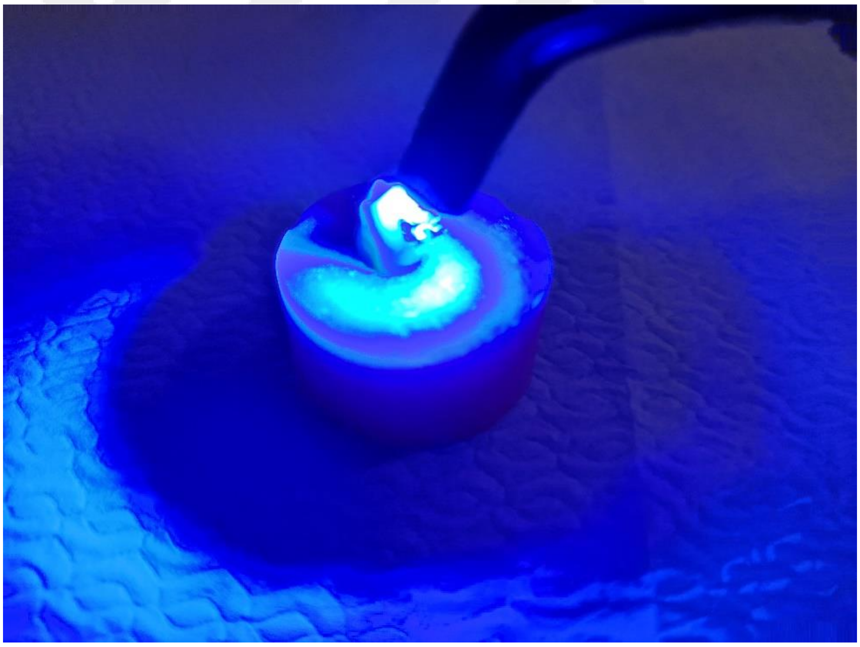

Figure 5.7. Curing the adhesive with Optilux 501.

5.2.3.Preperation of the samples

After bonding procedure completed, in order to transform the teeth into specimens suitable for the testing machine, steel molds were prepared. Then to inner surfacce of the molds treated with vaseline to achieve easy removal of the specimen after polimerization. After the autopolymerizing acrylic was filled into the molds, the tooth was placed in the middle of the acrylic and kept upright with the help of latches until the acrylic polymerization was completed. 12 random specimens selected to form G_1= Control Group and the stainless steel plates then placed into the bracket slot, carefully and tightly ligated to the bracket until there is no room for movement of the plate.

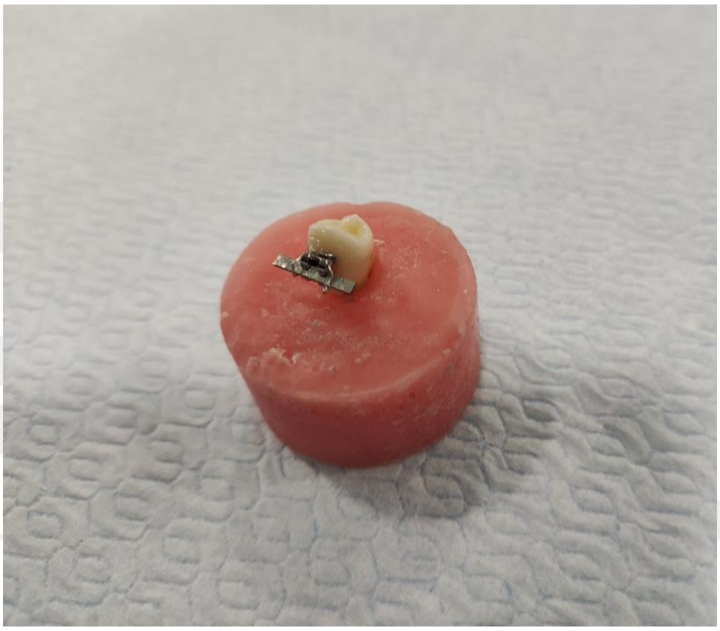

Figure 5.8. Prepared sample.

5.2.4.First shear-peel bond strenght test of the control group

Shear peel tests of the samples were performed in the hard tissue laboratory of T.C. Yeditepe University Faculty of Dentistry. Instron brand universal test device was used in the tests.

The acrylic blocks were firmly seated in the holder made of stainless steel at the bottom of the test device, and the acrylic block was fixed by tightening the screw on this holder to prevent any slippage during the test. The location of the block was adjusted according to the landing direction of the scraper blade.

The force transfer tip was placed between the wings of the bracket, descending perpendicular to the ligatured plate, and the direction of movement of the tip was parallel to the vestibule surface of the tooth and the base of the bracket. The test was started when the tip of the the blade was lightly touching the plate without applying force. The crosshead speed of the blade tip was set at 1 mm per minute. The maximum force (N) and maximum stress (MPa) amounts of each sample were recorded by the computer.

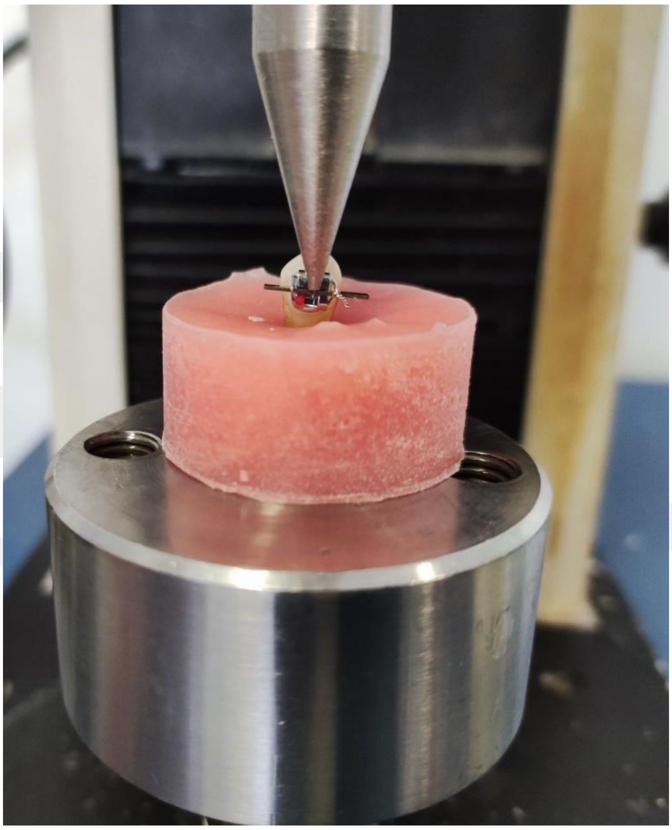

Figure 5.9. Shear/peel bond strength measurement with universal testing machine.

5.2.5.Adhesive remnant index (ARI)

After the shear-peel tests are completed, the specimens are evaluated in terms of the amount of adhesive remaining at the bracket base and on the teeth. In this study, both bracket base and the tooth surface were examined at 40x magnification with stereomicrpscope (Leica, MZ10F, Germany) in Yeditepe University Faculty of Dentistry Hard Tissue Laboratory and the bond failure area was determined. Adhesive Remnant Index(ARI) used by Bishara et al. 2008 (105,106)was used to evaluate the amount of remaining adhesive. The scores according to this index are as follows:

Table 5.1. Modified Adhesive Remnant Index by Bishara et al.

Score 1	All adhesive left on the tooth.
Score 2	More than %90 of the adhesive left on the tooth.
Score 3	More than %10 and less than %90 of the adhesive left on the tooth.
Score 4	Less than %10 of the adhesive left on tooth.
Score 5	All adhesive left on bracket base.

Figure 5.10. Steromicroscope used for evaluation of ARI scores.

5.2.6.Preperations of the groups

After the 12 samples formed as the control group were put into the test, the remaining 84 samples were separated from the teeth with a bracket remover forceps without damaging the brackets. Since 2 different processes will be applied to the tooth surface and 4 different processes to the bracket surface, the groups were formed as follows:

- After brackets were removed, teeth were randomly selected and groups A and B of 48 sample each were formed.
- The debonded brackets were randomly divided into 4 groups of 24 members and numbered from one to four.
- 8 different groups were obtained by randomly crossing the formed tooth and bracket groups.
- With the control group formed at the begining, total of 9 groups compared.
- For convenience in the study, group names were simplified as follows: G_1=Control, G_2 = A1, G_3=A2, G_4=A3, G_5=A4, G_6=B1, G_7=B2, G_8=B3, G_9=B4

5.2.6.1.Cleaning enamel surface with Henry Schein silicone polishing kit

The enamel surface of the teeth in Group A (n=48) was cleaned with a silicone bur (Henry Schein, Universal Silicone Kit, LOT:461363) with contra-angle handpiece at 15000 r.p.m. until there was no visible residual adhesive material under high power light source.

After the adhesives removed from the enamel surcafe, teeth in Group A kept in glass containers containing physiological saline (0.9% NaCl) at room temperature.

Figure 5.11. Henry Schein Universal Silicone Kit and the bur used (900-2116).

5.2.6.2.Cleaning enamel surface with low-speed tungsten-carbide bur

The enamel surface of the teeth in Group B (n=48) was cleaned with the tungsten-carbide bur with a contra-angle handpiece at 20000 rpm until there was no visible residual adhesive material under high power light source.

After the adhesives removed from the enamel surcafe, teeth in Group B kept in glass containers containing physiological saline (0.9% NaCl) at room temperature.

5.2.6.3.Recycling brackets with 110 µm Al_2O_3 sandblasting

For the removal of adhesives from the base of brackets in Group 1 (n=24), 110 µm Al_2O_3 particles (Renfert GmbH, Germany, LOT:15831012) were utilized. Sandblasting was accomplished by spraying Al_2O_3 particles on the bracket base at a pressure of 58 psi, from a distance of 10 mm until no residual resin could be seen on bracket base, and at a right angle using a sandblasting device. For sandblasting a sandblasting machine (Renfert GmbH, Basic Master, Germany) used in T.C. Medipol University.

Cleaned brackets then rinsed with air-water sprey and stored in physiological saline (0.9% NaCl) containing plastic boxes at room temperature.

Figure 5.12. Sanblasting a debonded bracket.

5.2.6.4.Recycling brackets with low-speed tungsten-carbide burs

A cylindrical shaped tungsten carbide bur (Wave Dental, Bur Plus, P.R.C., LOT: RA601601) and contra-angle handpiece (Dentsply Sirona, T2, Germany) at 20000 rpm was used to clean the adhesives remaining at the base of the brackets in Group 2 (n=24). Bracket base cleaned until no adhesive residue was visible to the naked eye.

Cleaned brackets then rinsed with air-water sprey and stored in physiological saline (0.9% NaCl) containing plastic boxes at room temperature.

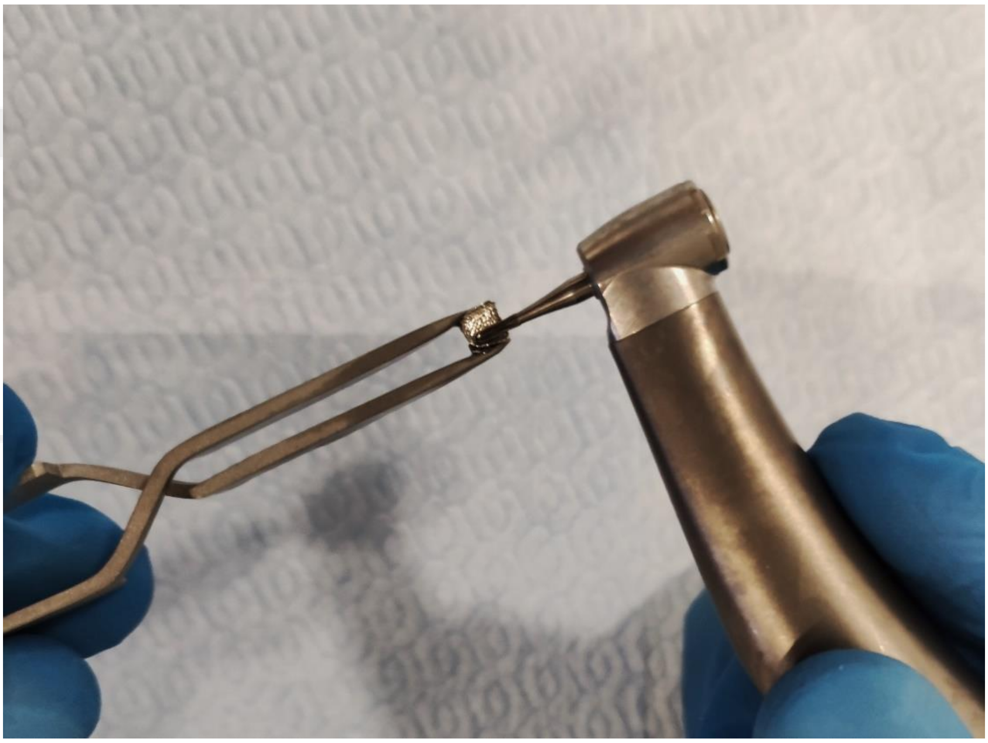

Figure 5.13. Cleaning adhesive residue from bracket base with tungsten caribe bur.

5.2.6.5.Recycling brackets with torch flame using heat

The brackets of Group 3 (n=24) were fixed in place with a holder used in soldering and heated at a right angle from a distance of 5 cm with a torch gun (Wans Torch, Bs-261, P.R.C.) until the bracket base became incandescent. After the heating process was completed, the brackets were cooled in containers containing distilled water. After cooling, the burnt adhesive residues on the bracket base were gently removed with a brush.

Cleaned brackets then rinsed with air-water sprey and stored in physiological saline (0.9% NaCl) containing plastic boxes at room temperature.

Figure 5.14. Burning adhesive on bracket base with direct torch flame.

5.2.6.6. Recycling brackets with ultrasonic device

Ultrasonic device was utilized to clean the brackets of group n4 (n=24) (Guilin Woodpecker Medical Instrument Co, HW-5L, P.R.C.). The device was used under water cooling and used on each bracket base at a frequency of 25-32 kHz until there was no remaining adhesives seen at the bracket base.

Cleaned brackets then rinsed with air-water sprey and stored in physiological saline (0.9% NaCl) containing plastic boxes at room temperature.

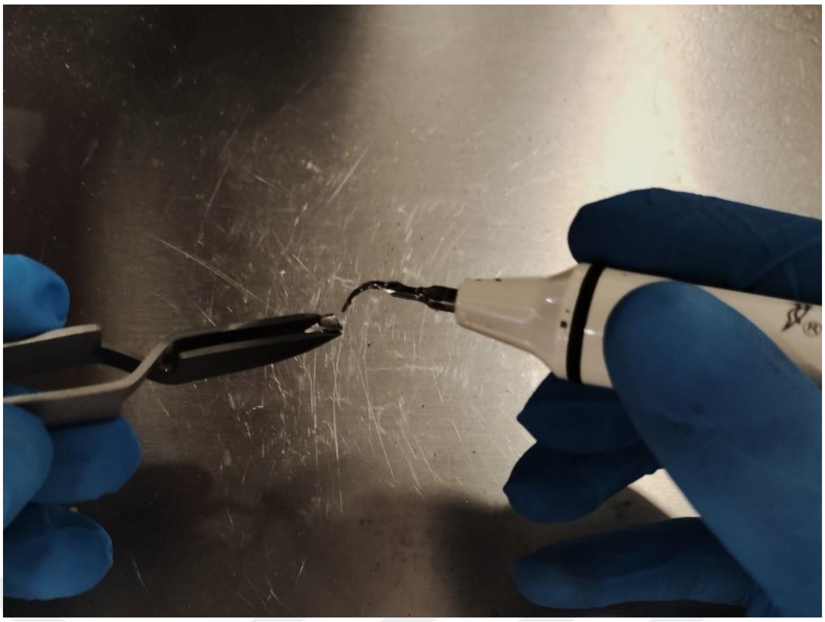

Figure 5.15. Cleaning bracket base with ultrasonic scaler.

Table 5.2. Organization of the groups

Group	Enamel Surface	Bracket Surface
G_1(n=12)	-	-
G_2(n=12)	H.S. Silicone Polishing Kit	110 µm Al_2O_3 Sandblasting
G_3(n=12)	H.S. Silicone Polishing Kit	Low-speed T.C. Bur
G_4(n=12)	H.S. Silicone Polishing Kit	Torch Flame Heat
G_5(n=12)	H.S. Silicone Polishing Kit	Ultrasonic Cleaning
G_6(n=12)	Low-speed T.C. Bur	110 µm Al_2O_3 Sandblasting
G_7(n=12)	Low-speed T.C. Bur	Low-speed T.C. Bur
G_8(n=12)	Low-speed T.C. Bur	Torch Flame Heat
G_9(n=12)	Low-speed T.C. Bur	Ultrasonic Cleaning

5.2.7.Bonding and debonding second time

After the enamel surface reconditioning and bracket base cleaning procedures were completed for each group, the initial bonding protocol was performed for rebonding of the brackets. One group at a time was rebonded and after each debonding with the test device, next group rebonded and put into the test. Results recorded in a computer program linked to the Instron Universal Testing Machine.

Once all debonding completed, teeth surfaces and bracket bases inspected under steromicroscope and photographed for ARI score determination.

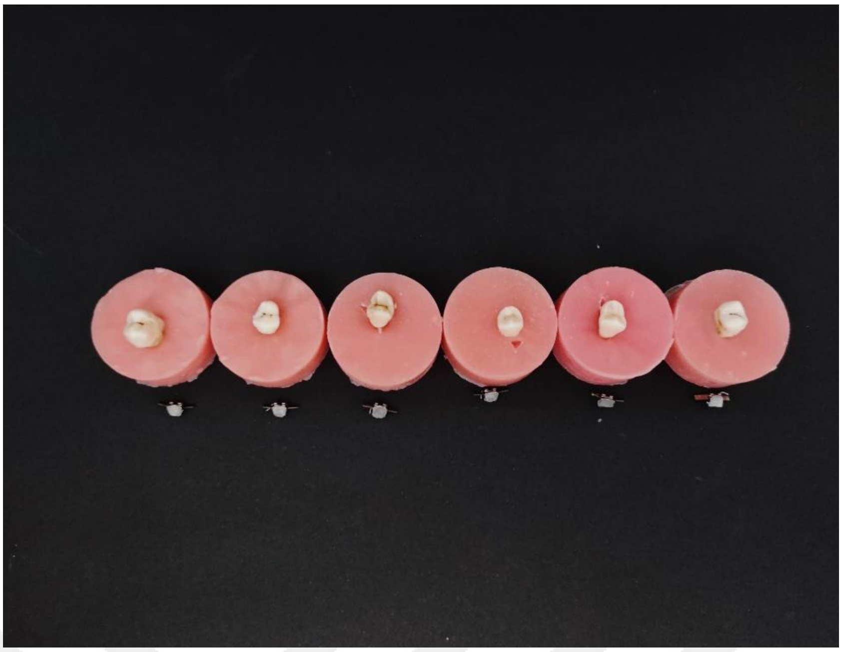

Figure 5.16. Second time debonded brackets.

6.RESULTS

The research was carried out between 01.03.2022 and 15.05.2022. It was performed in T.C. Yeditepe University Dental Hospital Hard Tissue Laboratory and T.C. Istanbul Medipol University Unkapanı Campus with a total of 96 individual specimens.

6.1.Statistical Analysis

NCSS (Number Cruncher Statistical System) 2007 (Kaysville, Utah, USA) program was used for statistical analysis. Descriptive statistical methods (mean, standard deviation, median, first quartile, third quartile, frequency, percentage, minimum, maximum) were used while evaluating the study data. The conformity of the quantitative data to the normal distribution was tested with the Shapiro-Wilk test and graphical examinations. Kruskal-Wallis test and Dunn-Bonferroni test were used for comparisons between groups of more than two quantitative variables that did not show normal distribution. Statistical significance was accepted as $p<0.05$.

NCSS (Number Cruncher Statistical System) 2007 (Kaysville, Utah, USA) program was also used for statistical analysis of Adhesive Remnant Index (A.R.I.). Descriptive statistical methods (frequency and percentage) were used when evaluating the study data. Qualitative variables were evaluated with the Fisher Freeman Halton test. Statistical significance was accepted as $p<0.05$.

For the purpose of comparing more than two groups within each other and for the evaluation difference, Post Hoc analysis conducted. In table x if $p<0.05$ there were significant difference between these individual groups.

A statistically significant difference was found between the shear-peel bond strenght measurements of the cases according to the groups ($p=0.001$; $p<0.01$). As a result of the pairwise comparisons made to determine the source of the difference.

Table 6.1. Evaluation of Max Strength(STR) (Mpa) Measurements According to Groups

Groups	Max STR (Mpa)		*p*
	Mean ± SD	***Median (Min-Max)***	
Control (n=12)	11,93±0,85	11,8 (10,9-14)	***[a]0,001****
H.S.-S.B. (n=12)	6,40±0,48	6,5 (5,4-7)	
H.S.-T.C (n=12)	5,43±0,61	5,2 (4,7-6,4)	
H.S.-HEAT(n=12)	4,85±0,47	5 (4,1-5,5)	
H.S.-U.S. (n=12)	5,85±0,29	5,9 (5,4-6,2)	
T.C.-S.B. (n=12)	10,79±0,38	10,9 (10,1-11,4)	
T.C.-T.C (n=12)	5,02±0,85	4,9 (3,7-6,3)	
T.C.-HEAT(n=12)	4,78±0,74	4,8 (3,4-5,9)	
T.C.-U.S. (n=12)	4,56±0,56	4,5 (3,8-5,4)	

[a]Kruskal Wallis Test

***p<0,01*

The shear-peel bond strenght measurements of the subjects in the Control group were statistically significantly higher than the , H.S.-T.C., H.S.-HEAT, T.C.-T.C., T.C.-HEAT and T.C.-U.S. groups (p=0.001; p<0.05).

Shear-peel bond strenght measurements of T.C.-S.B. group, were statistically significantly higher than those in the H.S.-HEAT, T.C.-HEAT, T.C.-T.C., H.S.-T.C. and T.C.-U.S. groups (p=0.017, p=0.013,p=0,016,p=0,001, p=0.002, p<0.05).

Shear-peel bond strength measurements of H.S.-S.B. group showed no statistically significant difference with control and T.C.-S.B. groups and had statistically significantly higher shear-peel bond strenght measurements than H.S-HEAT, T.C.-HEAT,T.C.-U.S. groups(p=0,017,p=0,013,p=0,002,p<0.05).

Shear-peel bond strenght measurements of the H.S.-HEAT group were statistically significantly lower than the Control,T.C.-S.B. and H.S.-S.B. groups and there were no statiscally significant difference between each other and other groups.

Table 6.2. Post Hoc Evaluation of Max STR (Mpa) Measurements According to Groups

Shear-peel	**Control**	**HS - SB**	**HS - TC**	**HS - HEAT**	**HS - US**	**TC - SB**	**TC - TC**	**TC- HEAT**	**TC - US**
Control	-								
H.S. - S.B.	***1,000***	-							
H.S. - T.C.	***0,001*****	***1,000***	-						
H.S. - HEAT	***0,001*****	***0,017****	***1,000***	-					
H.S. - U.S.	***0,057***	***1,000***	***1,000***	***0,469***	-				
T.C. - S.B.	***1,000***	***1,000***	***0,016****	***0,001*****	***0,671***	-			
T.C. - T.C.	***0,001*****	***0,094***	***1,000***	***1,000***	***1,000***	***0,001*****	-		
T.C .- HEAT	***0,001*****	***0,013****	***1,000***	***1,000***	***0,383***	***0,001*****	***1,000***	-	
T.C. - U.S.	***0,001*****	***0,002*****	***1,000***	***1,000***	***0,075***	***0,001*****	***1,000***	***1,000***	-

Dunn Bonferroni Test

**p<0,05   **p<0,01*

Results showed that highest shear-peel bond strength groups for rebonding the original brackets as T.C.-S.B. , H.S.-S.B. and H.S.-U.S respectively. Lowest shear-peel bond strength shown in groups T.C.-U.S., T.C.-Heat and H.S.-Heat. Generally burning the debonded brackets resulted in the lowest shear-peel bond strenght for both tooth surface cleaning methods

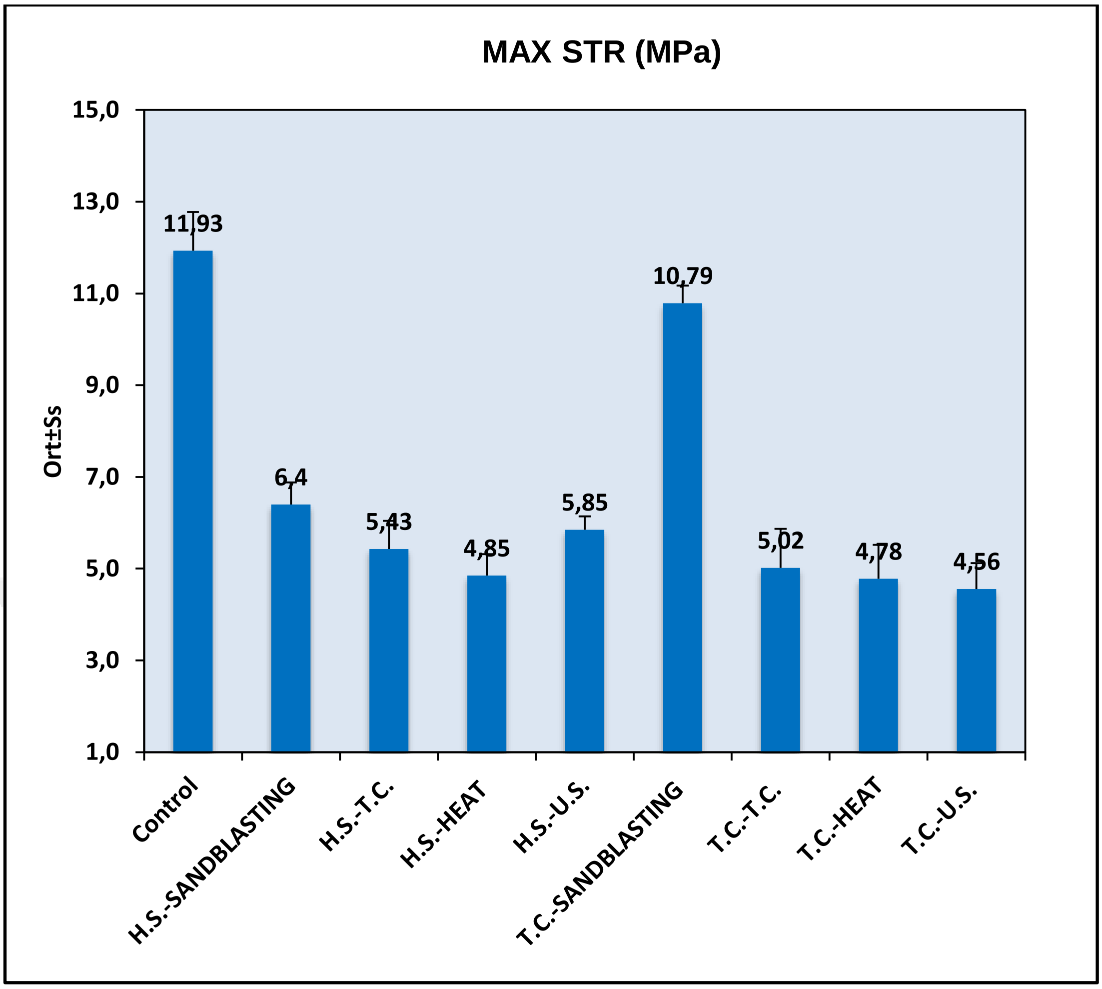

Figure 6.1. Distribution of Max STR (Mpa) measurements by groups

6.2.Results Of Adhesive Remnant Index (ARI)

In this study Adhesive Remnant Index used by Bishara et al. 2008 (105,106)was used to evaluate the amount of remaining adhesive. The scores according to this index are as shown in table 3.1.

Table 6.3. Evaluation of Adhesive Remnant Index Scores According to Groups

Groups	Adhesive Remnant Index Score 1 n (%)	Score 2 n (%)	Score 3 n (%)	Score 4 n (%)	Score 5 n (%)	Total n (%)
Group 2	5 (41,7)	6 (50,0)	0 (0)	1 (8,3)	0 (0)	12 (100)
Group 3	4 (33,3)	3 (25,0)	5 (41,7)	0 (0)	0 (0)	12 (100)
Group 4	2 (16,7)	4 (33,3)	5 (41,7)	1 (8,3)	0 (0)	12 (100)
Group 5	0 (0)	3 (25,0)	8 (66,7)	1 (8,3)	0 (0)	12 (100)
Group 6	0 (0)	3 (25,0)	3 (25,0)	4 (33,3)	2 (16,7)	12 (100)
Group 7	2 (16,7)	5 (41,7)	4 (33,3)	1 (8,3)	0 (0)	12 (100)
Group 8	5 (41,7)	5 (41,7)	1 (8,3)	1 (8,3)	0 (0)	12 (100)
Group 9	5 (41,7)	3 (25,0)	3 (25,0)	0 (0)	1 (8,3)	12 (100)
Total	23 (24,0)	32 (33,3)	29 (30,2)	9 (9,4)	3 (3,1)	96 (100)
p			***0,011****			
p	***0,015****	***0,856***	***0,012****	***0,175***	***0,316***	

Fisher Freeman Halton Test **p<0,05*

Adhesive Remnant Index scores showed statistically significant differences according to the groups (p=0.011; p<0.05). Pairwise comparisons were made in each score group to determine which group the difference originated from, and the results are as follows:

1. A statistically significant difference was found between the score 1 ratios according to the groups (p=0.015; p<0.05). The score 1 rates in group 2, group 8 and group 9 were higher than group 5 and group 6.
2. A statistically significant difference was found between the score 2 ratios according to the groups (p=0.856; p>0.05).
3. A statistically significant difference was found between the scores of 3 groups according to the groups (p=0.012; p<0.05). The score 3 ratios in group 5 are higher than group 1, group 6, group 8 and group 9. The score 3 ratios in group 3 and group 4 are higher than group 1.
4. A statistically significant difference was found between the score 4 ratios according to the groups (p=0.175; p>0.05).
5. A statistically significant difference was found between the score 5 ratios according to the groups (p=0.316; p>0.05).

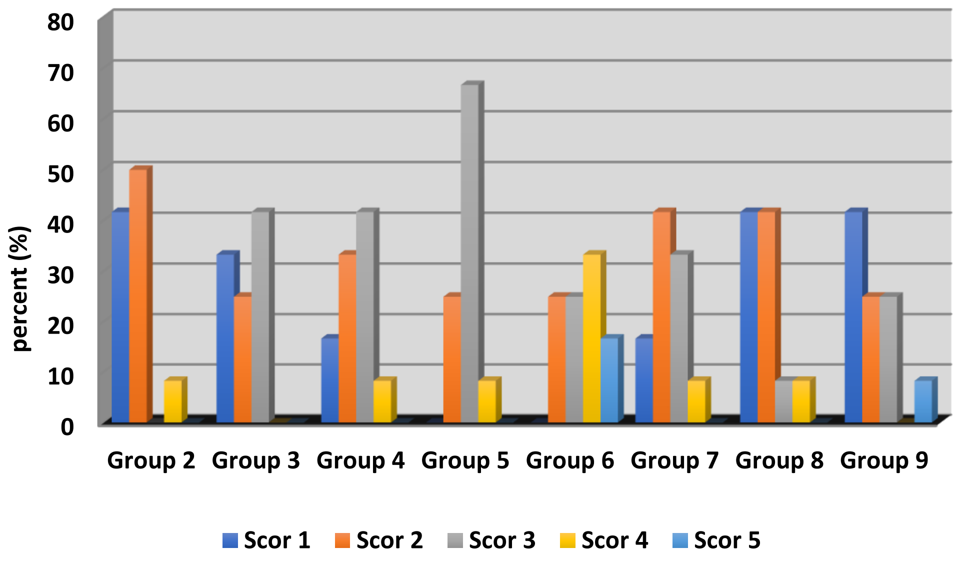

Figure 6.2. Evaluation of ARI scores according to individual groups

Table 6.4. Evaluation of adhesive remnant index according to enamel surface cleaning methods

	Adhesive Remnant Index					
	Score 1	**Score 2**	**Score 3**	**Score 4**	**Score 5**	**Total**
Groups	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**	**n (%)**
H.S.	11 (23,0)	16 (33,3)	18 (37,5)	3 (6,2)	0 (0)	48 (100)
T.C.	12 (25,0)	16 (33,3)	11 (22,9)	6 (12,5)	3 (6,2)	48 (100)
Total	23 (24,0)	32 (33,3)	29 (30,2)	9 (9,4)	3 (3,1)	96 (100)
p	***0,494***					

Fisher-Freman Halton test

No statistically significant difference was found between enamel surface cleaning methods (h.s. and t.c.) in terms of adhesive remnant index scores (p=0.494; p>0.05).

Most common score for the groups which teeth cleaned with h.s. was score 3 (37,5%). Groups which teeth cleaned with t.c. bur, most frequently showed score 2. Altough there was no statistically significant difference, when enamel surface cleaned with t.c. burs, it showed a tendency that, failure occured between bracket-resin interface more than when enamel surface cleaned with h.s. burs.

Table 6.5. Comparison **o**f max STR(Mpa) of enamel cleaning methods.

		Max STR (Mpa)			
	N	**Mean ± SD**	**Median**	**Min - Max**	***p***
H.S.	48	5,63±0,74	5,54	4,06-6,98	***0,127***
T.C.	48	6,29±2,71	5,06	3,43-11,45	
Total	96	5,96±2,00	5,38	3,43-11,45	

Mann Whitney U test

Although it was slightly lower in the h.s groups, no statistically significant difference was found between the Max STR measurements of the h.s and t.c methods. (p>0.05).

7.DISCUSSION

7.1.Discussion Of Aim

Over the last five decades modern straigth wire appliances have become gold standart in daily practice and orthodontic brackets with treatmen built in are the most important components of these fixed appliances. The manufacturing companies provide brackets with a variety of characteristics. These are metal alloy, width of the slots, the prescription, size and friction values with archwires, as well as the base designs. The importance of the various bracket designs can be explained as their ability to withstand intraoral forces, avoiding damaging the tooth during removal, and facilitating the orthodontist's work. Inadequate bonding between the bracket and the tooth will result in bracket failure throughout the treatment, and each rebonding will result in enamel loss. The desirable outcome of bracket removal is when the residual adhesive is on the base which will reduce enamel material loss caused by cleaning instruments. Cracks or fractures on the enamel surface are the unwanted outcome when the bracket and adhesive are detached from the enamel.

There are basically two reasons for rebonding during orthodontic treatment. The first of these is the removal and repositioning of the bracket by the physician in order to improve the treatment mechanics, and the second is involuntary bracket debonding as a result of adhesive failure or excessive intraoral force loading during treatment. In some cases, voluntary bracket removal may be required for various reasons. Some of these are situations such as the inability to place the bracket in the appropriate position in partially erupted teeth, excessively rotated teeth, benefiting from the versatility features of the brackets in McLauglin-Bennet-Trevisi mechanics, and inability to place the brackets in the desired position in cases of advanced crowding. Bracket failure during orthodontic treatment is an undesirable situation which no orthodontist wants to face.

According to Kafle et al.(71) 32 percent of the patients and 3.3 percent of the total brackets had experienced bracket failure at some point during the course of their treatment. Bracket failure has several negative consequences. These are as follow; prolongation of the treatment period, unwanted movements caused by treatment mechanics, discomfort in the patient, loss of time for the physician and the patient due to the extra session, loss of material in the enamel during the debonding of the bracket and removal of residual adhesive, formation of cracks or fractures, and the economic consequences of using new brackets or recycling the original bracket.

The process of preparing the tooth and bracket surface for rebonding has been defined as many different applications in the literature (107–111). However, there is no study that deals with both enamel surface preperation and bracket recycling together with these methods. Therefore, it is believed that this study will be important in terms of clinical applications. The null hypothesis of this study is that the adhesive cleaning methods applied to the bracket and enamel surface before rebonding have no significant effect on the bond strength of the bracket to the tooth.

There are three kinds of brackets according to the material they are made from. First is conventional metallic brackets and the others are aesthetic brackets which can be produced from plastic or ceramic. Metallic brackets were chosen in this study because debonding of ceramic and plastic brackets increase the risk of fractures of these attachments and enamel scratches, making difficult the preservation of enamel surface structure for the second round of debonding (112,113).

7.2.Discussion Of Materials And Methods

Review of the literature showed that, in vitro experiments examining the bond strength of the brackets to the enamel surface revealed two alternatives to which the bracket will be bonded. It can be seen that animal teeth (114–120) and extracted human (121–125) are used as bracket bonding samples.

In their research, Oesterle et al.(126) observed that human teeth had a 21-41% higher bond strength value than bovine teeth. According to Keçik et al.(127), the enamel and dentin layer of bovine teeth cultivate faster and have greater enamel crystals than human teeth. This difference due to the structure of the bovine teeth is believed to impact the bond strength results.

The extracted human premolar teeth are usually favored in studies because they are easy to obtain since premolars are usually the primary preference in orthodontic treatments with extraction (128,129). As a result, human premolar teeth extracted for orthodontic treatment were used in this study.

During bond strength tests, the force is transferred to the bracket using the universal tester's blade (119,131,132) or a wire wrapped around the bracket according to the literature (115,122). The results of these tests are influenced by variables such as the width of the wire used, its adaptation, and friction force (134). In this study, a stainless steel wire was placed in the bracket slot and secured to the bracket with a stainless steel ligature wire to better simulate intraoral forces. As a result, the force applied by the blade in this study will be at a distance from the bracket base.

It is expected that the resulting values will be lower than a standard shear bond strength test. Because this application will be standardized in all groups in an identical way, the relationship and correlation between groups will be unaffected.

According to the literature, the blade approach speed for bond strength tests appears to be 5 mm/min (131), 3 mm/min (115), 1 mm/min (123,133,135,136), and 0.5 mm/min (119,138). It has been observed that clinical conditions can not be accurately represented when the blade approach speed is less than 0.5 mm/min (119). Because the consistency of the tests decreased and the likelihood of enamel fracture increased as the blade approach speed increased (139), the blade head speed in our study was set at 1 mm/min.

In this study we are comparing the methods of enamel reconditioning and bracket recycling. The bonding system is the same in all groups and it needs to perform adequatly. Although there are variety of bonding systems in the market Transbond XT was chosen in this study due to its greater physical properties and wide clinical use, demonstrating satisfactory longitudinal results and also due to its greater bond strength when compared to other bonding systems(140,141).

About separation site during debonding when evaluating bond failures various interfaces examined so far. With stainless steel brackets, the most prevalent point of failure is the bracket/resin interface (142,143). As a result, it has been asserted that the bracket/resin bond is weakest link in orthodontic bonding (142,144,145) . In clinical practice, anterior bonds are more likely to separate at the bracket/resin interface, whilst posterior teeth are more likely to show an enamel/resin break (146,147). The reverse situation is noticeable in vitro, with bracket/resin failures greater for the posterior teeth (148). To precisely identify the various interfaces of bond failure, qualitative and quantitative metrics to describe the surfaces resulting from debonding have been developed. The Adhesive Remnant Index(ARI) was proposed by Artun and Bergland to describe the amount of resin remaining on the tooth surface after debonding (149).

Before rebonding, the adhesives remaining on the enamel surface should be cleaned with minimal damage to the enamel. For this, there are various methods such as high speed tungsten carbide bur, low speed tungsten carbide bur, silicone polishing burs, stainbuster burs, adhesive removal pliers, sandblasting, 3M Soflex abrasive discs, various polishing systems and various lasers.

Shah et al.(150) found that soflex discs created the most rougher enamel surfaces among Enhance system, One Gloss system, and fiber reinforced Stainbuster bur. Khosravanifard et al. looked at the shear bond strenghts of rebonded brackets after sandblasting and using high and low speed tungsten carbide burs for cleaning adhesive remnants from enamel surface. They found that using tungsten carbide burs were comparatively superior and enamel sandblasting was time-consuming and frequently damaged the enamel in all SEM figures (151). Kim et al. compared sandblasting the enamel surface and using low speed tungsten carbide bur for enamel surface cleaning after debonding. They found that even though surface profile was similar, sandblasting produced more heat on the enamel surface (152). Karan et al.(153) compared enamel surface roughness with atomic force microscopy after removing adhesive remnants from enamel surface with low speed tungsten carbide bur and fiber reinforced composite bur. They found that fiber reinforced composite bur created smoother surface but it was significantly more time consuming. Phillip M. Campbell (80) published a paper on comparison of two types of tungsten carbide burs and soflex dics and found that No:30 fluted t.c. bur left less scars on enamel. Hong and Lew (155) compared enamel surfaces using 5 differerent enamel cleaning methods after debonding. These were; low speed tungsten carbide bur, high speed tungsten carbide bur, diamond bur, high speed white stone finishing bur and band removing plier. Results showed that combination of three methods; namely, high speed tungsten carbide bur, slow speed tungsten carbide bur and band removing plier may proved ideal in the effective removal of composite remnants following debonding. Ahrari et al.(156) used a low speed and a high speed tungsten carbide burs, an ultra fine diamond bur and an Er:YAG laser (250 mJ, long pulse, 4 Hz) after debonding brackets and compared enamel surface roughness with profilometry analysis. The results showed that application of the ultrafine diamond bur or the Er:YAG laser caused irreversible enamel damage on tooth surface, and thus these methods could not be recommended for removing adhesive remnants after debonding of orthodontic brackets. Ulusoy(157) claimed in his research, cleaning residual adhesive after debonding with high speed tungsten carbide was more efficient that silicone polishing burs but left more scars on enamel surface. He proposed using silicone burs after cleaning enamel surface with t.c. burs as an ideal method.

Tungsten carbide bur has been the most recommended instrument for removal of adhesive remnant from enamel surface both at low (137,154,158,161) and high speed (160,162,164,165,166). However, when comparing the use of this bur at both speeds, Rouleau et al. and Eminkahyagil et al. verified best results at high-speed (165,166), while Ireland et al.(159) found them at low-speed. Removal of adhesive remnant with high speed tungsten carbide bur showed to be efficient. However, these instruments produced some irregularities on enamel surface (167). Because of the practical reasons and the aim of minimal enamel damage while debonding being one of the important components of this study low speed tungsten carbide burs and silicone polishing burs were selected for this study.

Rebonding the initial bracket requires bracket base cleaning. Rebonding without any preperation significantly reduces bonding strength as Egan et al. put forth in their study in 1996 (75).

There are various base cleaning, bracket recycling methods in use. Some of them are; using high speed or low speed tungsten carbide burs, ulrasonic cleaning, burning with direct flame, sandblasting and industrial recycling methods such as heating and using laser.

One of the most prominent bracket base cleaning method is sandblasting (168–172). Chung et al.(173) compared the bond strength of new brackets and sandblasted debonded brackets. They found that the bond strength of sandblasted used brackets were not significantly different than the new brackets. Yassaei et al.(109) found that the Er:YAG laser recycled brackets yielded shear rebond strength values comparable to those of the sandblasted brackets and the control groups.

Sandblasting in office settings is far more practical than industrial recycling using Er:YAG laser and since they performed similarly, sandblasting was chosen in this study.

Another method used in bracket base cleaning after debonding is using high or low speed tungsten carbide burs (97,175–178). Kulandaivelu et al.(179) prepared a study where they compared low speed t.c. bur with sandblasting, heating with direct torch flame and Er:YAG laser as braket base cleaning methods. They found that brackets reconditioned with laser had the highest bonding strength followed by sandblasting and low speed t.c. bur respectively. Aksu et al.(97) compared sandblasting and and low speed t.c. bur for bracket base cleaning in metal brackets. They bonded recycled brackets to both used and new teeth. The results of the study showed that when compared t.c. burs performed worse than sandblasted brackets and even though using t.c. bur is somewhat viable option, they suggested that practicioners should use it cautiously.

Another bracket base cleaning and reconditioning method is ultrasonic cleaning (174,180–184). Maaitah et al.(108) studied on the effect of different bracket base conditioning methods on shear bond strength (SBS) of rebonded brackets and compared the effects of low speed carbide bur, ultrasonic scaler and sanblasting. They found that there were no statistically significant differences between all groups in the aspect of bonding strength to the teeth and in the aspect of ARI scores. They concluded their study as “slow speed t.c. burs and ultrasonic scalers are effective, quick and cheap methods for bracket base cleaning for rebonding”. In the light of the findings of these studies, ultrasonic cleaning and low speed t.c. burs were selected as two of the methods for bracket recycling.

Using direct flame to burn remnant adhesives on the bracket base is a common and easy method of bracket reconditioning (94,97,110,183,184). Mirhashemi et al.(110) published a study where they look for rebonded shear bonding strength values after cleaning ceramic bracket base with; Er;YAG laser, Er;Cr:YSGG laser, sandblasting and direct flame. According to this study direct flame group had clinically acceptable results. Yassaei et al.(109) found in their study that mean shear rebonding strength of the direct flamed brackets, though significantly lower than control group, exceeded minimum clinically adequate level. Grazioli et al.(111) concucted a meta-analysis on residual adhesive removal methods and they included 12 studies on this subject. The methods they looked for were; sandblasting, t.c. burs and direct flame. The results showed that all 3 methods had lower bonding strength values than control group which was bonded with a new bracket. Also according to this study even though Er:YAG laser showed best results, direct flame and other methods had clinically acceptable shear bonding strength values and they are suitable for clinical use. Relying on these findings, heating with flame torch included in this study.

7.3.Discussion of Results

When we examine the data of our study, it is seen that the bond strength after rebonding is lower in all groups compared to the G_1(control)(11.93±0.85 MPa). The highest rebonding shear peel strength results after G_1(Control) were obtained in G_6(t.c.-s.b.)(10.79±0.38 MPa), followed by G_2(h.s.-sandblasting)(6.4±0.48 MPa), G_4(h.s.-u.s.)(5.85±0.29 MPa), G_3(h.s.-t.c.)(5.43±0.61 MPa), G_7(t.c.-t.c.)(5.02±0.85 MPa), G_5(h.s.-heat)(4.85±0.47 MPa), G_9(t.c.-heat)(4.78±0.74 MPa), G_8(t.c.-u.s.) (4.56±0.56 MPa) groups.

Sandblasting is a practical method that is widely used in the clinic. In our research, the least time consuming method of cleaning the bracket surface was sandblasting. Regardless of the method applied to the enamel surface, sandblasting has produced the most successful results. In the results, the blasting groups showed lower values than the control groups which coincides with the studies Yassaei et al.(109) and Maaitah et al.(108) published. Contrary to Willems et al.(187) suggested, Chung et al.(173) and Regan et al.(171) reported that the bond strength decreased due to deterioration in the bracket base morphology after sandblasting, and this is consistent with the results of this study. Millet et al.(92) and Arici et al.(188) suggested the adequate time and particle size for sandblasting and stated that the bond strength would decrease as the particle size increases and the time longer. At the same time Grazioli et al.(111) showed that residual particles at the base of the bracket can cause premature debonding. Although a decrease was observed in the bonding strength in this study, there was no significant difference with G1(Control). In groups with sandblasted brackets(G_2 and G_6), bond strength values of the samples whose enamel surfaces were cleaned with a tungsten carbide bur was found to be higher than the samples cleaned with Henry Schein silicone bur but results were not statistically significant.

Ultrasonic scaler stands out as an easy-to-access bracket recycling method that can be found in every clinic. However, in this study, cleaning with an ultrasonic scaler was a very time-consuming and impractical method. When we compared G_4(h.s.-u.s.) with G_2(h.s.-s.b.), G_3(h.s.-t.c.) ve G_7(t.c.-t.c.) there was no statistically significant difference but when compared with G_1(Control) and G_6(t.c.-sandblasting) bonding strength values were significantly lower ($p<0.05$). Moreover G_4(h.s.-u.s.) showed significantly higher shear-peel rebonding strength when compared with G_9(t.c.-heat), G_5(h.s.-heat), G_8(t.c.-u.s.)($p<0.05$). This results are in line with the study of Maaitah et al.(108), which revealed that there is no statistically significant difference between cleaning the bracket surface with tungsten carbide bur and ultrasonic scaler, but it does not coincide with the result of the same study that these samples were similar to the bond strengths of the new brackets. Possible reasons for this result may be the teeth and materials used in studies may. In our study, the G_4(h.s.-u.s.) showed significantly higher bond strength values than the G_8(t.c.-u.s.) group in the samples cleaned with an ultrasonic scaler($p<0.05$) and G_8(t.c.-u.s.) showed lowest rebonding strength amongst all groups. In this study, there was no significant difference between the enamel reconditioning methods. The reason for the significant difference in between G_4(h.s.-u.s.) and G_8(t.c.-u.s.), using ultrasonic scalers might be that the mesh structure at the base of the bracket is damaged due to the application of the ultrasonic scaler for a indeterminate period until there was no visible adhesive remnant.

Cleaning the bracket base with a tungsten carbide bur is a clinically practical and easily accessible method that can save time compared to various other methods. In groups which brackets cleaned with t.c. bur have achieved highest rebonding strength after sandblasted brackets but there was no significant difference between the groups that recycled with ultrasonic scaler or direct flame. Most crucial part of bonding strength of brackets is preservation of the mesh integrity (163). Tungsten carbide burs can damage the mesh structure during adhesive removal. In this study, the brackets cleaned with tungsten carbide bur showed significantly lower bonding strength values than G_1(control)($p<0.05$). This coincides with findings of Basudan et al.(170) and contradicts with what Maaitah et al.(108) suggested. The reason for this contradiction may be the type of bur or the type of bracket used.

Heating the bracket base with a direct flame was one method used to eliminate the adhesive remains after debonding. The removal of the bonding material is the most vital part of the recycling process when using this method, and it necessitates prolonged heat exposure (89). Direct flaming raises the temperature of the bracket base to around 600-800 C, which can cause disintegration of the metal alloy and, as a result, weakens its structure (189). Direct flame also caused significant discoloration on all of bracket surfaces which could be undesirable most of time. Chetan et al.(183) showed that heating bracket result in reduced hardness and makes bracket more vulnerable to damage.

In this study, direct flame was the least successful bracket recycling method in terms of bond strength and practicality. Samples in the G_5(h.s.-heat) and G_9(t.c.-heat) showed significantly lower bond strength values than the control and sandblasting groups ($p<0.05$). These results coincide with the literarure (170,172,183,190,191) but contradicts with the study Han et al.(192) have done which found that brackets heated with direct flame had higher rebonding strength than sandblasted brackets.

When the results of G_9(t.c.-heat) evaluated there was no significant difference with G_7(t.c.-t.c.), G_8(t.c.-u.s.), G_5(h.s.-heat), G_3(h.s.-t.c.) groups. However, rebonding shear-peel strength was signifacantly lower than G_4(h.s.-u.s.)($p<0.05$). On the other hand G5(h.s.-heat) had significantly lower values than G_1(Control), G_2(h.s.-sandblasting), G_3(h.s.-t.c.), G_4(h.s.-u.s.), G_6(t.c.-sandblasting) ($p<0.05$). There were no significant difference with G_7(t.c.-t.c.), G_8(t.c.-u.s.), G_9(t.c.-heat).

One of the aims of this study was comparing enamel surface cleaning methods. There was no study that compared t.c. burs and silicone finishing burs for ARI scores at the time this research conducted. Marchi et al.(24) compared two different silicone based polishing systems and found no significant difference between them in ARI scores. They used the ARI score table of Zachrisson and Årtun (87). Most frequent score for both systems was score 3 which means less than 50% of adhesive left on enamel surface.

In this study ARI scores also evaluated according to enamel surface cleaning methods. 4 h.s. groups and 4 t.c. groups compared against and no statistical significance found between them. Additionally same comparison has been done according enamel surface cleaning methods for max str and there was not significant difference between enamel cleaning methods in case of bond strength.

When literature reviewed, there was wide range of diversity for acceptable minimum bonding strength (173,193,194). While Mizrahi et al.(195) was 2.8-10 MPa, Reynolds et al.(196) suggested that it was 5.9-7.8 MPa. At the same time, there are studies in the literature stating that the initial bond has a higher bond strength than the rebonded brackets (129,130,166,186,197) , and there are also studies mentioning that the rebonded brackets have higher than bond strength than initially bonded brackets (171,185,198). The reasons for this variation in results may be the anatomical diversity in the buccal surfaces of the teeth, the types of teeth used in research, the use of new teeth, adhesive removal techniques, bonding systems, and the types of resin used.

8.CONCLUSION

The aim of this study was to examine the success of bracket recycling methods and enamel surface cleaning methods before rebonding**.** These methods was chosen due to their practicality and accessibility as well as previous positive experiences. When bracket failure occur, ideally a new bracket should be used and an ideal bracket recycling method should clean 100% of adhesive residue without damaging bracket base and should be easy to access and cost-effective. Unfortunately these methods do not exist yet.

Two different enamel surface cleaning methods and four different bracket recycling methods included and tested. In vitro tests have limitations. Test setup used in this study aimed to mimic intraoral forces better than standart shear bond strength tests however in an in vitro study it is difficult to achieve this in perfect standarts. There are wide range of enamel reconditioning and bracket recycling methods and few studies included both enamel reconditioning and bracket recycling methods together. Altough this study could not include all enamel surface cleaning and bracket recycling methods , it may help in determining a practical combination for easy-to-access rebonding procedure in-office conditions. Further studies should investigate wider range of combinations while better mimicing intraoral conditions and intraoral forces.

Within the limitations of this in vitro study, the conclusions can be summerised as follows:

1. Shear/peel bond strength of control group was higher than all of the rebonding groups but with **G_6 (t.c.-sb.)** and **G_2 (h.s.-sb**.), the difference was not statistically significant.
2. Amongst rebonding groups, cleaning enamel surface with low speed tungsten carbide bur combined with sandblasted brackets resulted in highest shear/peel bond strength values.
3. When shear/peel bond strength of rebonding groups compared ranking of values were: **G_6 (t.c.-sb.) > G_2 (h.s.-sb.) > G_4 (h.s.-u.s.) > G_3 (h.s.-t.c.) > G_7 (t.c.-t.c.) > G_5 (h.s.-heat) > G_9 (t.c.-heat) > G_8 (t.c.-us.).**

4. Altough there were shear/peel bond strength differences between G_6, G_2 and G_4, it was not statistically significant.
5. Best performing bracket recycling method appeared to be sandblasting. Ultrasonic scaler and low speed tungsten carbide bur are also viable options following sandblasting. Heating bracket with direct flame resulted in undesired aesthetics and lowest bond strength values overall.
6. There was no statistically significant bond strength difference between groups which enamel surface cleaned with Henry Schein silicon polishing bur and groups which enamel surface cleaned with tungsten carbide bur.
7. There was no statistically significant difference of ARI scores between groups which enamel surface cleaned with Henry Schein silicon polishing bur and groups which enamel surface cleaned with tungsten carbide bur.
8. Both tungsten carbide bur and Henry Schein silicone polishing kit are viable options for enamel conditioning.

The null hypothesis of this study was that the adhesive cleaning methods applied to the bracket and enamel surface before rebonding have no significant effect on the bond strength of the bracket to the tooth. The null hypothesis is rejected. Although there was no statistically significant difference between enamel cleaning methods in bond strength, bracket recycling methods significantly effects shear/peel bonding strength of rebonded brackets.

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10.APPENDICES

Appendix 1. Informed consent form in Turkish

T.C.
İstanbul Medipol Üniversitesi Dişhekimliği Fakültesi
Ortodonti Anabilim Dalı

KATILIMCILAR İÇİN GÖNÜLLÜ BİLGİLENDİRME VE ONAM FORMU

Araştırma yürütücüsü: Dt.Doruk Akçapınar

Araştırma adı: Tekrar Yapıştırılmış Ortodontik Braketlerin Makaslama/Ayırma Bağlantı Kuvveti : Bir In Vitro Çalışma

Sizin/refakat ettiğiniz kişinin İstanbul Medipol Üniversitesi Diş Hekimliği Fakültesi tarafından yürütülen bu çalışmaya katılmasını arzu ediyoruz. Aşağıda bu çalışma ile ilgili bazı bilgiler bulacaksınız. Bu bilgiler sizin çalışmaya katılımınızın kolaylaştırılması ve öneminin anlaşılabilmesi için hazırlanmıştır.

Araştırmanın Amacı ve Önemi: Bu araştırmanın sonucunda ortodontik amaçla taktığımız braketlerin düşmesi/sökülmesi durumunda tekrar yapıştırılma sürecinde diş yüzeyine ve/veya braket yüzeyine uygulanacak çeşitli işlemler sonucu sıyırma/ayırma kuvvet dirençleri karşılaştırılarak en başarılı yöntemler tespit edicektir.

Gerçekleştirilecek İşlemler: Bu çalışmaya katılmayı kabul etmeniz durumunda sizin/refakat ettiğiniz kişinin çekim endikasyonu konmuş daimi dişinizin çekimi gerçekleştirildikten sonra çekilen dişler uygun saklama solüsyonlarında deney süreci başlayana dek muhafaza edilip çalışmaya dahil edilecektir. Bu çalışmaya katılıp katılmamanız tamamen sizin kendi iradeniz ile vereceğiniz karara bağlıdır.

Katılımın süresi: Bu çalışmaya katılmaya karar verirseniz diş çekimi işleminin bitmesinin ardından çekilen dişinin uygun saklama solüsyonunun bulunduğu kaplara konması yaklaşık 3 dakika sürecektir.

Potansiyel Risk ve Sorunlar: Bu çalışmanın herhangi bir riskinin söz konusu olmayacağı düşünülmektedir.

Gizlilik: Size ait tüm tıbbi ve kimlik bilgileriniz gizli tutulacaktır ve araştırma yayınlansa bile kimlik bilgileriniz verilmeyecektir, ancak araştırmanın izleyicileri, yoklama yapanlar, etik kurullar ve resmi makamlar gerektiğinde tıbbi bilgilerinize ulaşabilir. Siz de istediğinizde kendinize ait tıbbi bilgilere ulaşabilirsiniz.

Kurumumuzun Sorumluluk Sınırları: Herhangi bir fiziksel yaralanma oluşmaması için gereken her türlü özen ve hassasiyet gösterilecektir. Cerrahi işlemler esnasında oluşacak herhangi bir komplikasyondan dolayı kurumumuz sorumluluk kabul etmemektedir. Fakat oluşacak zararlar konusunda yardımcı olmak için elimizden gelen gayret gösterilecektir.

Çalışmadan çıkmak: İstediğiniz takdirde başlangıçta çalışmaya katılmayı reddedebilirsiniz. İstediğiniz takdirde araştırmacıya haber vererek çalışma kapsamı dışında kalabileceği gibi araştırmacı tarafından gerek görüldüğünde araştırma dışı da bırakılabilirsiniz. Çalışma kapsamı dışında kalmanız İ.M.Ü. Diş Hekimliği Fakültesi'nin tedavi hizmetlerinden yararlanmanızı etkilemeyecektir.

Mali Sorumluluk: Katılımcı, araştırma için yapılacak harcamalarla ilgili herhangi bir parasal sorumluluk altına girmeyecektir. Ayrıca katılımcıya da bir ödeme yapılmayacaktır.

Sorularınız: Sizin çalışma ile ilgili sorularınız en kısa sürede yanıtlanacaktır. Sorularınızı doğrudan Dt. Doruk Akçapınar'a sorabileceğiniz gibi gerekirse [redacted]o'lu telefonu da kullanabilirsiniz.

Bu proje İstanbul Medipol Üniversitesi Diş Hekimliği Fakültesi Etik Kurul komitesi tarafından incelenmiş ve onaylanmıştır. Bu proje ile ilgili sorularınız gerekirse önceden telefon ile randevu alarak komiteye de yöneltebilirsiniz.

HASTA VELİSİNİN BEYANI

Sayın Dt. Doruk Akçapınar;

İstanbul Medipol Üniversitesi, Diş Hekimliği Fakültesi Ortodonti A.D.'da tıbbi bir araştırma yapılacağı belirtilerek bu araştırma ile ilgili yukarıdaki bilgiler bana aktarıldı. Bu bilgilerden sonra böyle bir araştırmaya "katılımcı" (denek) olarak davet edildim.

Eğer bu araştırmaya katılırsam hekim ile aramızda kalması gereken bana/refakat ettiğim kişiye ait bilgilerin gizliliğine bu araştırma sırasında da büyük özen ve saygı ile yaklaşılacağına inanıyorum. Araştırma sonuçlarının eğitim ve bilimsel amaçlarla kullanımı sırasında kişisel bilgilerimizin ihtimamla korunacağı konusunda bana yeterli güven verildi.

Projenin yürütülmesi sırasında herhangi bir sebep göstermeden araştırmadan çekilebilirim. (Ancak araştırmacıları zor durumda bırakmamak için araştırmadan çekileceğimi önceden bildirmemim uygun olacağının bilincindeyim). Ayrıca tıbbi durumuma herhangi bir zarar verilmemesi koşuluyla araştırmacı tarafından araştırma dışı da tutulabiliriz.

Araştırma için yapılacak harcamalarla ilgili herhangi bir parasal sorumluluk altına girmiyorum. Bana da bir ödeme yapılmayacaktır.

İster doğrudan ister dolaylı olsun araştırma uygulamasından kaynaklanan nedenlerle kendimde/refakat ettiğim hastada meydana gelebilecek herhangi bir sağlık sorununun ortaya çıkması halinde, her türlü tıbbi müdahalenin sağlanacağı konusunda gerekli güvence verildi. (Bu tıbbi müdahalelerle ilgili olarak da parasal bir yük altına girmeyeceğim).

Araştırma sırasında, çalışma ile ilgili bir sorun oluşması durumunda; mesai saatleri içinde, Dt. Doruk Akçapınar'ı [redacted]'lu telefondan arayabileceğimi biliyorum.

Bu araştırmaya katılmak zorunda değilim ve katılmayabilirim. Araştırmaya katılmam konusunda zorlayıcı bir davranışla karşılaşmış değilim. Eğer katılmayı reddedersem, bu durumun tıbbi bakımıma ve hekim ile olan ilişkime herhangi bir zarar getirmeyeceğini de biliyorum.

Bana yapılan tüm açıklamaları ayrıntılarıyla anlamış bulunmaktayım. Kendi başıma belli bir düşünme süresi sonunda adı geçen bu araştırma projesinde çocuğumun "katılımcı" (denek) olarak yer almasına kararını verdim. Bu konuda yapılan daveti büyük bir memnuniyet ve gönüllülük içerisinde kabul ediyorum.

İmzalı bu form kâğıdının bir kopyası bana verilecektir.

GÖNÜLLÜ ONAY FORMU

Yukarıda gönüllüye araştırmadan önce verilmesi gereken bilgileri gösteren metni okudum. Bunlar hakkında bana yazılı ve sözlü açıklamalar yapıldı. Bu koşullarla söz konusu klinik araştırmaya kendi rızamla hiçbir baskı ve zorlama olmaksızın katılmayı kabul ediyorum.

Katılımcının,

Adı-Soyadı:

Adresi:

Tel.-Faks:

Tarih ve İmza:

Açıklamaları yapan araştırmacının,

Adı-Soyadı: Doruk Akçapınar
Görevi: Diş Hekimi
Adresi: İstanbul Medipol Üniversitesi Diş Hekimliği Fakültesi Ortodonti Anabilim Dalı
Tel.-Faks: [redacted]
e-mail: [redacted]

Tarih ve İmza:

Rıza alma işlemine başından sonuna kadar tanıklık eden kuruluş görevlisinin,

Adı-soyadı:
Görevi:
İmzası: