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MICRO-COMPUTED TOMOGRAPHY ASSESSMENT OF MICROLEAKAGE AND VOID FORMATION UNDER CERAMIC ADHESIVE PRECOATED ORTHODONTIC BRACKETS

ARTEMISA ADIGÜZEL

THESIS SUPERVISOR
ASSOC. PROF. DR. ERSİN YILDIRIM

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SYMBOLS AND ABBREVIATIONS

2D	**:** Two-dimensional
3D	**:** Three-dimensional
APC	**:** Adhesive precoated brackets
Bis-GMA	**:** Bisphenol-glycidyl methacrylate
BMP	**:** Bit Map Picture
CBCT	**:** Cone-beam computed tomography
CCD	**:** Charged-coupled device
CO_2	**:** Carbon Dioxide
CT	**:** Computerized tomography
DICOM	**:** Digital Imaging and Communications in Medicine
Er: YAG Laser	**:** Erbium-doped yttrium-aluminum-garnet laser
LED	**:** Light-emitting diode
Micro-CT	**:** Micro-Computed Tomography
MPa	**:** Megapascal
N	**:** Newton
Nd: YAG Laser	**:** Neodyium-doped yttrium aluminum garnet laser
OTM	**:** Orthodontic tooth movement
ROI	**:** Regions of interest
SBS	**:** Shear bond strength
SEM	**:** Scanning Electron Microscope
TEGDMA	**:** Triethylene glycol dimethacrylate
TEM	**:** Transmission electron microscopy
TIFF	**:** Tagged Image File
TSEP	**:** Transbond Plus Self-Etching Primer

MICRO-COMPUTED TOMOGRAPHY ASSESSMENT OF MICROLEAKAGE AND VOID FORMATION UNDER CERAMIC ADHESIVE PRECOATED ORTHODONTIC BRACKETS

ABSTRACT

Aim: Evaluation of microleakage and void on ceramic adhesive precoated brackets using micro-computed tomography and to investigate their correlation with bond strength.

Materials and Methods: Fifty-two human premolar teeth were used in this study. Teeth were randomly divided into four groups containing 13 teeth. The brackets used in the study were APC Flash-Free ceramic bracket and Clarity Advanced Ceramic Bracket. The adhesive systems used were APC Flash-Free and Transbond XT Light Cure Adhesive. Teeth were scanned with micro-computed tomography for microleakage, void and gap analysis. Bond strength was measured and recorded in megapascals. Kruskal-Wallis H test and Mann-Whitney U test were used to analyze group differences and paired group differences. The relationship between variables was evaluated through Spearman's correlation analysis.

Results: The void volume value of Group 4 was significantly higher than Group 3 ($p<0.05$). The adhesive volume value of Group 1 was significantly higher than Group 3 ($p<0.05$). There was no statistically significant difference between groups regarding bond strength values, gap volume values, and total void and gap volume values ($p>0.05$). Spearman's correlation analysis results demonstrate that bond strength is significantly impacted by adhesive volume, gap volume, and total void and gap volume. The bond strength increases as the volume of adhesive is raised, and the total volume of voids and gaps is reduced.

Conclusion: There was no difference between the APC Flash-Free Ceramic Bracket and Clarity Advance Ceramic Bracket regarding void volume, gap volume, total void and gap volume. Both brackets demonstrated similar bond strength values. Clarity Advance Ceramic Bracket bonded with self-etching primer exhibited higher void volume than those bonded using the conventional method. Bond strength was

significantly impacted by adhesive volume, gap volume, and total void and gap volume. Bond strength rises with increased adhesive volume and decreased total void and gap volume.

Key Words: APC Flash-Free Ceramic Bracket, Clarity Advanced ceramic bracket, Micro-CT, Gap, Void, Microleakage.

ADEZİV KAPLAMALI SERAMİK ORTODONTİK BRAKETLER ALTINDA OLUŞAN MİKROSIZINTININ VE BOŞLUK OLUŞUMUNUN MİKRO-BİLGİSAYARLI TOMOGRAFİ İLE DEĞERLENDİRİLMESİ

ÖZET

Amaç: Adeziv kaplamalı seramik ortodontik braketlerin altında oluşan mikrosızıntı ve boşluk oluşumunun mikro-bilgisayarlı tomografi ile belirlenmesi ve bağlanma dayanımı ile ilişkisinin değerlendirilmesidir.

Gereç ve Yöntem: Bu çalışmada 52 adet insan premolar dişi kullanıldı. Dişler rastgele 13 diş içeren dört gruba ayrıldı. Çalışmada APC Flash-Free seramik braket ve Clarity Advanced Ceramic Braket kullanıldı. Adeziv sistemler olarak APC Flash-Free ve Transbond XT Light Cure Adeziv kullanıldı. Mikrosızıntı ve boşluk analizi için dişler mikro bilgisayarlı tomografi ile tarandı. Bağlanma dayanımı üniversal test cihazı ile ölçüldü ve megapaskal olarak kaydedildi. Grup farklılıkları ve ikili grup farklılıklarının analizinde Kruskal-Wallis H testi ve Mann-Whitney U testi kullanıldı. Değişkenler arasındaki ilişki Spearman'ın korelasyon analizi ile değerlendirildi.

Bulgular: Grup 4'ün boşluk hacmi değeri Grup 3'e göre istatistiksel olarak anlamlı derecede yüksekti ($p<0,05$). Grup 1'in adeziv hacim değeri Grup 3'e göre anlamlı derecede yüksekti ($p<0.05$). Gruplar arasında bağlanma dayanımı, aralık hacmi ve toplam boşluk-aralık hacmi değerleri açısından istatistiksel olarak anlamlı fark bulunmadı ($p>0.05$). Spearman'ın korelasyon analizi, bağlanma dayanımının adeziv hacmi, boşluk hacmi ve toplam boşluk ve aralık hacminden etkilendiğini göstermiştir. Bağlanma dayanımı, artan adeziv hacmi ve azalan toplam boşluk ve aralık hacmi ile artmaktadır.

Sonuç: APC Flash-Free Seramik Braketler ve Clarity Advance Seramik Braketler arasında boşluk hacmi, aralık hacmi, toplam boşluk ve aralık hacmi açısından fark yoktu. Her iki braket tipi de benzer bağlanma dayanım değerleri gösterdi. Kendinden asitli primer ile yapıştırılan Clarity Advance Seramik Braketler, geleneksel yöntemle yapıştırılanlardan daha yüksek boşluk hacmi sergiledi. Bağlanma dayanımının adeziv hacmi, boşluk hacmi, toplam boşluk ve aralık hacminden etkilendiğini göstermiştir.

Bağlanma dayanımı, artan adeziv hacmi ve azalan toplam boşluk ve aralık hacmi ile artmaktadır.

Anahtar Kelimeler: APC Flash-free Seramik Braket, Clarity Advanced seramik braket, Mikro-BT, Aralık, Boşluk, Mikrosızıntı.

1. INTRODUCTION AND AIM

Ensuring adequate adhesive bonding between orthodontic attachments and enamel surfaces is one of the essential factors in the success of orthodontic treatment (1). The first study focused on increasing the bond between the tooth and the bracket in 1955 by Buonocore, who showed the bond strength could be improved by etching the enamel surface (2).

A high-quality bond is required for fixed orthodontic treatment to be successful and for the brackets to remain bonded to the teeth throughout the entire treatment period. The bonding should have as few gaps as possible, as gaps in the adhesive layer can reduce the bond strength, cause the bond to break, and facilitate the formation of white spot lesions (3). Cavities in dental resins form when moisture and air remain in the material; this can occur during fabrication or when placing material for dental restorations in the cavity (4). The durability of the composite may decrease due to internal voids, which cause fractures and clinical failures in restorations (5). Traditional methods provide void formation data based on invasive and two-dimensional (2D) procedures such as Scanning Electron Microscope (SEM), high-pressure mercury intrusion porosimetry, and stereological volumetric analysis. These methods cannot precisely define void formation on a volumetric scale. Micro-computed tomography (micro-CT) allows the examination of the internal structure and the determination of the gap and mechanical properties without requiring any physical sectioning, keeping the structure's integrity intact. In addition, it allows internal and external structures to be reconstructed together or separately and to be evaluated volumetrically (6).

Microleakage may occur at the tooth-adhesive-bracket interface, depending on the polymerization shrinkage of the adhesive systems used in orthodontics (7). Micro-leakage is the microscopic passage of bacteria, liquids, molecules, enzymes, acids, and ions between the resin materials and the tooth surface (8). Most studies assessing the microleakage have used 2D methods such as dye penetration. However, X-ray micro-CT technology offers significant advantages over 2D methods involving the sectioning of samples. With the development of micro-CT, researchers have had the

opportunity to evaluate the microleakage of dental restorative materials and the leakage area and volume by three-dimensional (3D) image analysis (9). In addition, micro-CT has proven to be a powerful and applicable technique for detecting polymerization shrinkage and microleakage (10).

APC Flash-Free Adhesive Coated Application System was introduced in 2014, with adhesive placed in a particular structure. This structure consists of irregularly located polypropylene fibers at the base of ceramic flash-free brackets and a low-viscosity adhesive resin located into this structure. When the bracket is placed on the tooth, the "nonwoven mat" porous structure is compressed, and the leaking resin spreads and closes the gap between the bracket and the tooth(11).

The bond strength of orthodontic attachments should be sufficient during the treatment period, easy to remove during the debonding phase, and low enough to not cause permanent damage to the enamel surface (12). Reynolds (13) reported that the clinically acceptable bond strength is 5.9-7.8 Megapascals (MPa). Studies have emphasized that the bond strength of flash-free ceramic brackets is sufficient for clinical use (12,14,15).

This study aims to determine the microleakage and gap formation under the ceramic flash-free orthodontic bracket systems using micro-CT, to measure the amount of void and gaps formed in the adhesive after the brackets are bonded and to compare their possible correlation with bond strength.

2. GENERAL INFORMATION

2.1. ORTHODONTIC BONDING

One of the essential requirements for a successful fixed orthodontic treatment is ensuring that the brackets are securely bonded to the tooth surface, providing adequate retention. The low bond failure rate in orthodontic treatment should be the primary target because bracket bonding failure is a time-consuming and costly treatment-delaying condition (1). Buonocore (2) first introduced the basis of the adhesion of brackets to the enamel surface in 1955 as the "etching technique." Since the 1970s, orthodontic attachments have been bonded directly to the tooth surface. The first research on direct bonding was published in 1977 (16).

Since the adhesive systems used in direct bonding provide sufficient bond strength, their use in orthodontic clinics has become routine. The advantages and disadvantages of direct bonding in orthodontics are stated as follows (1):

Advantages:

- Precise bracket placement
- No need for separation before banding
- Partially erupted/fractured teeth can be bonded.
- Easy to apply and takes less time.
- Bonds are more hygienic and increase gingival and periodontal health.
- The risk of caries under loose bands is eliminated.
- Being more aesthetic and readily accepted by patients.
- Mesio-distal enamel reduction is possible.
- Interproximal areas are accessible for composite build-ups.

Disadvantages:

- Risk of fracture and crack formation in the enamel during bracket removal
- Possibility of allergic and cytotoxic effects depending on the adhesive.
- The fluorine-rich layer of the enamel can be damaged when removing adhesive residues on the tooth surface.
- Both direct and indirect bonding procedures involve steps as follows: enamel cleaning, enamel conditioning, sealing, and bonding.

2.1.1. Enamel Cleaning

This procedure consists of cleaning dental plaque and organic pellicle that covers teeth and is done by a polishing brush, or a rubber cup placed on a rotary instrument. It should be given extra care during the procedure to avoid traumatizing the gingival margin. Afterward, the enamel surface should be thoroughly washed with an air-water spray to remove pumice residues (17,18).

2.1.2. Enamel Conditioning

Before preparing the enamel surface, moisture control of the teeth must be ensured. For this purpose, are used saliva ejectors, retractors, cotton pellets, and tongue holders are used. Drugs that reduce saliva secretion can also be used (19). The primary purpose of enamel conditioning is to increase the surface area to which the bonding agent will be applied by removing the enamel between the enamel prisms and exposing the pores between the prisms. Conditioning of the enamel can be done by acid etching, air abrasion, or laser.

2.1.2.1. Acid etching: The most used method is conditioning with 33-37% phosphoric acid (20). Some studies refer to polyacrylic and maleic acid as etching agents (21). After the teeth are isolated, an acid or gel-like acid is applied to the enamel surface for 15-30 seconds. Studies report that 15 seconds of acid application is sufficient (22,23). At the end of the etching phase, the acid is washed with a lot of water spray. Afterward, the teeth are entirely dried using oil and a moister-free air source until the dull and frosty white surface is visible, and if this appearance is not achieved, the procedure should be repeated (1).

2.1.2.2. Laser etching: This is achieved through ongoing evaporation and micro explosions due to the evaporation of water trapped in the hydroxyapatite crystals in the enamel. Based on the laser type and the energy applied to the enamel surface, the induced enamel changes vary from 10 to 20 μm. The rate of surface roughening may vary depending on the wavelength of the laser (1).

2.1.2.2.a. Carbon dioxide laser: These lasers, with a wavelength of 10.6 μm and a continuous beam emitting feature, can modify human enamel's physical and chemical properties. Laboratory studies on the bonding of composite resins to enamel roughened by continuous carbon dioxide laser (CO_2 laser) application show that bond strengths are weaker or like that of acid application (24). More recent pulsed mode studies have shown that the bond strengths tested under laboratory conditions are superior to the acid application (25).

2.1.2.2.b. Neodymium-doped yttrium aluminum garnet laser: These lasers have a wavelength of 1,064 μm and generate a high-intensity pulsed beam. Researchers who have examined the effects of Neodymium-doped yttrium aluminum garnet laser (Nd: YAG laser) on tissue have shown that they cause melting and crack formation on the enamel and cause negative thermal changes in the pulp (26). In an in vitro study, the effects of different surface preparation methods on the microleakage of pit and fissure sealants were compared, and it was found that Nd: YAG laser application did not reduce the degree of microleakage (25).

2.1.2.2.c. Erbium-doped yttrium-aluminum-garnet laser: It is frequently used in dentistry because of its high affinity for hard tissues. It creates an irregular enamel surface by selectively removing hydroxyapatites on the enamel surface (27). In a study, it was found that there is no difference in the mean shear bond strength and enamel surface etching compared with 37% phosphoric acid etching (28).

2.1.2.3. Air abrasion etching: It is also called sandblasting is an alternative method that provides roughening on the enamel surface by spraying aluminum oxide particles on the tooth surface with the help of high air pressure. Many factors, such as particle size, air pressure, working time, and surface microstructure to be applied, must be considered to achieve a suitable bond with this method. Air abrasion alone is insufficient for promoting a sealant's high bond strength to enamel (29). A study reported

that the most positive bond strength and microleakage values were obtained when air abrasion was combined with acid etching (30).

2.1.3. Sealing and Priming

After the enamel etching and chalky-like appearance is seen after air drying, a thin layer of adhesive primer is applied to the enamel surface, and the brackets are bonded. Primer is often used to reduce marginal leakage, increase bond strength, and provide integrity between etched enamel, bracket base, and adhesive material. However, it is controversial whether using primers in orthodontic treatment is necessary (31).

2.1.4. Bonding

Direct and indirect bonding methods are used to bond brackets, but direct bonding is the most used one. The recommended bracket bonding procedure (with any adhesive) consists of the following steps (1):

1. Transfer
2. Positioning
3. Fitting
4. Removal of excess
5. Curing

2.1.4.1. Transfer: The bracket held by tweezers should be positioned in the correct position on the tooth immediately after adhesive is applied to the bracket base (1).

2.1.4.2. Positioning: A placement scaler is used to position the bracket mesiodistally and inciso-gingivally and orientate them according to the long axis of the teeth. The horizontal positioning of the brackets on all teeth can be controlled using a mouth mirror (1).

2.1.4.3. Fitting: The bracket, which is in an appropriate position, is pressed against the tooth surface with a single-point contact using a scaler (1).

2.1.4.4. Removal of excess adhesive: After the bracket is positioned, the residual adhesive that overflows from the bracket edges is removed with the help of

scalers and dental burs. Cleaning the overflow adhesive reduces the possibility of periodontal damage and decalcification. Excessive adhesive close to the gingiva causes the rapid development of gingival hyperplasia and inflammation (16,32).

2.2. ADHESIVES USED IN ORTHODONTICS

The success of orthodontic treatment is directly affected by the bonding of orthodontic brackets to teeth, and research on developing effective adhesive systems has increased. An ideal bonding material should meet specific criteria. According to Proffit et al, (33) these criteria are as follows:

1. It should be able to penetrate the enamel surface.
2. It must have sufficient bond strength.
3. There should be no shrinkage during polymerization.
4. It should be of sufficient fluency.
5. It should be easy to use clinically.

2.2.1. Composite Resins

Resin composites are nowadays the commonly used orthodontic adhesives. These composites contain two essential parts: organic matrix Bisphenol-glycidyl methacrylate (Bis-GMA) and reinforced ceramic as filler. Bis-GMA has fast-curing properties and increases the strength of the resin but exhibits polymerization shrinkage. Bis-GMA is usually used to provide the appropriate viscosity. It is diluted with monomers such as triethylene glycol dimethacrylate (TEGDMA). The filler particles can be spherical, cylindrical, or irregular in shape. Irregular particles provide better mechanical retention. Increasing the number of ceramic particles strengthens the structure of the composite and reduces the amount of polymerization shrinkage (34).

Substances such as quartz, molten silicate, barium, aluminum silicate, and barium fluoride are used as fillers. The primary purposes of the fillers are to increase hardness and resistance by strengthening the resin, reduce wear, reduce polymerization shrinkage, minimize heat-induced expansion and contraction, reduce water absorption and staining, and reveal color properties to match the natural tooth

appearance. The adhesive bond between the organic matrix of composite resins and the part used as filler is essential for the durability of the resin (35,36).

Resin cements are divided into three classes according to the way of polymerization (34):

- Chemically polymerized,
- Polymerized by light,
- Both chemically and light-cured (dual cure)

Composites, both light and chemical-cured composites, contain initiators and accelerators. Light-cured ones have a photoinitiator that absorbs blue light, usually camphorquinone. The accelerator is an organic amine with carbon bonds. In chemically cured composites, the initiator is the reaction between an organic amine-catalyst paste and an organic peroxide universal paste (37).

2.2.1.1. Cemichally polymerized resin cement: It may consist of chemically cured single or two-layer systems. Its application is practical, but the disadvantage is that there is a short time for bracket adjustments. Depending on the technique, it may also contain inhomogeneous polymerization areas (34).

2.2.1.2. Light-Cured Resin Cement: It is the most preferred adhesive system today. Light-cured resin cement provides sufficient bond strength and is easy to use, it only adheres to tooth enamel by micro-retention, requiring a dry area. The advantage of these adhesives is that they reduce the working time during bracket placement since the polymerization is provided with light (34).

2.2.1.3. Cemichally and Light-cured Resin Cement: Due to their fluid properties, they are usually used as bonding material. Although these systems are produced to take advantage of both, their use is not as usual as light-cured adhesive systems (34).

2.2.2. Glass Ionomer Cement

Glass ionomer cement is used to bond orthodontic bands because it causes less demineralization to the enamel surface (38). Glass ionomer cement is chemically bonded to enamel, dentin, and metal. As a result of the interaction of the carboxylate groups in the glass ionomer adhesive with the calcium in the tooth structure, it

provides physicochemical retention (39). Glass ionomer cement contains significant levels of fluoride, which protects the enamel surface from decalcification. In addition, they have advantages such as low solubility in oral fluids, less enamel damage, and easier debonding (40). Despite these advantages, since the bond strength of glass ionomer cement with metal brackets is lower than that of composite resins, conventional glass ionomer cement is not recommended for bonding brackets (41,42).

2.3. ORTHODONTIC BRACKETS

Orthodontic brackets are the most used elements in modern orthodontics. Brackets can be classified, according to the material that they are made of, into three groups: metal, ceramic, and plastic (43,44).

2.3.1. Metal Brackets

Metal brackets were first used in 1967 and are most preferred type of bracket (45). Four types of brackets are used in modern orthodontics: stainless steel brackets, cobalt-chrome brackets, titanium brackets, and precious metal brackets. Metal brackets are attached to the tooth by mechanical retention, and this retention is conventionally provided with mesh bases (46).

Orthodontic metal brackets are mainly produced by casting, milling, and metal injection molding techniques (47). The stainless-steel bracket type is the most used one in orthodontic practice due to its good physical properties, corrosion resistance, and affordability (46). Stainless steel brackets can contain nickel in their structure, and it is recommended not to be used in patients with nickel allergy and to prefer titanium brackets instead (1). Titanium brackets are biocompatible, non-allergenic, and corrosion-resistant (48,49).

Precious metal brackets are usually produced by electroplating stainless steel with precious metals such as gold, platinum, and palladium. Brackets coated with 16, 18, and 24-carat gold are used mainly in lingual orthodontics. These brackets were popular at that time, when tooth-colored or transparent brackets were not yet available, because they were aesthetic compared to stainless steel brackets (1,50).

2.3.2. Plastic Brackets

Plastic brackets are produced by using polymer materials such as polyurethane and polycarbonate, which are more aesthetic than metal brackets. The most important disadvantages are discoloraton over time, wearing out, high friction, and not being resistant to torque forces. Deformations may occur in the slots of these brackets over time (34,51,52).

2.3.3. Ceramic Bracket

Ceramic brackets have emerged to eliminate the adverse effects of plastic brackets, like discoloration. After the mid-1980s, they started to be produced as more durable, more resistant to coloration, and not absorbing liquid (33).

Ceramics are a broad class of metallic or non-polymer inorganic materials. There are glass, clay, precious stones, and metal oxides in the structure of ceramics. Ceramic is the third most rigid material, more complex than stainless steel and enamel. Ceramics are neither metallic nor polymeric (53).

Ceramic brackets are attached to tooth enamel in two different ways. The first is the mechanical retention provided by the grooves in the bracket base, and the second is the chemical bonding that occurs thanks to the silane coupling agents (1). Ceramic brackets have higher adhesion strength, high aesthetics, high wear resistance, and better color stability than plastic brackets. Ceramic brackets are inert and, therefore, can be used safely in patients with nickel and chromium allergies (46).

The ceramic brackets have disadvantages such as being expensive, being harder than metal brackets, causing enamel abrasion if they encounter teeth, and enamel cracks that may occur during debonding (1,33). Three ceramic brackets are used for orthodontic purposes: aluminum oxide, zirconia, or calcium phosphate (46).

2.3.3.1. Aluminum Oxide brackets: Aluminum oxide brackets are divided into monocrystalline and polycrystalline brackets (46).

2.3.3.1.a. Monocrystalline brackets: These brackets are also called sapphire or monocrystalline sapphire brackets. Monocrystalline brackets were initially produced from natural sapphire, but nowadays, these brackets are made from synthetic sapphire. Monocrystalline brackets have a transparent appearance (46).

Monocrystalline brackets are produced by melting pure aluminum oxide particles at a temperature above 2100 degrees and then slowly cooling until crystallization is complete. Thus, a single large crystal or aluminum oxide rod is formed for milling brackets using various cutting tools (ultrasonic cutting technique, diamond cutters, or Nd: YAG laser). The stresses and surface defects that occur after the milling of the brackets are removed by applying heat treatment. The primary advantage of monocrystalline production is that it eliminates possible stress-causing impurities or defects. The disadvantage is the difficulty of the process and the additional expense of grinding the third most rigid material known. Since polycrystalline brackets are easier to manufacture, they are currently more accessible. Unlike plastic brackets, monocrystalline and polycrystalline brackets resist staining and discoloration (53).

2.3.3.1.b. Polycrystalline brackets: These brackets are called polycrystalline brackets because they contain multiple alumina crystals. These brackets are produced by sintering aluminum oxide. This process involves mixing micron-sized (average particle size 0.3 μm) aluminum oxide particles using a binder and shaping the mixture into the desired shape. The mixture is then melted by heating it to a temperature above 1800 degrees but below the melting point of aluminum oxide to burn off the binder particles in this molded part. Magnesium is used in the sintering process to facilitate the growth of each crystal in the manufacture of polycrystalline brackets (46).

Another method used to manufacture polycrystalline brackets is injection molding. With this method, the brackets do not require cutting operations; therefore, the defects created on the bracket surface are eliminated (54).

Optical properties and strength are opposite for polycrystalline brackets. If the ceramic grains dimensions get bigger it led to the increase of the clarity and transparency of the polycrystalline bracket. However, the bracket becomes weaker if the crystal grain sizes reach over 30 microns. The essential advantage of producing polycrystalline brackets is that they are moldable, and therefore, their products are extensive, and their costs are reduced (53).

2.3.4. Adesive Precoated Brackets

Introduced in 1991, adhesive precoated brackets (APC) contain an adhesive agent at the base of the brackets, and each is placed in a unique platform in its boxes. The advantages of APC brackets over conventional systems are as follows (55):

- Contain sufficient quality and quantity of adhesive,
- Easier cleaning of the excessive adhesive during bonding,
- Better control of asepsis,
- Reduce the bonding time.

The first type of APC brackets was named APC I, and problems arose during the positioning of the bracket to the tooth surface due to their high viscosity adhesive (23). APC II brackets contained low viscosity, leading to better bracket insertion and positioning to the teeth (56). APC Plus brackets include an adhesive that releases fluorine and can change color after polymerization (57).

2.3.5. Flash-Free Brackets

A structure composed of polypropylene fibers infused with low-viscosity adhesive is positioned at the base of the flash-free ceramic bracket. When the bracket is placed on the tooth, the "nonwoven mat" porous structure is compressed, and the leaking resin spreads and closes the gap between the bracket and the tooth (11). In this system, the brackets are individually packaged with the optimum amount of adhesive on the bases, and polymerization of the adhesive is allowed without cleaning the excessive adhesive (14). The manufacturer claims its advantages include reliable shear bond strength, reduced bonding time, and less than 2% bracket drop rate (58). In vitro studies on this bracket system have shown adequate bond strength (14,59), shortened bonding time compared to conventional bonding systems (14,58), and low microleakage has been demonstrated (59).

2.4. MICROLEAKAGE IN ORTHODONTICS

Microleakage is the microscopic passage of bacteria, liquids, molecules, enzymes, acids, and ions between the resin materials and the tooth surface. Polymerization shrinkage of resin leads to microleakage at the tooth-adhesive-bracket interface (8). The difference between dimensional changes of restorative material

caused by thermal contraction and mechanical stresses and dimensional changes of dental hard tissues is the main reason that causes microleakage. Due to this difference, the change in intraoral temperature creates negative pressure between the material and the tooth surface, causing the leakage of intraoral fluids (60). Microleakage at the adhesive enamel interface may cause white spot lesions, enamel decalcification, enamel discoloration, and decreased bond strength. (61). There are various methods to measure and evaluate microleakage, such as the dye penetration method, bacterial working method, air pressure method, radioactive isotope method, neutron activation analysis method, electrochemical method, and microscope analysis method.

2.4.1. Dye Penetration Studies

The dye penetration method is the most popular technique in studies evaluating microleakage. Methylene blue (0.2-2%), basic fuchsin (0.5-2%), erythrosine (2%), crystal violet (0.05%), fluorescent (2-20%), and silver nitrate (50%) are among colored agents used in this method (62). The advantages of dye penetration methods are using water as a solvent, determining microleakage areas under visible light, establishing easy and fast measurements, low cost, and nontoxicity. Disadvantages include being a sensitive technique and the need for standardization and subjective assessment of results often carried out by multiple examiners (63).

2.4.2. Bacterial studies

This method consists of immersion of teeth in bacterial culture and evaluation of bacterial growth at the tooth restoration interface. The gap between the cavity wall and the restoration interface should be 0.5-1 μm or larger to detect bacterial leakage. The method's main disadvantage is that the results are qualitative and complex, especially in controlling bacterial populations (62,64).

2.4.3. Air Pressure Method

It is based on sending compressed air to the tooth, root canal, and pulp chamber and detecting the leak by measuring the pressure lost in the static system. The advantages of this method are its technical repeatability and protection of the integrity of tooth tissues. The disadvantage of this method is that it does not reflect the actual clinical situation. (62,65).

2.4.4. Radioisotope

Radioactive isotopes have been widely used in microleakage studies. In this technique, samples are immersed in isotope solution, and isotope leakage at the tooth-restoration interface is detected by autoradiography of a sectioned sample. The most used isotopes are; I^{131}, Ca^{45}, C^{14}, S^{35}, P^{32} Na^{22}. Isotopes such as Ca^{45} may have an affinity toward a dental structure or restorative materials that can lead to a misleading distribution on the autoradiograph. Autoradiography is a qualitative and technique-sensitive approach to evaluating microleakage (62, 65).

2.4.5. Neutron Activation Analysis Method

This is a method of determining microleakage by placing a non-radioactive chemical marker such as Manganese-56 on the edge of the restoration and allowing it to leak from the edges, then placing the samples in the core of a nuclear reactor and bombarding them with Manganese-56 and measuring the amount taken up by each tooth. This is a method that allows measuring microleakage in vivo and in vitro. Although the results obtained using the technique have been reported to be quantitative, it has been reported that this technique is expensive and complex (62,65).

2.4.6. Electrochemical Method

In this method, the main principle is to measure the current passing through the edge gap, if any, when a plate acting as an electrode is placed in contact with the base of the restoration. When the repair is completed, the tooth is entirely isolated, immersed in an electrolyte bath, and connected to an external power source. Any electric current deviation indicates a gap has formed at the restoration interface. It is an inappropriate technique for use in metallic restorations (62,65).

2.4.7. Microscopy Method

Most researchers use microscopic analysis to evaluate the findings obtained from examining the leakage in the restoration materials with different techniques (62).

2.5. MICRO-COMPUTED TOMOGRAPHY

Micro-CT was first developed in the early 1980s (66). It is a 3D X-ray imaging technique in which images consist of voxels, which involves obtaining X-ray projection images of an object from different angles around an axis and applying a

tomographic reconstruction algorithm to create a stack of thin tomographic images of successive transaxial slices along the object. After the samples are fixed in the device, scanning is performed by rotating them on the vertical axis by a fixed X-ray source (67,68).

2.5.1. Principles of Micro-Computed Tomography

The structure and working principle of the micro-CT device are like the structure of computerized tomography devices. The main components of the device are the X-ray tube, a computer-controlled motor that rotates the fixed sample at certain intervals, an image intensifier that concentrates the X-ray in the environment on the camera sensor, a charged-coupled device (CCD) camera that converts the X-rays falling on it into image data, an image collector an advanced computer that controls all the units (69).

While it is feasible to perform scans with voxel sizes of 1 mm^3 in standard computerized tomography (CT), micro-CT allows for scans with much higher resolution, ranging from 5 to 50 μm^3 voxel sizes (70,71).

In these devices, the object is positioned on a rotating platform on the vertical axis, and the detector and X-ray tube remain fixed. Thus, the sensor and X-ray source have the opposite working principle of conventional CT devices that rotate around the fixed object. This way, a 3D image of the object is obtained around the object to be imaged with the micro focal spot and high-resolution detectors providing the X-ray. These images are transferred to the computer environment, and 3D models are created through related programs (69,72).

In micro-CT scanning, the scanned object is rotated around itself at a certain acute angle, 180° or 360° (Figure 2.1). A shadow image and a transition image are created at each angle position. Shadow images of beams sent during the object's rotation are saved in Tagged Image File format (TIFF). The number of 16-bit shadow images obtained varies depending on the rotation speed of the device, the total number of rotations, and how many degrees the object moves with each cycle. The smaller the rotation angle, the higher the number of shadow images and, thus, the higher the quality of the resulting 3D image. The resulting 16-bit TIFF images are used to

reconstruct virtual slices throughout the entire object and reconstructed by combining serial cross-sectional images taken from the sample (68).

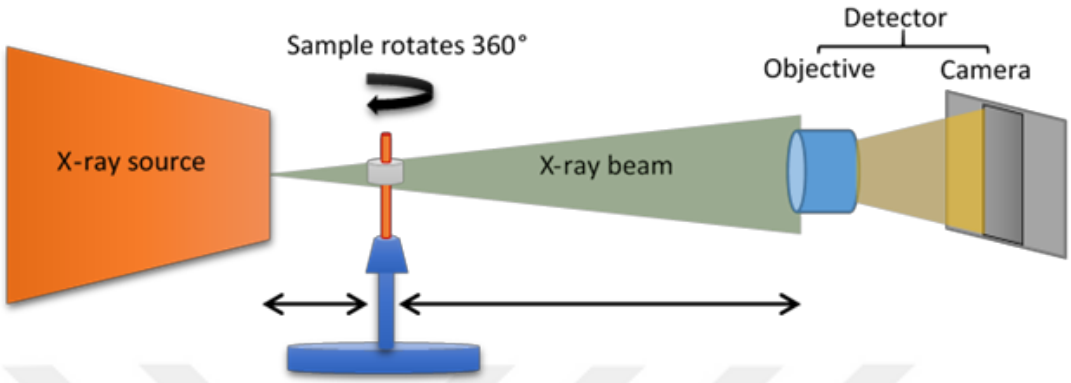


Figure 2.1: Schematic representation of micro-CT imaging

2.5.2. Applications of Micro-Computed Tomography in Orthodontic Researches

Micro-CT is used in orthodontics mainly to evaluate bone development and determine bone changes during tooth movement (73). The applications of micro-CT in orthodontic research are as follows:

- Orthodontic tooth movement (OTM)
- Microleakage in orthodontic brackets
- Evaluation of the bone
- Tooth root resorption

2.5.2.1. Orthodontic tooth movement: Orthodontic treatment is based on the principle of tooth movement when the bone around the tooth is remodeled after a force is applied to the tooth for a period of time. Since the periodontal ligament provides the bone response, tooth movement is primarily a periodontal ligament phenomenon (33). Histological studies have limitations because of the restriction of a small number of tissue samples. Studies on OTM used light microscopy, SEM, and transmission electron microscopy (TEM). However, it is impossible to achieve a total

3D view of tooth movement using these methods. (74). Arai et al. (75) developed a micro-CT system for in vivo animal imaging. A study on rats concluded that micro-CT could accurately measure dynamic alveolar bone changes during OTM (73).

2.5.2.2. Microleakage in Orthodontic Brackets: Microleakage has been defined as the passage of bacteria, liquids, molecules, or ions across the tooth restoration interface (8). Compressed air, neutron activation, electrochemical, liquid filtration, electron scanning microscope, transmission electron microscope, bacteria, and dyes were used as in vitro methods to examine microleakage. However, such sample preparation techniques are 2D and do not consider the entire tooth restoration interface since some randomly generated sections are taken to measure microleakage (76). Santis et al. (77) first used micro-CT to study microleakage and presented it as a nondestructive method. With the development of micro-CT, researchers have been able to evaluate the microleakage of dental restoration materials. The leak area and volume determined by 3D image analysis have been correlated with various materials (9). Moreover, micro-CT has proven to be a powerful and viable technique for detecting polymerization shrinkage and microleakage (10).

2.5.2.3. Evaluation of the bone: As a nondestructive analytical method, micro-computed tomography eases examining sutural bone modeling during rapid maxillar expansion. It removes the need for specific skills in microscopy and arduous specimen preparations. Micro-CT is used in studying the properties of trabecular and spongy bone, including trabecular none thickness connectivity and bone density (78,79,80).

2.5.2.4. Root Resorption: Tooth root resorption may occur after orthodontic tooth movement and is seen as root shortening in the apical regions on X-ray images. Root resorption has been evaluated with 2D radiographic methods, histological methods (SEM), cone-beam computed tomography (CBCT), and micro-CT (81). High radiation levels are required to obtain high-resolution images in vivo, limiting the use of micro-CT images in vivo (82,83).

2.6. BOND STRENGTH

Bond strength tests guide dental practitioners to evaluate resin adhesives and the development processes of resin adhesives (84,85). The assessment of orthodontic

bond strength can be classified according to the test environment as in vitro tests, ex vivo, and measurements of the failure rates of brackets in vivo. In vitro tests are performed in laboratory environments by mechanical testing machines or simulation of clinically applied debonding procedures. Ex vivo studies are characterized by using finite element analysis modeling of the stress distributions in the parts of the enamel-adhesive bracket complex. In vivo studies include the evaluation of the failure rates of brackets generally during orthodontic treatment.

Different loading modes like shear, tension, and torsion are present in bond strengths. The most used test is the shear bond strength test because of its simplicity of the experimental configuration and presumably increased reliability of simulating debonding that occurs during treatment. The tension and torsion loadings are less relevant to clinical practice (85,86).

There is variation in the experimental conditions of studies applying bond strength testing. In a meta-analysis study, it was concluded that the storage type, the photopolymerization time, and the speed of the applied force significantly affect in-vitro bond strength testing results. According to this study, using distilled water as a storage method decreases the bond strength values. İncreased polymerization time provided higher bond strength values, but the optimal time for the adhesive polymerization was not determined. The application rate of force generally varies between 0.1 and 5 mm/min, and the most used speed is 0.5 mm/min (87).

3. MATERIALS AND METHODS

Ethics committee approval for this study was obtained from the Health Sciences University, Hamidiye Scientific Research Ethics Committee, with the decision dated 11.12.2020 and numbered 27/17 (Appendix -1). The informed consent form was obtained from the patients who decided to have premolar extraction due to orthodontic malocclusions by telling them about using their extracted teeth in the study (Appendix 2). This thesis was supported by the University of Health Sciences, Scientific Research Projects Coordinatorship with project number 2021/048. Micro-computed tomography scanning of samples and the measurement of brackets bond strength were completed at Erciyes University, Faculty of Dentistry Research Laboratory.

3.1 POWER ANALYSIS

G*Power software (Version 3.1.9.7, HHU, Düsseldorf, Germany) was used to perform a power analysis to determine the number of samples. As a result of the analysis made for this thesis study, taking effect size (d): 0.5. It was defined that the total number of samples should be at least 52 (n) to obtain 0.05 (5%) error level and 0.81 (81%) power value. Considering the power analysis result, 52 human premolar teeth were used in the study.

3.2 TEETH

3.2.1. Selection of Teeth Used in the Study

In our study, 52 human premolar teeth were used (Figure 3.1). These teeth were obtained from patients who applied to the Department of Orthodontics, Hamidiye Faculty of Dentistry, University of Health Sciences for treatment and had their premolar teeth removed due to crowding. The teeth used in the study were evaluated with the help of a magnifying glass in daylight. The following criteria were considered in the selection of the teeth as samples:

- Teeth should not contain caries
- Enamel should not be cracked

• There should be no restoration on the tooth surface

• Teeth should not have enamel defects

• Enamel damage should not have occurred during tooth extraction.

• There should be no malformations on the vestibule surface of the teeth

3.2.2. Storage Conditions of the Teeth Used in the Study

Soft tissue residues and plaque on the selected teeth were cleaned with the help of a scaler (Hu-Friedy Mfg. Co., LLC, UK) and a toothbrush and then kept in 0.1% thymol solution for one week to inhibit bacterial growth. After the teeth were disinfected, they were washed with distilled water and kept in distilled water in a glass bottle, at room temperature, in a place out of the sun until the time of the study. The solution was renewed once a month.



Figure 3.1: Teeth used in the study

3.3. BRACKETS USED IN THE STUDY

In our study, two different types of brackets produced by 3M Unitek (Monrovia, CA, USA), Clarity Advanced APC Flash-Free Ceramic Bracket and Clarity Advanced Ceramic Bracket, are shown respectively in Figure 3.2 and Figure 3.3.

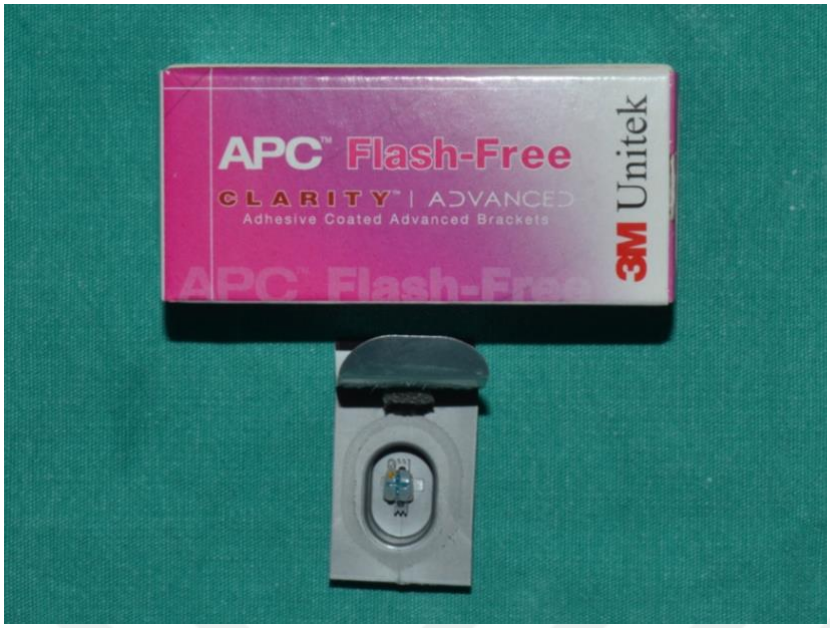


Figure 3.2: Clarity Advanced APC Flash-Free Ceramic Bracket

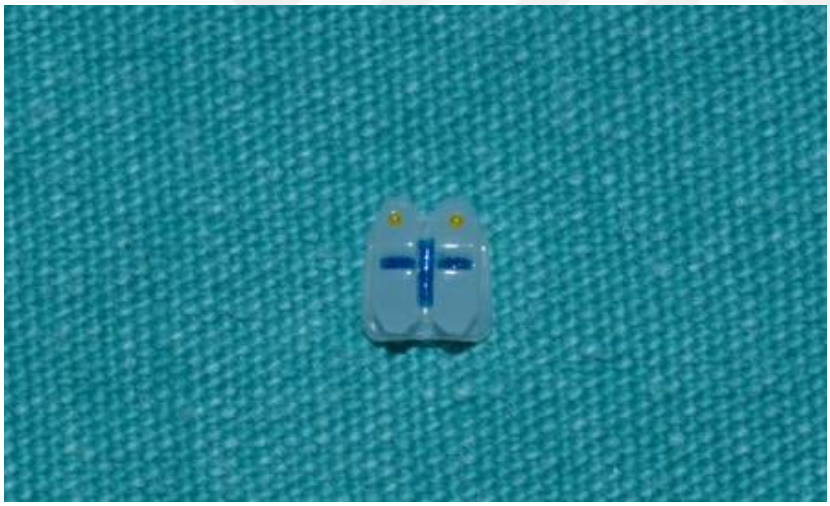


Figure 3.3: Clarity Advanced Ceramic Bracket

3.4. ADHESIVE SYSTEMS USED IN THE STUDY

3.4.1. APC Flash-Free Adhesive

Clarity Advanced APC Flash-Free Ceramic Brackets have a lower viscosity adhesive on their bracket base. When the bracket is pressed against the tooth surface, the

optimum amount of existing adhesive spreads to the surface uniformly, and it is stated that there is no need to clean the excessive adhesive.

3.4.2. Transbond XT

Transbond Light Cure Adhesive by 3M Unitek (Monrovia, CA, USA) is an adhesive that can be used to bond metal and ceramic brackets (Figure 3.4).



Figure 3.4: Transbond XT Light Cure Adhesive

3.4.3. Transbond Plus Self-Etching Primer

Transbond Plus Self Etching Primer by 3M Unitek (Monrovia, CA, USA) enables one to etch and prime the enamel in one step (Figure 3.5).



Figure 3.5: Transbond Plus Self-Etching Primer

3.5. CREATION OF EXPERIMENTAL GROUPS

The teeth used in the study were randomly divided into four groups, with 13 teeth in each group. The materials used in this study according to the manufacturers are given in Table 3.1.

Table 3.1: Materials used in the study

Group	Number of Samples	Acid Etch	Primer	Adhesive	Bracket Type	Company
1	13	Phosphoric acid (37%)	Transbond™ XT Liquid Primer	APC™ Flash-Free Adhesive	Clarity™ Advanced APC™ Flash-Free Ceramic Bracket	3M Unitek, Monrovia, CA, USA
2	13	-	Transbond™ Plus Self-Etching Primer	APC™ Flash-Free Adhesive	Clarity™ Advanced APC™ Flash-Free Ceramic Bracket	3M Unitek, Monrovia, CA, USA
3	13	Phosphoric acid (37%)	Transbond™ XT Liquid Primer	Transbond™ XT Light Cure Adhesive	Clarity™ Advanced Ceramic Bracket	3M Unitek, Monrovia, CA, USA
4	13	-	Transbond™ Plus Self-Etching Primer	Transbond™ XT Light Cure Adhesive	Clarity™ Advanced Ceramic Bracket	3M Unitek, Monrovia, CA, USA

3.6. BONDING OF THE BRACKETS

All teeth were removed from the solution and washed with water. Afterward, the teeth were cleaned with pumice and then dried with airflow. The procedure for bonding the brackets is illustrated in Figure 3.6. and it is explained in detail for each group.

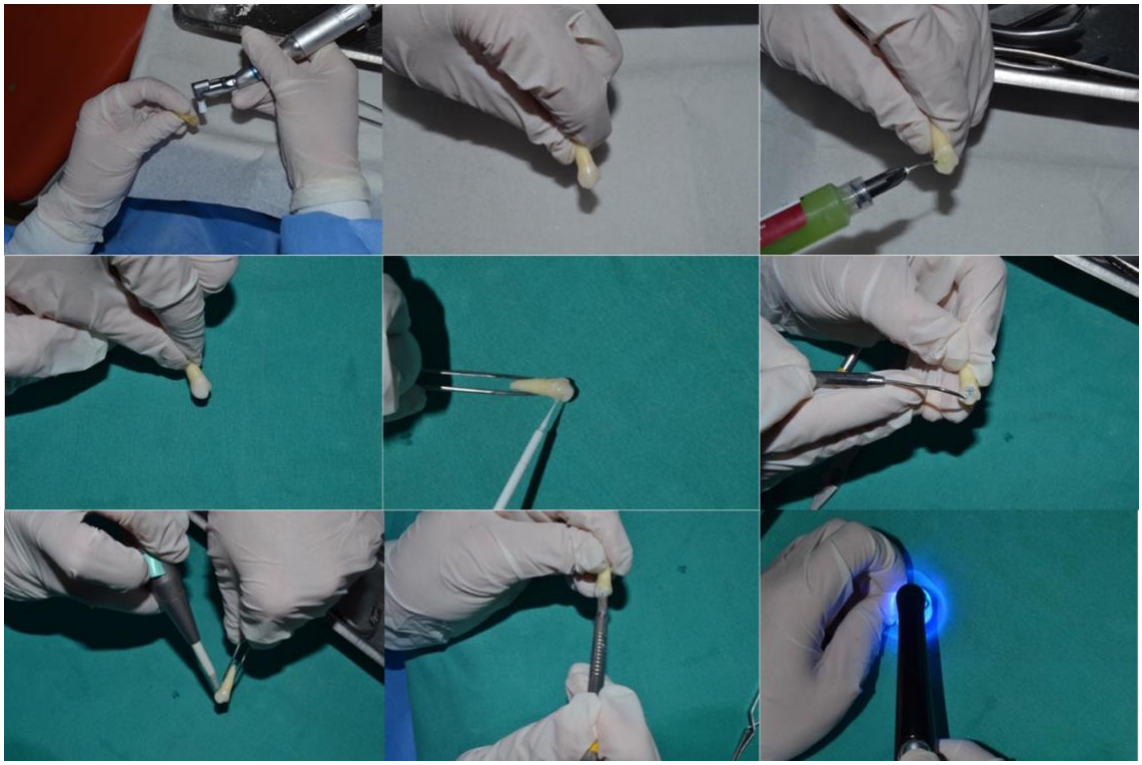


Figure 3.6: The procedure of bonding applied in the study

3.6.1. Group 1- Phosphoric acid, Transbond XT Primer, Clarity Advanced APC Flash-Free Ceramic Bracket

A gel-like acid containing phosphoric acid with a concentration of 37% was applied to the vestibule surfaces of the teeth. Then, after waiting for 30 seconds, the teeth surface was washed with water spray and dried. After the enamel had a chalky white surface, Transbond XT primer was applied with an applicator on the enamel. Since the Clarity APC Flash-Free bracket precoated with Transbond XT adhesive contained self-adhesive at its base, it was directly removed from its special package, applied to the tooth surface, and pressed in the middle of the clinical crown. Then, the adhesive polymerization was performed with the help of a light-emitting diode (LED)

device VALO Cordless® (Ultradent, UT, USA) for 10 seconds from the mesial and distal directions for a total of 20 seconds.

3.6.2. Group 2- Transbond Plus Self Etching Primer, Clarity Advanced APC Flash-Free Ceramic Bracket

This group used a self-etch primer instead of the etching and rinse method. Transbond Plus Self Etching Primer was applied to the vestibule surfaces of the washed and dried teeth with circular movements for 3 seconds. After applying primer on the tooth surface, the air was sprayed on the surface for 1-2 seconds. The upper premolar Clarity APC Flash-Free bracket, precoated with Transbond XT adhesive, was applied to the tooth surface and pressed in the middle of the clinical crown. Adhesive polymerization was performed with the help of a VALO Cordless® device for 20 seconds in total, 10 seconds both from the mesial and distal sides of the bracket.

3.6.3. Group 3- Phosphoric acid, Transbond XT Primer, Trasbond XT Light-Cured Adhesive, Clarity Advanced Ceramic Bracket

Gel-like acid containing phosphoric acid with a concentration of 37% was applied to the vestibule surfaces of the teeth. Then, after waiting for 30 seconds, the enamel surface was washed with water spray and dried. After the tooth had a chalky white surface, Transbond XT primer was applied with the help of an applicator on the enamel surface. Transbond XT Light-Cure Adhesive was placed on the base of the brackets Clarity Advanced Ceramic brackets, and the bracket was immediately positioned on the tooth in the appropriate position and pressed with the help of a scaler. Adhesive polymerization was performed using a VALO Cordless® device for 20 seconds in total, 10 seconds both from the mesial and distal sides of the bracket.

3.6.4. Group 4- Transbond Plus Self Etching Primer, Trasbond XT Light-Cured Adhesive, Clarity Advanced Ceramic Bracket

In this group, Transbond Plus Self Etching Primer was applied to the vestibule surfaces of the teeth with circular movements for 3 seconds. After applying it on the tooth surface, the air was sprayed on the surface for 1-2 seconds. Transbond XT Light-Cure Adhesive were placed on the base of the Clarity Advanced Ceramic brackets positioned on the tooth in the appropriate position and pressed. The excessive adhesive around the bracket was removed with the help of a probe. Then, the adhesive

polymerization was performed using a VALO Cordless® device for 10 seconds, 20 seconds each, from the mesial and distal sides.

3.7. MICRO-COMPUTED TOMOGRAPHY SCANNING

Desktop-type SkyScan 1272 Micro-CT system (Bruker micro-CT, Kontich, Belgium) was used in the study (Figure 3.7). It consists of a high-voltage powered microfocus tube, a sample carrier with a precision manipulator, an X-ray CCD camera connected to the image catcher, and a high-capacity computer.

The teeth were fixed to the sample carrier arm by positioning them centrally and vertically to prevent deviations in axial positions that will change the distance between the x-ray tube and the sample during rotational scanning and cause the teeth to go out of the exposure area. After the fixing process was completed, the scanning process was started.

The samples were placed on the SkyScan 1272 Micro-CT device for scanning, and a total of 850-900 cross-sectional images were taken from each model with a thickness of approximately 9.9 microns, with the help of a 16 MP camera using 90 kV power, 111 µA current, 1 mm aluminum filter. The teeth were scanned using 360-degree rotation, and the rotation step was determined as 0.50 degrees. Scanning time at these settings took approximately 90-100 minutes per teeth scan. Digital Imaging and Communications in Medicine (DICOM) compatible images taken from the sections were converted to Bit Map Picture (BMP) format. The resolution of each cross-sectional image was 2452x2452 pixels, and the pixel size was 9,000 microns.

Initially, each of the teeth was fixed in the sample holder of the system, the X-ray source was set to the appropriate parameters, and the filter was used to scan all samples. Each sample was rotated 360 degrees with a rotation step of 0.50 degrees. Exposure time has been adjusted, and appropriate pixel size images were obtained by adjusting the magnification. All projected X-ray images were used in the reconstruction of the samples. The surface areas of the bracket bases were evaluated using software that allows observation of all scans and identification of microleakage areas. Each microscope was cropped to have a smaller sample containing regions of interest (ROI). Later, these smaller micro-CT slices were selected and saved as BMP image files with sufficient pixel resolution to display 2D images. Later, these BMP files were imported into the analyzer software. A circle ROI was selected slice by slice

in each data set. Finally, the void and gap volume and percentage (void and gap volume / ROI × 100) were evaluated.



Figure 3.7: Skyscan 1272 Micro-CT system where samples were scanned

3.7.1. Preparation of Micro Computed Tomography Images for Analysis

The raw radiological images obtained after micro-CT scanning were processed in NRecon 1.7.4.6 (SkyScan, Kontich, Belgium) program with a 53% correction rate for 3-unit smoothing, 8-unit ring artifact correction and beam hardening correction to eliminate image impurities and radiological artifacts (Figure 3.8). In addition, unnecessary areas outside the radiological image areas were removed, reducing the image size and making it suitable for faster mathematical analysis on the computer.

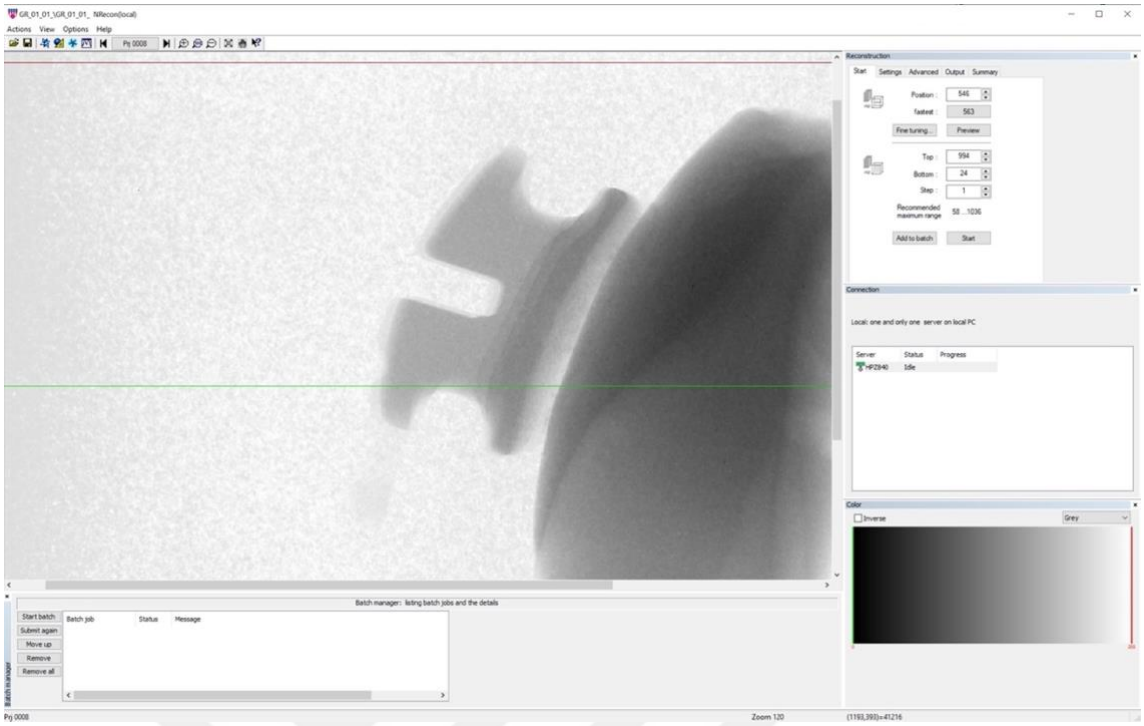


Figure 3.8: Preparing the micro-CT images for analysis in the software

3.7.2. Analysis of Micro Computed Tomography Images

A high-capacity (Intel® Xeon® CPU E-5-2680 v4 Q 2.40 GHz (two processors), 128 GB RAM, 64–Bit) workstation (Dell, Dell Company, Austin, Texas, USA) was used for the analysis of the images.

The data obtained were loaded into the CTAn (Version 1.20.8.0+, SkyScan, Kontich, Belgium) program, and the active examination area was determined by choosing the first section where the adhesive began and the last section where the adhesive ended (Figure 3.9).

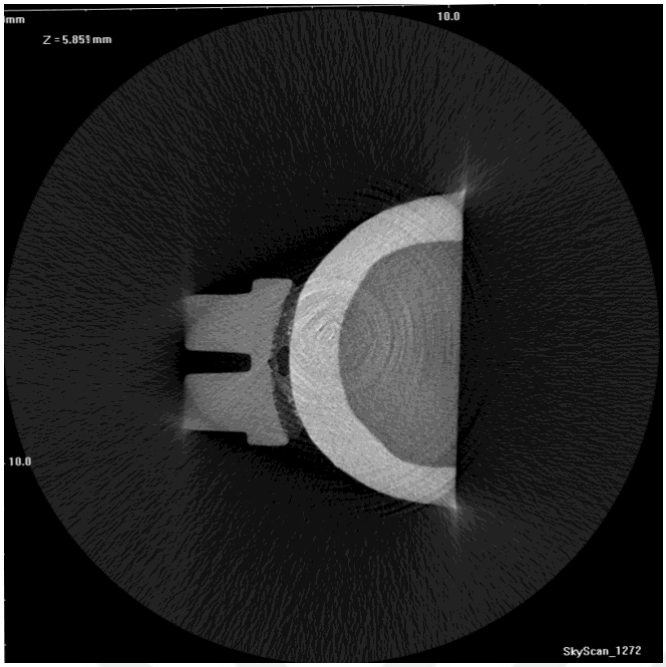


Figure 3.9: Raw images page, active review area detection

The adhesive region under the bracket base is drawn in each section using the regional division (ROI) function in the CTAn program. The adhesive area was separated from other elements in all three space planes by separating it from the surrounding enamel tissue, the bracket base, and the air gap on the outer surface (Figure 3.10).

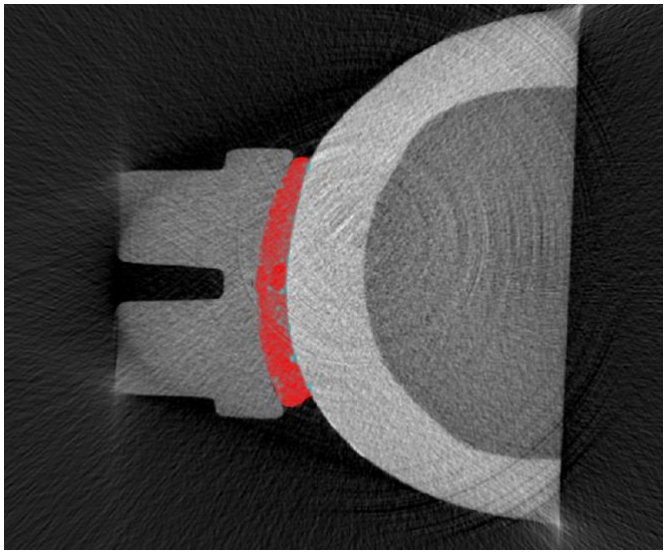


Figure 3.10: Region of Interest

Then, the adhesive area's black-and-white image (binary selection) page, separated from the adjacent tissues and air space in three dimensions, was switched, and the operating threshold value range in the gap/void areas was determined (Figure 3.11).

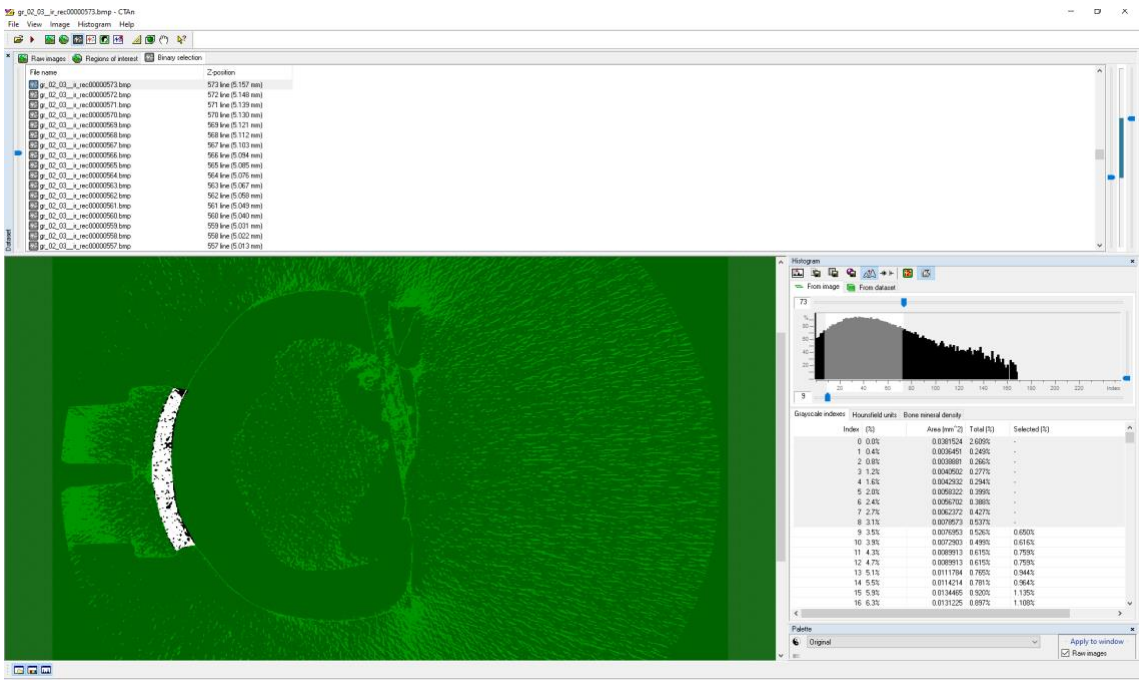


Figure 3.11: Binary page view

The three measured variables were the gap in contact with an interface (either the bracket or enamel), the void located entirely inside the bulk of the adhesive, and the total void and gap (Figure 3.12). Analyzes were performed blindly for all samples by the same investigator.

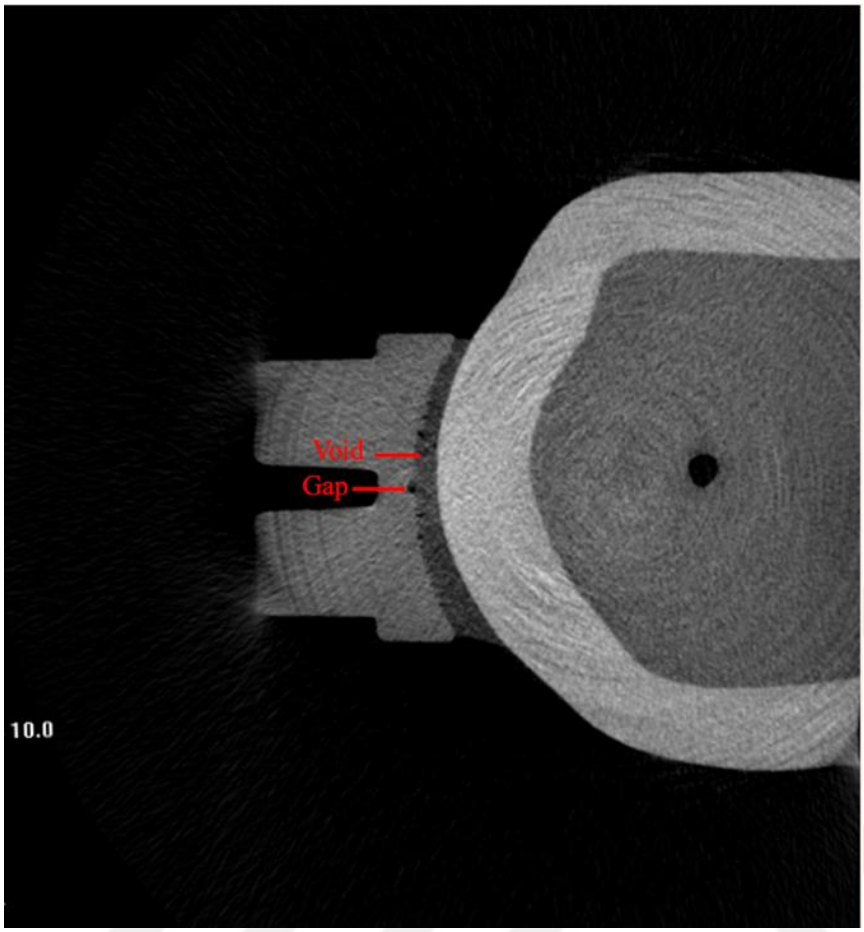


Figure 3.12: Void and Gap visualization

3.8. MEASUREMENT OF THE BOND STRENGTH

The teeth were embedded in blocks composed of auto-polymerizing acrylic in the form of a rectangular prism from 1 mm apical of the enamel-cement junction, with the long axis of the tooth perpendicular to the ground plane to be appropriately placed to the device where the bond strength would be evaluated (Figure 3.13).



Figure 3.13: Tooth sample embedded in an acrylic block

The bond strength test of the bonded brackets was performed using the Universal Test Device (Instron, MA, USA) (Figure 3.14). In the device, the loading tip sharpened towards the end like a knife tip, was placed in a parallel position with the bracket-enamel surface. A 0.5 mm/min compression force was automatically applied to the dental bracket interface until the bracket was separated (Figure 3.15). The force applied in the electronic display of the machine is registered in Newtons with an accuracy of 1N. The results were then converted to MPa using the equation Mpa=N/mm².

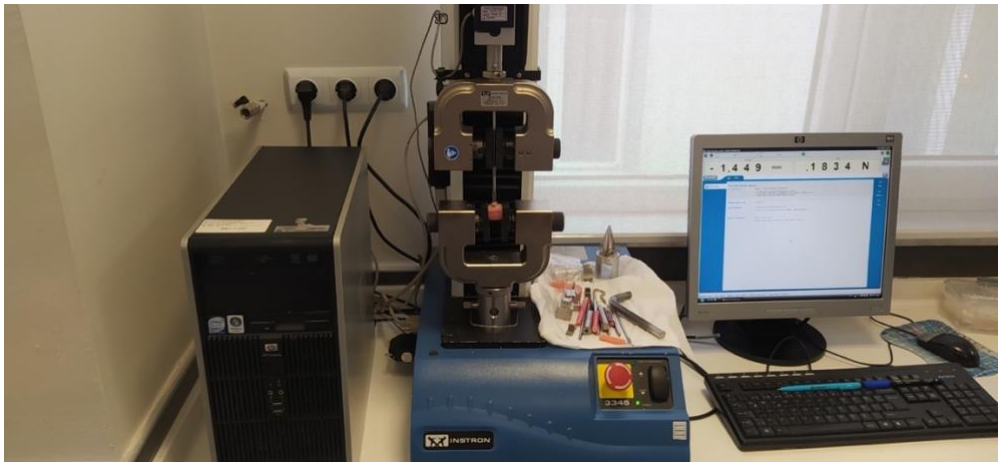


Figure 3.14: Instron device

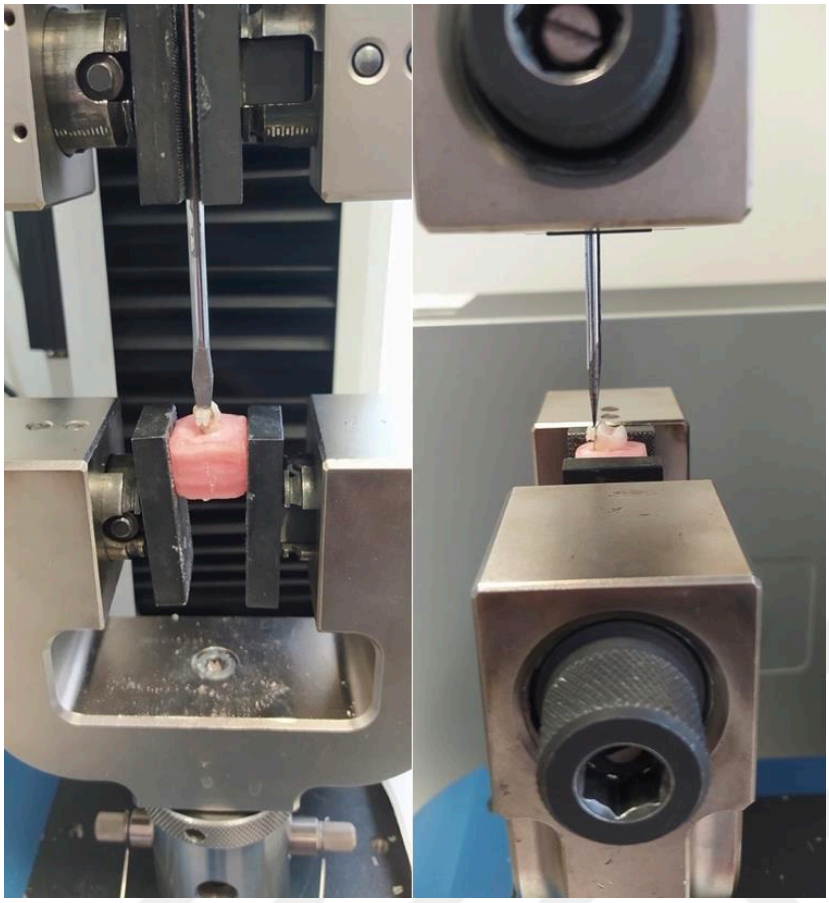


Figure 3.15: Front and side view of the acrylic block fixed to the Instron device

3.9. STATISTICAL ANALYSIS

The data obtained in this study were analyzed with the licensed IBM SPSS 21 (IBM SPSS Inc., Armonk, NY, USA) package program. Shapiro Wilk test was used while evaluating data with a normal parameter distribution. The Kruskal-Wallis H test was used to examine the differences between the groups when its parameters didn't show normal distribution, and the groups with differences were determined with the Post-Hoc Multiple Comparison Test. While examining the differences between groups, the Mann-Whitney U test was used in two-group comparisons when the parameters didn't show normal distribution. Spearman's Correlation Coefficient was used when examining the relationships between variables that did not come from the normal distribution. Significance was evaluated at the $p<0.05$ level.

4. RESULTS

Calculations were carried out to determine the data parameter's mean values and standard deviations. These parameters include adhesive volume, void volumes, gap volumes, total void and gap volumes, and shear bond strength within the evaluated groups.

The results of the analysis comparing the differences between the groups are given in Table 4.1, Table 4.2, Table 4.3, Table 4.4, Table 4.5, and Table 4.6, respectively.

Group 1 and Group 2 analysis (Table 4.1) consistently showed no significant differences across all parameters. This trend persisted for bond strength values ($p>0.05$) and was similarly observed in adhesive volume values, void volume values, gap volume values, and total void and gap volume values ($p>0.05$).

Table 4.1: Analysis result of comparison of the difference between Groups 1 and 2

		Group 1-2						Mann-Whitney U Test	
		n	Mean	Median	Min	Max	Sd	Mean Rank	z	P
Bond strength (MPa)	**Group 1**	13	20.42	20.17	13.09	28.56	5.31	13.46		
	Group 2	13	19.87	19.9	8.57	27.49	5.01	13.54	-0.026	0.98
	Total	26	20.14	20.04	8.57	28.56	5.06			
Adhesive volume (mm^3)	**Group 1**	13	4.05	4.03	2.86	5.3	0.67	15.81		
	Group 2	13	3.58	3.61	1.93	4.69	0.71	11.19	-1.539	0.124
	Total	26	3.82	3.77	1.93	5.3	0.72			
Void volume (mm^3)	**Group 1**	13	0.07	0.06	0.02	0.13	0.03	14.85		
	Group 2	13	0.06	0.05	0.01	0.12	0.03	12,15	-0.897	0.369
	Total	26	0.06	0.06	0.01	0.13	0.03			
Gap volume (mm^3)	**Group 1**	13	0.58	0.47	0.09	1.34	0.37	13		
	Group 2	13	0.64	0.47	0.26	1.86	0.44	14	-0.333	0.739
	Total	26	0.61	0.47	0.09	1.86	0.4			
Total Void and Gap volume (mm^3)	**Group 1**	13	0.65	0.54	0.15	1.39	0.37	13.31		
	Group 2	13	0.7	0.51	0.29	1.87	0.42	13.69	-0.128	0.898
	Total	26	0.67	0.53	0.15	1.87	0.39			

There was no statistically significant difference in bond strength values between Group 1 and Group 3 (Table 4.2) ($p>0.05$). However, a statistically significant difference was observed in adhesive volume, Group 1 have higher values than Group 3 ($p<0.05$). The void volume, gap volume, and total void and gap volume did not display statistically significant differences between the two groups ($p>0.05$).

Table 4.2: Analysis result of comparison of the difference between Groups 1 and 3

		Group 1-3						Mann-Whitney U Test	
		n	Mean	Median	Min	Max	Sd	Mean Rank	Z	p
Bond strength (MPa)	**Group 1**	13	20.42	20.17	13.09	28.56	5.31	14.62		
	Group 3	13	19.28	16.96	7.22	39.75	8.57	12.38	-0.744	0.457
	Total	26	19.85	18.49	7.22	39.75	7.01			
Adhesive volume (mm^3)	**Group 1**	13	4.05	4.03	2.86	5.3	0.67	17.38		
	Group 3	13	3.32	3.33	1.99	4.42	0.63	9.62	-2.59	**0.01**
	Total	26	3.68	3.72	1.99	5.3	0.74			
Void Volume (mm^3)	**Group 1**	13	0.07	0.06	0.02	0.13	0.03	15.77		
	Group 3	13	0.05	0.05	0.01	0.1	0.03	11.23	-1.513	0.13
	Total	26	0.06	0.06	0.01	0.13	0.03			
Gap volume (mm^3)	**Group 1**	13	0.58	0.47	0.09	1.34	0.37	11.62		
	Group 3	13	0.76	0.78	0.26	1.57	0.37	15.38	-1.256	0.209
	Total	26	0.67	0.69	0.09	1.57	0.37			
Total Void and Gap volume (mm^3)	**Group 1**	13	0.65	0.54	0.15	1.39	0.37	11,85		
	Group 3	13	0.81	0.82	0.28	1.58	0.36	15.15	-1.103	0.27
	Total	26	0.73	0.75	0.15	1.58	0.37			

Group 1 and Group 4 (Table 4.3) exhibited no statistically significant differences in bond strength, adhesive volume, void volume, gap volume, and total void and gap volume values ($p>0.05$).

Table 4.3: Analysis result of comparison of the difference between Groups 1 and 4

		Group 1-4						Mann-Whitney U Test	
		n	Mean	Median	Min	Max	Sd	Mean Rank	z	P
Bond strength (MPa)	**Group 1**	13	20.42	20.17	13.09	28.56	5.31	14.23		
	Group 4	13	19.47	20.67	8.7	38.01	7.96	12.77	-0.487	0.626
	Total	26	19.94	20.31	8.7	38.01	6.65			
Adhesive volume (mm^3)	**Group 1**	13	4.05	4.03	2.86	5.3	0.67	14.92		
	Group 4	13	3.7	3.47	2.36	5.36	0.98	12.08	-0.949	0.343
	Total	26	3.87	3.89	2.36	5.36	0.84			
Void volume (mm^3)	**Group 1**	13	0.07	0.06	0.02	0.13	0.03	12.62		
	Group 4	13	0.08	0.08	0.02	0.14	0.04	14.38	-0.59	0.555
	Total	26	0.07	0.08	0.02	0.14	0.04			
Gap volume (mm^3)	**Group 1**	13	0.58	0.47	0.09	1.34	0.37	13.92		
	Group 4	13	0.54	0.39	0.19	1.13	0.32	13.08	-0.282	0.778
	Total	26	0.56	0.46	0.09	1.34	0.34			
Total Void and Gap volume (mm^3)	**Group 1**	13	0.65	0.54	0.15	1.39	0.37	13.81		
	Group 4	13	0.62	0.53	0.22	1.15	0.33	13.19	-0.205	0.837
	Total	26	0.64	0.54	0.15	1.39	0.34			

No statistically significant differences were found between Group 2 and Group 3 (Table 4.4) concerning bond strength, adhesive volume, void volume, gap volume, and total void and gap volume values ($p>0.05$).

Table 4.4: Analysis result of comparison of the difference between Groups 2 and 3

		Group 2-3						Mann-Whitney U Test	
		n	Mean	Median	Min	Max	Sd	Mean Rank	z	P
Bond strength (MPa)	**Group 2**	13	19.87	19.9	8.57	27.49	5.01	14.69		
	Group 3	13	19.28	16.96	7.22	39.75	8.57	12.31	-0.795	0.427
	Total	26	19.58	19.45	7.22	39.75	6.89			
Adhesive volume (mm^3)	**Group 2**	13	3.58	3.61	1.93	4.69	0.71	14.73		
	Group 3	13	3.32	3.33	1.99	4.42	0.63	12.27	-0.821	0.412
	Total	26	3.45	3.57	1.93	4.69	0.67			
Void volume (mm^3)	**Group 2**	13	0.06	0.05	0.01	0.12	0.03	14,46		
	Group 3	13	0.05	0.05	0.01	0.1	0.03	12.54	-0.615	0.538
	Total	26	0.05	0.05	0.01	0.12	0.03			
Gap volume (mm^3)	**Group 2**	13	0.64	0.47	0.26	1.86	0.44	11.77		
	Group 3	13	0.76	0.78	0.26	1.57	0.37	15.23	-1.154	0.249
	Total	26	0.7	0.69	0.26	1.86	0.4			
Total Void and Gap volume (mm^3)	**Group 2**	13	0.7	0.51	0.29	1.87	0.42	12.31		
	Group 3	13	0.81	0.82	0.28	1.58	0.36	14.69	-0.795	0.427
	Total	26	0.75	0.75	0.28	1.87	0.39			

Group 2 and Group 4 (Table 4.5) showed no statistically significant differences in bond strength values, adhesive volume, void volume, gap volume, and total void and gap volume values ($p>0.05$).

Table 4.5: Analysis result of comparison of the difference between Groups 2 and 4

		Group 2-4						Mann-Whitney U Testi	
		n	Mean	Median	Min	Max	Sd	Mean Rank	z	P
Bond strength (MPa)	**Group 2**	13	19.87	19.9	8.57	27.49	5.01	14		
	Group 4	13	19.47	20.67	8.7	38.01	7.96	13	-0.333	0.739
	Total	26	19.67	20.21	8.57	38.01	6.52			
Adhesive volume (mm^3)	**Group 2**	13	3.58	3.61	1.93	4.69	0.71	13.38		
	Group 4	13	3.7	3.47	2.36	5.36	0.98	13.62	-0.077	0.939
	Total	26	3.64	3.57	1.93	5.36	0.84			
Void volume (mm^3)	**Group 2**	13	0.06	0.05	0.01	0.12	0.03	11.31		
	Group 4	13	0.08	0.08	0.02	0.14	0.04	15.69	-1.462	0.144
	Total	26	0.07	0.07	0.01	0.14	0,04			
Gap volume (mm^3)	**Group 2**	13	0.64	0.47	0.26	1.86	0.44	14.54		
	Group 4	13	0.54	0.39	0.19	1.13	0.32	124.6	-0.692	0.489
	Total	26	0.59	0.47	0.19	1.86	0.38			
Total Void and Gap volume (mm^3)	**Group 2**	13	0.7	0.51	0.29	1.87	0.42	14.19		
	Group 4	13	0.62	0.53	0.22	1.15	0.33	12.81	-0.462	0.644
	Total	26	0.66	0.52	0.22	1.87	0.37			

There were no statistically significant differences in bond strength values ($p>0.05$) or adhesive volume values ($p>0.05$) between Group 3 and Group 4 (Table 4.6). However, a statistically significant difference was observed in void volume values ($p<0.05$), with Group 4 exhibiting a higher void volume than Group 3. However, no statistically significant differences were found between the two groups regarding gap volume values ($p>0.05$) or total void and gap volume values ($p>0.05$).

Table 4.6: Analysis result of comparison of the difference between Groups 3 and 4

		Group 3-4						Mann-Whitney U Test	
		n	Mean	Median	Min	Max	Sd	Mean Rank	z	P
Bond strength (MPa)	**Group 3**	13	13	19.28	16.96	7.22	39.75	8.57	-0.128	0.898
	Group 4	13	13	19.47	20.67	8.7	38.01	7.96		
	Total	26	26	19.38	17.06	7.22	39.75	8.11		
Adhesive volume (mm^3)	**Group 3**	13	3.32	3.33	1.99	4.42	0.63	12.54	-0.641	0.522
	Group 4	13	3.7	3.47	2.36	5.36	0.98	14.46		
	Total	26	3.51	3.4	1.99	5.36	0.83			
Void volume (mm^3)	**Group 3**	13	0.05	0.05	0.01	0.1	0.03	10.38	-2.077	**0.038**
	Group 4	13	0.08	0.08	0.02	0.14	0.04	16.62		
	Total	26	0.06	0.06	0.01	0.14	0.04			
Gap volume (mm^3)	**Group 3**	13	0.76	0.78	0.26	1.57	0.37	15.85	-1.564	0.118
	Group 4	13	0.54	0.39	0.19	1.13	0.32	11.15		
	Total	26	0.65	0.69	0.19	1.57	0.35			
Total Void and Gap volume (mm^3)	**Group 3**	13	0.81	0.82	0.28	1.58	0.36	15.54	-1.359	0.174
	Group 4	13	0.62	0.53	0.22	1.15	0.33	11.46		
	Total	26	0.71	0.75	0.22	1.58	0.35			

The mean bond strength values of the groups and the correlation between variables are given in Figure 4.1.

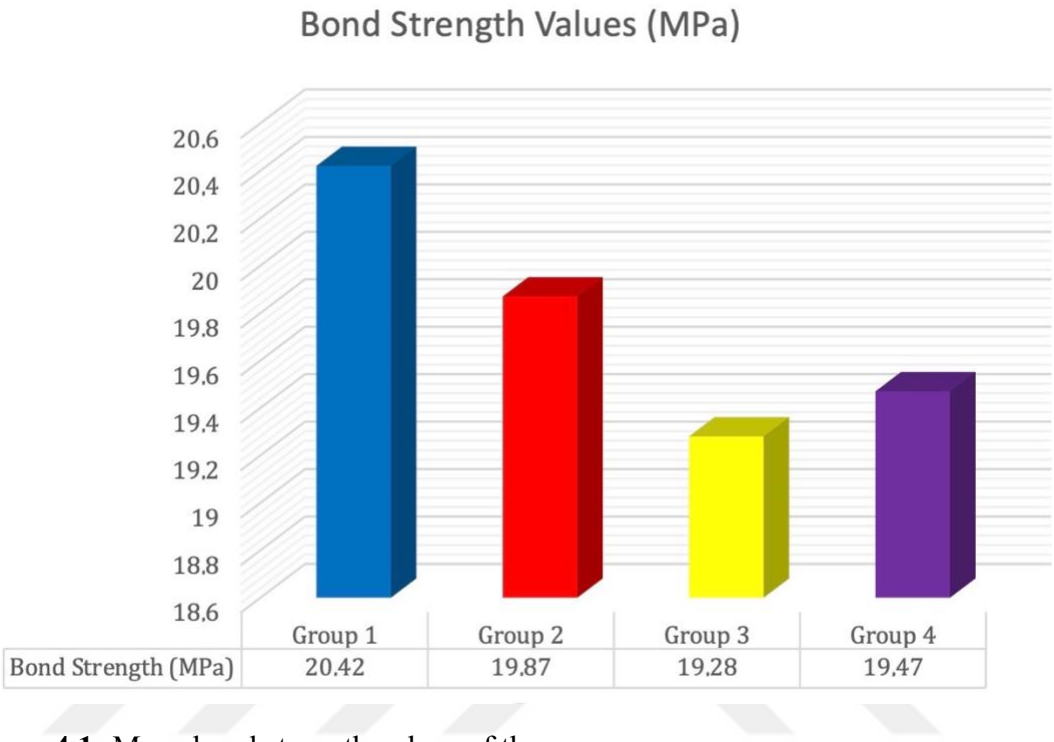


Figure 4.1: Mean bond strength values of the groups

Spearman's Correlation Coefficient was used to examine the relationships between variables that did not show normal distribution (Table 4.7). Significance was evaluated at the $p<0.05$ level. The following significant associations were identified:

- Bond Strength and Adhesive Volume: A statistically significant and positively weak relationship emerged between bond strength and adhesive volume values ($p<0.05$, $r=0.334$). This implies that adhesive volume values also tend to increase as bond strength values rise.
- Bond Strength and Gap Volume: A strong and inversely significant relationship was established between bond strength and gap volume values ($p<0.05$, $r=-0.870$). With increasing bond strength, gap volume values showed a tendency to decrease.
- Bond Strength and Total Void and Gap Volume: A strong and inversely significant relationship exists between bond strength values and total void and

gap volume values ($p<0.05$=-0.889). This indicates that total void and gap volume values tend to decrease as bond strength values increase.

- Adhesive Volume and Void Volume: A weak and positively significant relationship was observed between the adhesive and void volume values ($p<0.05$, r =0.490). As adhesive volume values rise, void volume values also rise.
- Adhesive Volume and Gap Volume: A weak and inversely significant relationship was detected between adhesive and gap volume values ($p<0.05$, r=-0.357). Increasing adhesive volume values were linked to a decrease in gap volume values.
- Adhesive Volume and Total Void and Gap Volume: A weak and inversely significant relationship was established between adhesive volume values and total void and gap volume values ($p<0.05$, r =-0.308). With rising adhesive volume values, total void and gap volume values tended to decrease.
- Gap Volume and Total Void and Gap Volume: A strong and positively significant relationship was identified between gap volume values and total void and gap volume values ($p<0.05$, r=0.987). This suggests higher gap volume values are associated with elevated total void and gap volume values.

Table 4.7: Analysis of the relationship between measurement values

		Bond strength (MPa)	Adhesive volume (mm^3)	Void volume (mm^3)	Gap volume (mm^3)
Adhesive volume (mm^3)	**r**	.334			
	p	**0.016**			
	n	52			
Void volume (mm^3)	**r**	-0.007	.490**		
	p	0.962	**0.001**		
	n	52	52		
Gap volume (mm^3)	**r**	-.870**	-.357**	-0.185	
	p	**0.001**	**0.009**	0.188	
	n	52	52	52	
Total Void and Gap volume (mm^3)	**r**	-.889**	-.308*	-0.065	.987**
	p	**0.001**	**0.027**	0.649	**0.001**
	n	52	52	52	52

5. DISCUSSION

Orthodontic treatment can be successful if a high-quality bond of attachments on teeth is achieved throughout the entire treatment period. Polymerization shrinkage of adhesives can lead to microleakage formation at the enamel-adhesive-bracket interface. Microleakage is the microscopic passage of bacteria, liquids, molecules, enzymes, acids, and ions between the resin materials and the tooth surface (8). Microleakage can cause decalcified areas under the bracket and reduce the bond strength of the brackets (60,88).

This study aims to determine the microleakage and void formation under ceramic flash-free orthodontic brackets using micro-computerized tomography, also to measure the amount and distribution of void formed in the adhesive after the brackets are bonded and to observe if there is any relation between void and bond strength.

Human and animal teeth have been used in many in vitro studies in orthodontics (7,19,59,89,90). It has been reported that the bond strength obtained with bovine teeth is less than that of human teeth (91). Human premolar teeth are the most frequently extracted teeth for orthodontic reasons and are usually used in in-vitro studies, especially in studies examining microleakage and bond strength (7,59,89,92,93). Our study used maxillar and mandibular premolar teeth extracted for orthodontic reasons.

Teeth are kept in various solutions to prevent dehydration and bacterial colonization. Many solutions, such as saline, distilled water, chloramine, and thymol, are used as storage options for teeth to be held until the testing time (7,14,58,94). Williams et al. (95) studied the effect of time and storage conditions on the bond strength of extracted teeth, and they found that the bond strength of teeth kept in distilled water and thymol solution did not change even after five years. On the contrary, Eliades et al. (86) stated that six months is the maximum storage period for extracted teeth to avoid standardization errors that may occur in the experiments. In our study, the teeth were kept in 0.1% thymol solution for one week to inhibit bacterial growth. After the teeth were disinfected, they were washed with distilled water and kept in distilled water in a glass bottle, at room temperature, in a place out of the sun until the time of the study, and the solution was renewed once a month.

Teeth used in this study were selected by evaluating with a magnifier glass in daylight, and the ones chosen had the following criteria: intact buccal enamel, caries-free,

no fillings, no congenital defects, and no prior orthodontic usage. Soft tissue residues were removed using a scaler, and enamel was cleaned using a fluorine-free pumice for 15 seconds with a bristle brush attached to the micromotor for 15 seconds, washed with pressurized water for 20 seconds, and dried with oil-free air-water spray for 10 seconds (28,96).

This study used a Flash-free ceramic bracket to evaluate the bond strength and microleakage compared to a conventional ceramic bracket. If the results of bond strength and microleakage of the flash-free ceramic bracket are clinically acceptable, it can be widely used as an advantage in reducing bonding steps in orthodontic clinical practice.

APC brackets were designed to minimize the chair time spent during direct bonding. APC I was first presented in 1991 and contained high-viscosity adhesive that led to problems with bracket positioning. Consequently, APC II was introduced, followed by APC Plus, which includes a pink-colored adhesive that turns white after polymerization to provide a visual aid in bracket positioning and flash cleaning. In 2014, a new bracket system called APC Flash-Free Adhesive Coated Application System was introduced, which does not need to be cleaned of excessive adhesive. In vitro studies on this bracket system have shown adequate bond strength (14,59), shortened bonding time (14,58), and low microleakage compared to conventional bonding systems (59).

We used ceramic brackets in our study to avoid metal artifacts of metal brackets that would appear during micro-computed tomography scanning and to achieve a high-quality 3D image. Enamel etching was performed using a conventional etching and primer technique (37% Phosphoric acid and Transbond XT Liquid Primer) and Transbond™ Plus Self-Etching Primer and compared etching type's effect on brackets bracket strength. Adhesive systems used in the study were APC Flash-Free Adhesive and Transbond™ XT light-cured adhesive and primer. The polymerization of light-cured adhesive was done in 10 seconds using VALO Cordless curing light, which utilizes a multiwavelength LED for producing high-intensity light at 385–515 nm. Arıkan et al. (88) evaluated the effect of different light sources on microleakage using the dye penetration method and found that LED had the lowest microleakage scores.

Many studies are using various in vitro methods to evaluate and quantify microleakage. In these studies, different ways such as dye penetration method, air pressure method, bacterial working method, radioactive isotope method, chemical

markers method, neutron activation analysis method, electrochemical method, and scanning microscope analysis method were used. The dye penetration method is the simplest and most preferred method (62).

Researchers used colored dyestuffs or chemical markers that penetrated the samples in the dye penetration method. Specimens are sectioned longitudinally and evaluated with a stereo optical or scanning electron microscope. The depth of dye penetration is recorded only from the sections; therefore, this does not give the full view of the microleakage, which is three-dimensional. Therefore, this method has low reproducibility, precision, and reliability compared to 3D tests (7,62).

With the development of micro-CT, researchers have had the opportunity to evaluate the microleakage of dental restorative materials and the leakage area and volume by 3D image analysis (9). In addition, micro-CT has proven to be a powerful and viable technique for determining polymerization shrinkage and microleakage (97).

Micro-CT in dental material studies is used as follows: 3D evaluation of the microleakage area and volume, examination of demineralization, analysis of the mineral content of enamel and dentin, determination of structures and changes at the adhesive interfaces (9, 97-103). It has also been used to detect 3D and qualitative marginal fit (104). Among the advantages of this method are being a non-invasive technique and it provides precise information in terms of quality and quantity by evaluating the material to be examined in 3D. However, despite these features, its high cost creates a disadvantage in terms of use (105).

The shear bond strength test is one of the most used methods to evaluate bond strength in orthodontics (1). The bond strength test of the bonded brackets is performed using the Universal Test Device. To ensure standardization of in-vitro studies examining bracket bond strength, the teeth are transferred to the universal test device with carrier molds. In many studies, cold acrylic resin is used to standardize the samples due to its usability and easy accessibility (93,106-108). In our study, the teeth were embedded in blocks composed of auto-polymerizing acrylic in the form of a rectangular prism from 1 mm apical of the enamel-cement junction, with the long axis of the tooth perpendicular to the ground plane to be appropriately placed to the Universal Test Device.

The force applied to the bracket on the universal tester is transmitted with the help of the blade located on the bracket or with a wire passed around the bracket (109,110). In

tests conducted this way, factors such as the wire thickness, its adaptation, and friction force affect the results (86). Therefore, in our study, the bond strength test was applied with a metal blade at the bracket-adhesive junction to avoid factors such as the adaptation of the wire and the friction force. The speed of the blade used in the studies varies from 0.5 mm/min to 1 mm/min (109,111). As the blade movement speed increases, the reliability of the tests decreases, and the probability of enamel fracture increases (112). In this study, the blade head speed was applied as 0.5 mm/min. A study reported that the angle change affects the bond strength, which decreases as the angle increases (90). In our study, attention was paid to keeping the blade parallel to the base of the bracket.

The efficient bond strength between the bracket and tooth is essential for the success and longevity of orthodontic treatment. The polymerization shrinkage stress in composite resins may result in marginal disintegration, microleakage, reduced bond strength, compromised mechanical properties, and interfacial gaps between composite and tooth structure (3,6,97,113,114). In a study, it was demonstrated that micro-CT could precisely determine polymerization shrinkage by comparing composite volumes before and after polymerization (115). Sun et al. (97) used micro-CT to scan composites positioned within a sequence of model cavities characterized by controlled C-factors and volumes to precisely determine their location and volume before and after the photopolymerization process. Shrinkage was determined by comparing the composite volumes before and after the polymerization, and leakage was predicted based on gap formation between cavity walls and composites. A dye penetration experiment validated the micro-CT results. Studies have evaluated the void of adhesives in dentistry (6,116,117). Still, no research has been done to investigate voids on orthodontic adhesives and their possible association with bond strength.

Our results showed no significant difference among tested groups for the gap volume values and total void and gap volume values. A statistically significant difference was found between Group 3 and Group 4 regarding the void volume values ($p<0.05$, $p=0.038$). The ceramic bracket of Group 4 bonded with a self-etching primer system had a higher void volume than the ceramic bracket of Group 3 bonded with a conventional method.

In a study by Uysal et al. (118), a total of sixty recently extracted human mandibular premolar teeth were divided into four groups: Group 1, 37% phosphoric acid

gel + Transbond XT liquid primer + stainless steel bracket; Group 2, Transbond Plus Self-Etching Primer + stainless steel bracket; Group 3, 37% phosphoric acid gel + Transbond XT liquid primer + ceramic bracket; Group 4, Transbond Plus Self-Etching Primer + ceramic bracket. All ceramic and metal brackets were bonded to teeth with Transbond XT light-cure adhesive system. Brackets bonded with a self-etching primer system revealed significantly higher microleakage at the enamel-adhesive interface of the gingival side.

Using micro-CT, Öztürk et al. (7) evaluated microleakage under orthodontic ceramic brackets bonded with direct and indirect bonding techniques and adhesives. The use of diverse adhesives in direct and indirect bonding techniques did not significantly impact the extent of microleakage.

Grünheid et al. (59) used 24 bovine incisors that were divided into two groups and bonded with adhesive-precoated ceramic maxillary central incisor brackets (Clarity Advanced,) using a system with a flash-free adhesive (APC Flash-Free Adhesive Coated Appliance System) in group 1 and a system with a conventional adhesive (APCII Adhesive Coated Appliance System) in group 2. Enamel was etched with 35% orthophosphoric acid and primed using a light cure adhesive primer (Transbond XT Primer). All teeth were submerged in a 50 percent aqueous solution of silver nitrate at room temperature for 24 hours to allow the detection of microleakage into the adhesives. As a result, the microleakage was minimal, with no significant differences between the two adhesives.

Kim et al. (58) evaluated APC Flash Free and APC Plus ceramic brackets for microleakage. APC Flash Free brackets showed more microleakage, but no statistically significant difference existed.

In our study, it was found that there was a statistically significant difference between Group 1 and Group 3 regarding adhesive volume values ($p<0.05$). The adhesive volume measured in the adhesive-coated brackets of Group 1 was higher than the conventional brackets of Group 3 ($p<0.05$). The The reduction in the necessity for flash cleaning in adhesive-coated systems is believed to contribute to the possibility that these samples experience fewer marginal composite ruptures during flash cleaning than conventional methods. However, no study concerning this specific subject was identified during the literature review.

The adhesive systems used in orthodontic practice should have bond strength forces that are sufficiently high to establish a reliable bond of brackets and teeth throughout orthodontic treatment. However, these bond strength forces should also be low enough to prevent enamel damage during debonding at the end of treatment and to ensure easy cleaning of the remaining adhesive on the tooth (119). Reynolds (13) stated that 5.9-7.8 MPa bond strengths would be sufficient for clinical conditions. The bond strength values obtained from our study's result are higher than these values. The mean shear bond strength for Group 1 (APC Flash-Free) was 20.42 ±5.31 MPa, for Group 2 (APC Flash-Free) was 19.87± 5.01 MPa, for Group 3 (Transbond XT) was 19.28 ± 8.57 MPa and for Group 4 (Transbond XT) was 19.47 ± 7.96 MPa. There was no statistically significant difference between groups regarding bond strength values ($p>0.05$). Our study results are similar to those reported by Marc et al. (15), who evaluated the bond strength of ceramic brackets bonded differently on 45 mandibular premolars. In the first group, the brackets were precoated with the APC Flash-Free system; in the second group, with the APC Plus system; in the third group, the brackets were bonded manually with the Transbond XT resine composite. The enamel was etched in all groups using 37% orthophosphoric acid following the application of the Transbond XT primer adhesive. Even though the mean shear bond strength value for the APC Flash-Free group was lower than the values of the other two groups, it did not show statistical significance ($p=0.276$).

In our study in Group 1 and Group 3, enamel was etched using %37 Phosphoric acid etching using 37% phosphoric acid, followed by the application of the adhesive primer Transbond XT, and the bracket used were, respectively, Clarity Advanced APC Flash-Free Ceramic bracket and Clarity Advanced Ceramic Bracket. The mean shear bond strength for Group 1 is 20.42 ±5.31 MPa, and for Group 3 is 19.28 ± 8.57 MPa. These values are similar to those mentioned in the study of Ansari et al. (120). In their in-vitro study, it was reported a mean shear bond strength value of 20.13 Mpa for the APC Flash Free group (n=10) and a value of 27.26 MPa for the ceramic brackets that were manually bonded using Transbond XT (n=10). The enamel surface treatment was similar: etching with 37% phosphoric acid and applying the adhesive primer Transbond XT. Unlike our results, Ansari et al. showed that the mean SBS of Clarity Advanced (APC Flash-free) was statistically significantly lower than that of Clarity Advanced ceramic brackets.

Using an etching primer reduces the number of steps during bonding, and clinicians can save time and reduce the potential for error and contamination during the bonding procedure. Bishara et al. (107) found that using a self-etching primer can lead to lower bond strength than conventional etching. However, studies by Büyükyılmaz et al. (121) and Bishara et al. (108) reported a higher bond strength result using self etching primer when comparing it with %35 orthophosphoric acid. Some studies have found no significant difference in bond strength between self etching primer and conventional etching (122-124).

In our study at Group 2 and Group 4, enamel was etched by Transbond Plus self-etching primer, and the brackets used were Clarity Advanced APC Flash-Free Ceramic bracket and Clarity Advanced Ceramic Bracket. According to the results of our study, the mean shear bond strength values of groups where the enamel surface treatment was performed using a self-etching primer obtained were higher than those mentioned in the survey conducted by Lee et al. (14) who used the same enamel etching type. In their study, the mean shear bond strength value of ceramic brackets was reported as 13.7 MPa for the APC Flash-Free group (n = 12), 10.8 MPa for the APC Plus group (n = 12), and 10.4 MPa for the group of ceramic brackets manually coated with Transbond XT (n = 12). In their study, adhesive flash-free brackets were evaluated regarding bonding time, bond strength, and residual adhesive remaining on the enamel surface. Self-etching primer was used in all three groups. APC Flash Free ceramic brackets showed higher shear bond strength values than the other groups.

In this study Spearman's correlation analysis was used to evaluate the correlation among the variables. The results of this analysis demonstrate that bond strength is significantly impacted by adhesive volume, gap volume, and total void and gap volume. Bond strength rises with increased adhesive volume and decreased total void and gap volume. The correlations between adhesive volume and total void and gap volume emphasize the essential role of adhesive impact in the occurrence of voids and gaps. The strong positive correlation between gap volume and total void and gap volume emphasizes that higher gaps indicate greater overall void and gap volumes.

6. CONCLUSIONS AND RECOMMENDATIONS

- This study showed no significant difference among the groups using APC Flash-Free Ceramic Brackets and the groups using Clarity Advance Ceramic Brackets regarding void volume, gap volume, and total void and gap volume.

- A statistically significant difference in void volume values was observed between Clarity Advance Ceramic Brackets which were bonded with Transbond Plus Self Etching Primer along with Transbond XT, and Clarity Advance Ceramic Brackets which were bonded with the conventional method. The Clarity Advance Ceramic Brackets bonded with Transbond Plus Self Etching Primer and Transbond XT exhibited a higher void volume than Clarity Advance Ceramic Brackets bonded with the conventional method.

- APC Flash-free ceramic brackets demonstrated similar bond strength values to ceramic brackets bonded using the conventional method. However, further studies are recommended to provide additional insights into the practical benefits of flash-free brackets in orthodontic practice.

- The Micro-CT technique's ability to analyze samples in three dimensions makes it effective and gives accurate information for microleakage studies.

- Bond strength was significantly impacted by adhesive volume, gap volume, and total void and gap volume. Bond strength rises with increased adhesive volume and decreased total void and gap volume.

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APPENDIX

APPENDIX-1. Ethics Committee Approval

Evrak Tarih ve Sayısı: 18/12/2020-44084

T.C.
SAĞLIK BİLİMLERİ ÜNİVERSİTESİ
HAMİDİYE BİLİMSEL ARAŞTIRMALAR ETİK KURULU

Toplantı Tarihi : 11/12/2020
Toplantı Sayısı : 2020/27
Karar Sayısı : 27/17

Kurulumuza değerlendirilmek üzere sunulan, Dr. Öğr. Üyesi Ersin YILDIRIM'ın sorumlu araştırmacı ve Artemisa ADIGÜZEL'in yardımcı araştırmacı olduğu 20/490 kayıt numaralı "***Adeziv Kaplamalı Seramik Ortodontik Braketler Altında Oluşan Mikrosızıntının ve Boşluk Oluşumunun Mikro-Bilgisayarlı Tomografi ile Değerlendirilmesi***" başlıklı proje önerisi kurulumuzun 11.12.2020 tarihli toplantısında değerlendirilmiş ve etik açıdan uygun bulunmuştur.

Aslı Gibidir
e-imzalıdır
Prof. Dr. Fatih GÜLTEKİN
Başkan

Prof. Dr. Günseli GÜVEN POLAT
Başkan Yardımcısı

Prof. Dr. Kadriye ÖNEŞ
Etik Kurul Üyesi

Prof. Dr. Nesrin KARAMUSTAFALIOĞLU
Etik Kurul Üyesi

Prof. Dr. Mahfuz ELMASTAŞ
Etik Kurul Üyesi

Prof. Dr. Hüseyin Avni BALCIOĞLU
Etik Kurul Üyesi

Doç.Dr. Papatya KELEŞ
Etik Kurul Üyesi

Dr. Öğr. Üyesi Arzu Kader HARMANCI SEREN
Etik Kurul Üyesi

Doç.Dr. Yasemin AYDIN KARTAL
Etik Kurul Üyesi

Dr. Öğr. Üyesi Faruk Berat AKÇEŞME
Etik Kurul Üyesi

Dr. Öğr. Üyesi Şükriye TÜRKOĞLU
Etik Kurul Üyesi

Dr. Öğr. Üyesi Banu BAYRAM
Etik Kurul Üyesi

Dr. Öğr. Üyesi Elif GÜLTEKİN
Etik Kurul Üyesi

13/12/2020 Mühendis Ayşe OKUTAN

Evrakı Doğrulamak İçin : http://ebys.sbu.edu.tr/enVision/Validate_Doc.aspx?V=BE6L46EPL

APPENDIX-2. Informed Consent Form

BİLGİLENDİRİLMİŞ GÖNÜLLÜ OLUR FORMU

Bilgilendirme

Muayene, fotoğraf, alçı model ve röntgen filmi incelemeleri sonucunda ortodontik sorununuzun 1. küçük azı dişlerinizin çekilmesi yolu tedavi edilmesine karar verilmiştir.

Ortodonti kliniğinde tedavi planmasında 1. Premolar dişlerin çekim endikasyonları belirgindir. ***Artmış overjet ve sınıf II molar ilişki varlığında*** üst ön dişlerin geriye alınması için ihtiyaç duyulan yerin karşılanması amacıyla üst 1. Premolar dişlerin çekimi gerekebilmektedir. Diğer yandan dental arklarda dana önceden kaybedilmiş yerler nedeniyle görülen ***orta veya şiddetli çapraşıklığın çözülmesinde***, ***gömülü kalıp yer bulamayan dişlerin ağız içine sürdürülmesinde*** veya ***ark dışından süren köpek dişlerin ağız içine yerleştirilmesi*** amaçlarıyla da 1. Premolar dişlerin çekimi gerekebilmektedir. Yer kazanmak amacıyla 1. Premolar dişlerin çekimi yerine, dişlerin kemik dışına doğru sürüklenmesi hem fonskiyonel hem de estetik sorunlar yaratabilmektedir. Diğer yandan stabil olmayan bu dental durum tedavi bittiğinde dişlerin eski yerlerine hareket etme eğilimi ile relapse neden olabilmektedir. Bu nedenlerle ilgili vakalarda dişleri kemik içinde anormal pozisyonlara yerleştirmek yerine yer kazanmak için 1. Premolar dişlerin çekimi tercih edilmektedir. Diğer bir diş çekim gerekçesi ise ***açık kapanış durumlarıdır***. Ön dişlerin geride hazırlanan yerlere doğru hareket ettirilmesi ile açık kapanışta düzelme ve kapanışın derinleşmesi diş çekimli ortodontik tedaviler ile sağlanmaktadır. ***Kesici dişlerin öne doğru fırlak olduğu durumlarda*** hastanın ***dudaklarını yeterince kapatamadığı ve üst dudak görünüşünün rahatsız edici olduğu*** da gözlenebilir. Bu durumlarda da dişlerin geriye toplanması için 1. Premolar dişlerin çekimi ile yer kazanılması planlanır. ***Bimaksiller protruzyon*** ismini verdiğimiz çene gelişim durumunda da önde konumlanmış alt ve üst ön dişler ve önde konumlanan dudak yapısı ile çoğu etnik estetik algısına göre hoş karşılanmayan bir yüz görünümü oluşabilmektedir. Bu nedenle alt ve üst ön dişlerin 1. premolar dişlerin çekimi ile geriye toplanması, alt ve üst dudak belirginliğinin azaltılması hedeflenir. ***Ortognatik cerrahi hastalarının cerrahi öncesi hazırlığında*** ise dişlerin mevcut iskeletsel uyumsuzluğu maskelemesi durumu tam tersine çevrilmelidir. Bu nedenle de bazen ark içinde yere ihtiyaç duyulabilmektedir. Ortognatik cerrahi hastaların cerrahi öncesi hazırlığı da diş çekimli ortodontik tedaviler için bir endikasyon olabilmektedir.

Periodontal sebeplerle dişin bulunduğu alveol kemikte madde kaybı tedavi edilemiyecek kadar fazla ise ve dişte 2. dereceden fazla mobilite varsa çekim endikasyonu gerekebilir.

Belirlenen tedavi planı gereğince çekilecek olan diş veya dişlerinizin kullanılacağı bir çalışma planlanmaktadır.

Bu araştırmanın adı; **"Adeziv Kaplamalı Seramik Ortodontik Braketler Altında Oluşan Mikrosızıntının ve Boşluk Oluşumunun Mikro-Bilgisayarlı Tomografi ile Değerlendirilmesi"**dir.

Çalışmamızın amacı; seramik flash-free ortodontik braket sistemlerinin altında oluşan mikrosızıntı ve boşluk oluşumunun mikro-bilgisayarlı tomografi kullanılarak belirlenmesiyle birlikte braketler yapıştırıldıktan sonra adezivde oluşan boşlukların miktarını, dağılımını ölçmek ve bağlanma dayanımı ile arasındaki olası korelasyonun karşılaştırılarak incelenmesidir.

Bu çalışmada ortodontik nedenlerle çekilmiş 52 adet insan premolar dişi kullanılacaktır. Dişler her grupta 13 diş olacak şekilde rastgele 4 gruba ayrılacaktır. Toplanan dişlerin ışık altında incelenmesi sonucunda üzerinde dolgu, çürük, çatlak veya

davye tahribatı olan dişler çalışmaya dahil edilmeyecektir. Dişler çekildikten sonra yumuşak doku artıkları, plak temizlenecek ve 1 hafta boyunca dezenfekte amacıyla %0,1'lik timol solüsyonu içerisinde bekletilecektir. Dişler dezenfekte olduktan sonra distile su ile yıkanarak çalışmanın yapılacağı zamana kadar distile su içerisinde oda sıcaklığında bekletilecektir. Adezivlerin altında oluşan mikrosızıntının ve boşlukların saptanmasına olanak sağlamak için dişler, oda sıcaklığında %50 gümüş nitrat solüsyonunda 4 saat boyunca bekletilecektir. X-ışını görüntülerini elde etmek için mikro-BT sistemi kullanılacaktır.

Bu araştırma hasta ve tedavisi için hiçbir risk yaratmamaktadır. Tedavinin gerektirdiği şekilde ve hekimin uyarıları doğrultusunda hareket edildiği takdirde tedavi planlandığı şekilde sürdürülecektir.

Bu araştırmaya katılım hastanın isteğine bağlıdır, hasta istediği zaman herhangi bir ceza veya yaptırıma maruz kalmaksızın araştırmaya katılmaktan ve çekilmiş dişlerinin kullanılmasından vazgeçebilir.

Hastanın kimliğini ortaya koyacak kayıtlar gizli tutulacaktır; kamuoyuna açıklanmayacak; araştırma sonuçlarının yayımlanması halinde bile hastanın kimliği gizli kalacaktır

Gönüllü Oluru Bölümü

Çalışmaya Katılma Onayı:

Yukarıda yer alan ve araştırmaya başlanmadan önce gönüllüye verilmesi gereken bilgileri okudum ve sözlü olarak dinledim. Aklıma gelen tüm soruları araştırıcıya sordum, yazılı ve sözlü olarak bana yapılan tüm açıklamaları ayrıntılarıyla anlamış bulunmaktayım. Çalışmaya katılmayı isteyip istemediğime karar vermem için bana yeterli zaman tanındı. Bu koşullar altında, bana ait tıbbi bilgilerin ve materyallerin gözden geçirilmesi, transfer edilmesi ve işlenmesi konusunda araştırma yürütücüsüne yetki veriyor ve söz konusu araştırmaya ilişkin bana yapılan katılım davetini hiçbir zorlama ve baskı olmaksızın büyük bir gönüllülük içerisinde kabul ediyorum.

Gönüllünün,
Adı-Soyadı:
Adresi:
Tel.: **Tarih ve İmza:**

Velayet veya vesayet altında bulunanlar için veli veya vasinin,
Adı-Soyadı:
Adresi:
Tel.: **Tarih ve İmza:**

Açıklamaları yapan araştırmacının,
Adı-Soyadı:
Adresi: Sağlık Bilimleri Üniversitesi Hamidiye Diş Hekimliği Fakültesi Ortodonti Anabilim Dalı İstanbul
Tel.: **Tarih ve İmza:**

Tanıklık eden kişi