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IN VITRO EVALUATION OF SHEAR BOND STRENGTH OF ORTHODONTIC BRACKETS WITH DIFFERENT ADHESIVES

DOCTOR OF PHILOSOPHY THESIS

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APPROVAL

This thesis has been deemed by the jury in accordance with the relevant articles of Yeditepe University Graduate Education and Examinations Regulation and has been approved by Administrative Board of Institute with decision dated .... and numbered ....

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DECLARATION

I hereby declare that this thesis is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree except where due acknowledgment has been made in the text.

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°C	Celsius
°	Degree
%	Percent
cm^2	Square centimeter
µSBS	Micro-shear bond strength
µTBS	Micro-tensile bond strength
Bis-GMA	Bisphenol a diglycidyl ether dimethacrylate
HAp	Hydroxyapatite
LED	Light emitting diode
MDp	Methacryloyloxydecyl dihydrogen phosphate
MPa	Megapascal
mW	Milliwatt
N	Newton
NCSS	Number cruncher statistical System
nm	Nanometer
PAC	Plasma arc
PO	Push-out
QTH	Quartz tungsten halogen
SBS	Shear bond strength
TBS	Tensile bond strength

ABSTRACT

Üzrek, B. (2023). *In vitro* Evaluation of Shear Bond Strength of Orthodontic Brackets with Different Adhesives. Yeditepe University, Institute of Health Sciences, Department of Orthodontics PhD Thesis, İstanbul.

The aim is to evaluate the shear bond strength of stainless-steel orthodontic brackets bonded with two different adhesive systems. Sixty extracted bovine incisors were divided randomly into three groups. To bond, the brackets to the enamel surface used two different methods: 37% orthophosphoric acid+Transbond XT Adhesive+Transbond XT Primer, BracePaste Adhesive+BracePaste Primer, and only BracePaste Adhesive. Valo Ortho Curing Light was used to polymerize the adhesive materials. After polymerization, the specimens were measured for the shear bond strength on the universal testing machine. Transbond XT Adhesive+Transbond XT Primer group showed a mean SBS of 11.73 ± 1.74 MPa, BracePaste Adhesive + BracePaste Primer group a mean SBS of 11.11 ± 1.51 MPa. There is a statistically significant difference between the shear bond strength scores of BracePaste Adhesive + BracePaste Primer and BracePaste Adhesive without BracePaste Primer. BracePaste Adhesive without BracePaste Primer group showed a mean SBS of 2.42 ± 0.81 MPa. There is a statistically significant difference between the mean shear bond strength of BracePaste Adhesive+ BracePaste Primer and BracePaste Adhesive ($p=0.0001$). There is no statistically significant difference between the mean shear bond strength of Transbond XT Adhesive+Transbond Primer and BracePaste Adhesive+BracePaste Primer ($p=0.357$). In conclusion, our study indicates no statistically significant difference between the mean shear bond strength of Transbond XT and BracePaste Adhesive with BracePaste Primer. Furthermore, we found a statistically significant difference between the mean shear bond strength of BracePaste Adhesive with BracePaste Primer and BracePaste Adhesive without BracePaste Primer.

Keywords: Shear bond strength, Transbond XT, BracePaste Adhesive, Brackets

ÖZET

Üzrek, B. (2023). Farklı Adeziv Sistemleri ile Yapıştırılan Ortodontik Braketlerin Tutuculuklarının *İn Vitro* Olarak Değerlendirilmesi. Yeditepe Üniversitesi, Sağlık Bilimleri Enstitüsü, Ortodonti ABD, Doktora Tezi, İstanbul.

Bu çalışmanın amacı, iki farklı adeziv sistemi kullanılarak yapıştırılan metal braketlerin dayanım güçlerinin *in vitro* olarak değerlendirilmesidir. Altmış çekilmiş sığır kesici dişi gelişigüzel üç gruba ayılmıştır. Braketleri mine yüzeyine yapıştırmak için iki farklı yöntem kullanılmıştır: Birinci gruba, %37'lik ortofosforik asitle pürüzlendirme+Transbond XT Primer+Transbond XT Adeziv uygulanmıştır. İkinci gruba, %37'lik ortofosforik asitle pürüzlendirme+BracePaste Adeziv+BracePaste Primer uygulanıp son gruba ise %37'lik ortofosforik asitle pürüzlendirme ve sadece BracePaste Adeziv uygulanmıştır. Adeziv materyallerin polimerizasyonu için Valo Ortho Cordless Curing Light cihazı kullanılmıştır. Braketleme işleminden sonra universal test makinesi kullanılarak örneklerin kesme bağlanım kuvvetleri ölçülmüştür. Transbond XT Adeziv+Transbond XT Primer Adeziv 11.73 ± 1.74 MPa, BracePaste Adeziv+BracePaste Primer ise 11.11 ± 1.51 MPa olarak bulunmuştur. BracePaste Adeziv+BracePaste Primer ile BracePaste Adeziv sistemi kullanılan örneklerde istatiksel olarak anlamlı bir fark bulunmuştur. Sadece BracePaste Adeziv kullanılan örneklerde dayanım gücü 2.42 ± 0.81 MPa olarak bulunmuştur. BracePaste Adeziv+BracePaste Primer Primer ile BracePaste Adeziv gruplarının dayanım güçleri ortalamaları arasında istatiksel olarak anlamlı derecede düşük bulunmuştur(p=0.0001). Transbond XT Adeziv+Transbond XT Primer ile BracePaste Adeziv+BracePaste Primer gruplarının kesme bağlanım dirençleri ortalamaları arasında istatiksel olarak anlamlı bir fark gözlenmemiştir (p=0.357). Sonuç olarak, araştırmamız Transbond XT ve BracePaste Adeziv+BracePaste Primer materyalleri arasında makaslama bağlanma dayanımı oranları açısından istatiksel olarak anlamlı bir fark göstermemiştir. Bunun aksine, BracePaste Adeziv+ BracePaste Primer ile primersiz BracePaste Adeziv arasında makaslama bağlanma dayanımı oranları açısından istatiksel olarak anlamlı bir fark bulunmuştur.

Anahtar Kelimeler: Kesme bağlanma kuvveti, Tranbond XT Adeziv, BracePaste Adeziv, Braket

1. INTRODUCTION AND AIM

Orthodontists expect strong and long-term attachment between teeth and appliances from orthodontic adhesives. In the early days of Orthodontics, Chemical resins were used to bind the brackets and tooth tissue. One of the major problems was shrinkage during the polymerization. Because of viscosity, polymerization causes the contraction of the material. Development of modern adhesive systems started when Buonocore (1) introduced a new modification to solve all these disadvantages of adhesive systems in 1955. He observed that the dental tissue and resin connected stronger than chemical resins if the teeth were applied %85 orthophosphoric acid. As a result of phosphoric acid, microporosities can be seen in the enamel surface of teeth. After that, the tooth enamel etching procedure was widely initiated to use in orthodontic treatments to strengthen the adhesion of dental materials (2). Newman (3) used this technic to bond the orthodontic appliance to the tooth surface. He preferred an epoxy resin and applied %40 phosphoric acid for 60 seconds. The cure time of epoxy resin was approximately 15 minutes. He modified the technic by reducing the cure time from 15 minutes to 5 minutes. Retief (4) applied the epoxy resin system to attach headgear to molar tubes and edgewise torque using rectangular wire, but this was not practical because of curing time.

Adhesive systems are divided into three groups according to how they attach to the dental tissue. These groups are glass ionomer systems, etch and rinse, and self-etch adhesive systems. Glass ionomers release low-level fluoride and reabsorb fluoride ions from fluoride-containing substances. Donly et al. (5) found a statistically significant reduction of early carious lesions using glass ionomers. This feature of glass ionomers has made it an attractive alternative for bonding orthodontic brackets.

Recently, light-cured adhesive systems have been widely used to attach orthodontic brackets to the teeth surface. These systems provide the clinician with enough time to position the brackets on the enamel.

The aim is to evaluate the shear bond strength of stainless-steel orthodontic brackets bonded with two different adhesive systems.

2. LITERATURE REVIEW

2.1. Dental Adhesives

Dental Adhesives are used to provide retention between a dental restoration and tooth structure. This retention can be achieved with three different mechanisms: chemical, mechanical and physical bonds.

Dental adhesives consist of a solution of resin monomers that allow to bond dental surfaces. These monomers of the features show both hydrophilic and hydrophobic groups. The inorganic structure of dental tissue replaces with this resin monomer in adhesive materials.

Adhesive dentistry was developed to achieve aesthetic expectations and minimally invasive tooth restoration. Different types of adhesives are classified according to their bonding mechanism and application procedures, such as self-etch and etch-and-rise adhesives (6). Also, dental adhesives can be classified as single-step or two-step systems.

2.1.1. Mechanism of Dental Adhesives

Enamel and dentin have different structures**.** Because of these differences**,** bonding adhesives to dentin is more difficult than enamel. The main reason for this difficulty is that dentin has 45% inorganic material, and enamel consists of 92% inorganic hydroxyapatite crystals (7).

Table 1. The composition of tooth tissue (8).

Contents	**Enamel**	**Dentine**
Inorganic phase (%)	94-96	50-70
Ca^{++} phosphate ratio	1.64	1.56
Organic phase	4-5	20-30
Water (%)	1-4	10-20

2.2. History of Dental Adhesive Systems

Sevriton cavity seal which was the first dental adhesive material was introduced by Oskar Hagger in the late 1940 (9). This adhesive material which contains glycerolphosphoric acid and dimethacrylate was chemically bonded to dental tissue (10). After this development, Kramer et al. (11) suggested that glycerolphosphoric acid and dimethacrylate strengthened bonding to dentin surface. However, the later studies showed poor clinical outcome because of the high stress and thermal expansion caused by methacrylate (12).

The main improvement in dental adhesives was made by Buonocore. He enhanced bonding between dental tissue and resin material by using 85% phosphoric acid (1). The etching process of enamel was introduced by Buonocore (13) and was used for treating metallic surfaces to achieve better adhesion in the industrial area. Micromechanical retention was formed by increasing surface roughness and chemical bonding due to acid-etching between enamel and resin material (14).

The basic expectation from adhesive systems is to produce a good bonding between dental tissue and adhesive resin (15). It is more challenging to achieve sufficient bonding on dentin compared to enamel. This is because, in dentin, there is more organic content than in enamel (16). Whilst the enamel is composed of 96% hydroxyapatite, dentin accommodates higher content of water and organic material (17).

New techniques of dental adhesive systems, which are self-etch and total-etch, are less biologically aggressive. Because This technique allows for acid monomers, a process without having to be removed by irrigation and subsequent drying, to be replaced by phosphoric acid. Also, the biocompatibility of adhesive systems has been developed compared to old techniques (18).

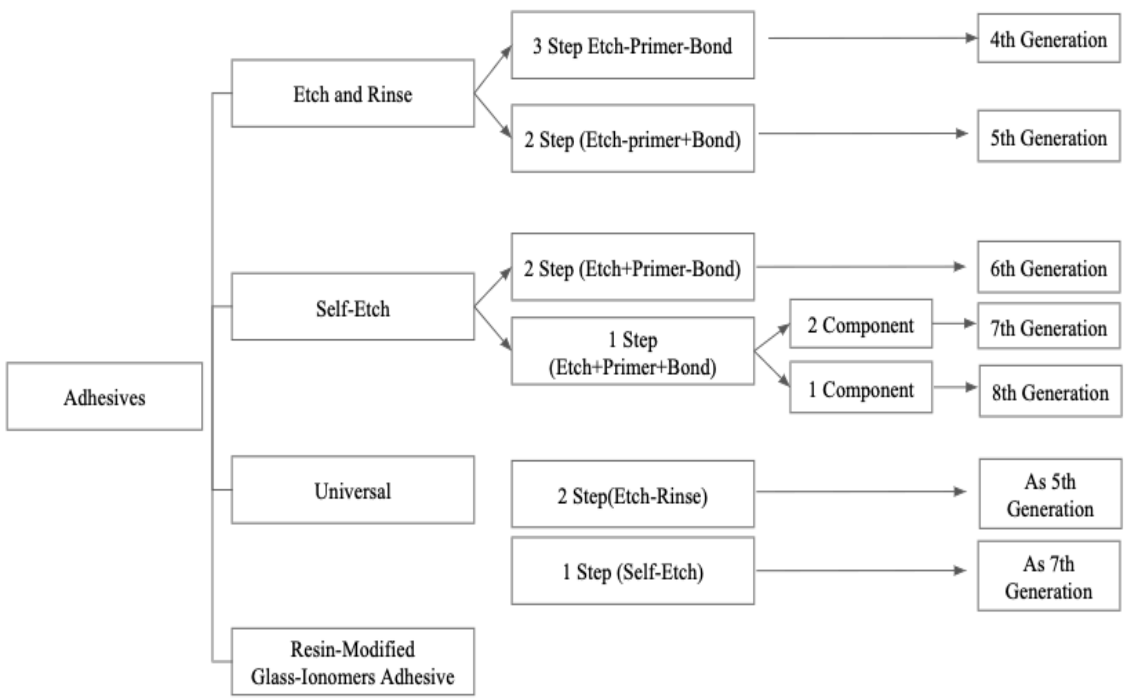
2.3. Classification of Dental Adhesives

- First Generation Bonding Systems - First Generation bonding systems were anticipated as ionic bonding to hydroxyapatite or as covalent bonding to collagen and were published by Buonocore in 1956 (19). Nevertheless, water can reduce this bond.

As a result of this weakness, inferior clinical results were founded for low bond strength within the range of 1-3 MPa (19).

- Second Generation Bonding Systems - Second generation bonding systems use polymerizable phosphates to increase the calcium in tooth structure (20). This generation is not very useful because bonding to the smear layer is too weak. Bond strength is 4-6 MPa (21).
- Third Generation Bonding Systems - Third generation bonding systems partially removed the smear layer with using acid etching of the dentin (19).
- Fourth Generation Bonding Systems - By the late 1980s and early 1990s fourth generation was introduced. Primer, etchant, and bonding are packaged in containers. This generation was the first with the aim of removing the smear layer from the surface (19).
- Fifth Generation bonding systems - The fifth generation helped to reduce the clinical steps. This generation was introduced as being one bottle or one step (22). In the application of this generation, the first step is an etching, and the second is primer and bonding. Bond strength is 3 to 25 MPa.
- Sixth Generation Bonding Systems - In the late 1990s and the early 2000s, the sixth generation was introduced as the “self-etching primers”. This generation was planned to eliminate the etching procedure. There are two bottles; one contains self-etching primers, and the other has adhesive. It is suggested that the components of this generation are mixed together before use (23).

- <u>Seventh Generation Bonding Systems</u> - By the late 1999s and early 2005 seventh generation was introduced. It is known as a one-bottle system that contains the etch, primer, and adhesive. Because of that, mixing is not necessary (24).
- <u>Eight Generation Bonding Systems</u> - In 2010, eight generation which contains nanosized fillers was introduced (25). Nanofillers enhance the penetration of the hybrid layer thickness and resin monomers. Therefore, This helped to improve the mechanical properties of adhesives in this generation (26).



Scheme 1. Classification of adhesive systems(8).

2.3.1. Etch and Rinse Adhesive System

Etch and rinse adhesive systems are the oldest bonding systems introduced in the early 1990s. This system was classified as three or two-step materials according to whether primer and bonding were separated or combined in a single bottle. These systems are the method that provides the most effective and durable adhesion to the enamel. It involves adhesive, acid etching, and primer. Three steps of this system give a hydrophilic surface (27). The major target of etching is to expanse the surface area and bonding area and enhance porosity in dental tissue, called a demineralized area. The primer resin fills the demineralized area, and resin tags expose to penetrate this area (28). After the etching process, micromechanical bonding occurs with infiltration and polymerization of resin monomers into microporous areas (29). Then, the rinse process enhances the accessibility to open the smear plugs and remove the smear layer.

2.3.2. Self-Etch Adhesive Systems

Self-etch adhesive systems were introduced to decrease the clinical chair time and simplify the clinical procedures of adhesion application by eliminating the rinsing phase (30). While it dissolves the smear layer, it does not eliminate this layer; eliminating the rinsing phase significantly decreases the sensitivity of dental tissue during the adhesive application.

Self-etch adhesive systems are classified as two steps or one-step adhesives (31). The first step has a hydrophilic acidic primer, and the second step has hydrophobic resin. One-step self-etch adhesive systems are named all-in-one adhesives which consist of an etchant, primer, and bonding agent in a bottle. In the two-step self-etch system, enamel conditioning, primer, and adhesive resin are separated. As a result of this, self-etch systems prevent discrepancies the depth of etching and resin monomer penetration (28).

Self-Etch adhesives are an aqueous solution of acidic functional monomers whose have higher pH value than other phosphoric acids. As a result of the pH difference, this system are classified as the power of their acidity degree, including a strong (pH ≤ 1), intermediate (pH=1.5), and mild (pH ≥ 2) (32). While mild self-etch adhesives form a demineralized layer on the dentin surface, strong self-etch adhesives demineralize dentin. Mild self-etch adhesives yield fewer post-operative pain by using a smear layer as a bonding substrate (33).

Even though some advantages of self-edge adhesive systems, some researchers show that these systems give less shear bond strengths and demineralization on the enamel tissue when it is compared to the other adhesive systems (34,35).

2.3.3. Universal Adhesive Systems

Universal adhesive systems, were also named as "multi-mode" or "multi-purpose," has been used since 2001 in adhesive dentistry. They may be chosen as each of two as self-etch adhesives and etch rinse adhesives or using self-etch adhesives for dentin surface and using etch rinse adhesives for enamel surface (36).

Universal adhesives differ from self-etch adhesives in terms of their composition, which have carboxylate and phosphate monomers that attach to hydroxyapatite. Universal adhesives produce chemical and microchemical bond strength to the dental structure (37). Methacryloyloxydecyl Dihydrogen phosphate (MDP), found in universal adhesives, is a monomer to help promote strong adhesion to the dental structure by the formation of Ca^{++} salts formed during adhesion in self-assembled nanolayers (38). Combining these new adhesives helps contact the hydrophilic tooth surface and hydrophobic resin material. Some universal adhesives may contain silane in their combination. This silane in formulation eliminates the silanization procedure to bond resin composites and ceramics (39). It also helps resin cements to etch porcelain and optimize overall assembly strength.

2.3.4. Glass Ionomer-Based Adhesives

Glass ionomer-based adhesives were developed in 1965. They were categorized as conventional glass ionomers and resin-modified glass ionomer cements. Glass ionomer material is only self-adhesive systems that bond the resin material and dental tissue without surface treatment (40). These can be caused by chemical interactions of polyalkenoic acids with hydroxyapatite (HAp). They provide fluoride release, mechanical strength, and wear resistance (41). While conventional glass ionomers bond the tooth structure micromechanically, in resin-modified glass ionomers, furthermore, there is a chemical bond among the resin component and the resin of the enamel or adhesive (42).

Some researchers show that resin-modified glass ionomer adhesives have low bond strength in comparison to the other adhesive systems (6). This can be caused by the nominal cohesive strength of the glass ionomer materials (43). Glass ionomers bond seems very well clinically, but they are not resistant to excessive loads (6). Because of that, it is recommended that using glass ionomer adhesive with 10% polyacrylic acid solution provides stronger bonding to dental tissue (44).

2.4. Light Cured Units

Dental light curing units are necessary to start the polymerization process because the polymerization process determines the success of the clinical success of resins. Inadequate polymerization leads to decreasing wear resistance, weakening of mechanical retention, caries, and color instability (45). Light-activated composite resins are preferred because of their easy handling, aesthetics, and physical and mechanical properties. The main disadvantage of them is that they need sufficient polymerization.

The rate of polymerization of the adhesive composite depends on the intensity of the light curing device. Incomplete polymerization causes decreased physical and mechanical adhesion and the color stability of the material (46). In addition, sensitivity after the operation, early failure of the restoration, and toxicity to the pulp can be seen by insufficient polymerization (47). Also, some extrinsic and intrinsic factors may play a role in polymerization. The extrinsic factors are intensity time of the light exposure, intensity of light cure units, light source distance, water or food colorants, and heat. Intrinsic factors are properties of the resin matrix, the residue of double bonds (48).

In the early 1960s, bonding systems became available to provide retention between the tooth and the orthodontic appliances (39). Today, light-cured adhesives are used by the majority of orthodontics. Because these adhesives reduce the contamination risk, provide enough working time, exact bracket placement, and effortlessly eradication of the excess adhesive material during bonding (39).

Ideal light cure units are expected to have some properties. These requirements are; broad emission spectrum, sufficient light intensity, durability, easy-to repair (49).

The light source units are classified as quartz-tungsten halogen (QTH), light-emitting diode (LED) plasma arc curing (PAC), and argon laser units.

2.4.1. Quartz Tungsten Halogen Curing Units

Early in the 1990s, quartz tungsten halogen units were produced instead of the ultra-violet curing unit (50). These lamps produce ultraviolet irradiation and visible light, which emit blue light with a 400-500 nm wavelength range that is within the camphorquinone spectrum (51). Quartz-tungsten halogen curing unit lamps consist of quartz tungsten thread, inert gas, filter, refrigerating system, and optic fibers. Most of these units have tungsten filament halogen lamps which incorporate the blue filter (52).

Quartz tungsten halogen curing units use 99% of their energy capacity to heat the tungsten filament until it shines. Only one percent of energy converts to the light (53). QTH heats the tungsten filament to 2700 °C. During this process, the blistering of light filters and discoloration of reflectors can be seen because of heat production (52).

The disadvantages of quartz tungsten halogen curing units are that they have very high heat, causing loss of high energy and short-curing depth (52).

2.4.2. Plasma Arc Curing Units

Plasma arc curing units are a curing system that was planned as high-speed curing light and cheaper in the 1990s (52). Light is emitted from an electricity-conductive gas in these curing units. The PAC lamps have high light intensity and a narrow spectrum, which provide a reduction of curing time (52,54).

Plasma arc curing units allow short-term exposure with high irradiance. Some manufacturers show that three-second exposure with PAC light is almost equal to 30-45 seconds of exposure with QTH (54). On the contrary, short curing time may cause inadequate polymerization, insufficient marginal filling (55). Also, PAC devices are much more expensive than QTH devices (56).

Signorelli et al. (57) reported that a plasma arc system with a curing time of six seconds has a bond fracture and bond strength similar to that of the halogen light cure systems with a curing time of twenty seconds. Yusoff et al. (58) found no significant difference under shearing pressure when you bonded orthodontic brackets using the light emitting diode system through curing at 0°, 45°, and 90° angle. Oesterle investigated that Plasma arc units improve the SBS of orthodontic brackets with curing time. They studied with halogen light for 40 seconds and plasma arc curing for 3, 6, and 9 seconds. Also, they found no significant difference between halogen light and plasma arc units when comparing the bond strength of orthodontic brackets.

2.4.3. Light-Emitting Diode Curing Units

Light-emitting diode (LED) curing units are produced to eliminate the disadvantages of QTH curing units (54). Different LED curing units continued to evolve over the years.

The spectral output of LEDs resides within the absorption spectrum of camphorquinone photoinitiator. Because of that, LED units do not need filters to produce blue light. Nevertheless, there is no decrease in the light power of the LED systems. LED units can be used for thousands of hours (59). They make low power consumption, causing minimal heat, and resistant to vibration (60,61).

In 1999, the first generation of Led units started to be used. They had low power energy, which required 60 seconds for curing times (62). In the second generation, the main difference was mini chips which produce more power output and adequate irradiance (62). The third generation emits different and identical wavelengths. Also, this generation has important advances in orthodontic and restorative practice due to the shortening of the curing time (62).

Tarle et al. (63) observed QTH showed a higher conversion value than PAC and LED. However, Yoon et al. (64) investigated that PAC and LED were not significantly different from QTH while the same light energy was applied. Bouillaguet et al. (65) reported that LED units convert energy to light better than QTH units. Also, they found that the wavelength of light emitted by LED pairs with the absorption spectrum of camphorquinone. Hofmann et al. (66) investigated that the amount of heating released due to irradiation is more with LED units compared to QTH units.

2.4.4. Argon Laser Curing Units

In the early 1990s, argon laser curing units were introduced as versatile multiwavelength lasers. It has been used for cyst removals and soft tissue procedures of buccal mucosa and gingival tissues (67).

Argon laser curing units emit blue and green light in wavelengths between 450 and 500 nm (68). Blue light laser provided significantly higher efficacy in polymerizing dental composite resins. This blue light has the highest energy photons of the wavelength of visible light (68).

Powell et al. (69) indicated that SBS was increased significantly in both dentin and enamel after polymerization with argon laser curing units. In another study, Anić et al. (70) demonstrated that temperature increased when argon laser units were used to cure composite resins. Noel et al. (71) found that argon laser units possibly help adequate reduction in the demineralization area. Talbot et al. (72) studied whether argon laser curing units increase bond strength in respect of laser energies. They discovered that argon laser units could polymerize orthodontic adhesives faster with higher bond strength in all tested energy levels with no statistical significance in between.

2.5. Adhesion in Orthodontics

Ideal orthodontic adhesive systems should have adequate bond strength due to be able to stand stronger against chewing and orthodontic forces (73). After the demonstration of phosphoric acid by Buonocore (1) in 1955, adhesion between orthodontic appliances and dental tissue became more durable. He planned an enamel surface strengthened to increase micro-mechanical adhesion as a result of the penetration of resin to microporosities of acid-exposed enamel (1).

Various removable and fixed appliances were used to solve the malocclusions and dental problems in orthodontic treatment. Most used fixed appliances were brackets attached to teeth with different adhesive materials. Traditionally, brackets had been clamped to dental tissue mechanically. Nowadays, dental adhesive systems are widely used due to their many advantages (74). Detachment of brackets resides as the major concern, and an appropriate bonding procedure of brackets is essential for a successful orthodontic treatment (75–77).

Moreover, debonding of brackets causes damage to dental tissue, increased treatment time, and increased chair time (78). For this reason, adhesive systems are essential in orthodontic treatment.

Several generations of adhesive systems were introduced as orthodontic adhesives with different properties. These advancements in adhesive systems helped orthodontists to treat patients efficiently, predictably, and effectively (74). Orthodontists can use either the light-cured composite or chemically attach the brackets to dental tissue. While chemically-cured composite resins have some disadvantages, such as mixing and limiting curing time, light-cured composite resins enable controlled polymerization time, easily removing excess adhesive. Recent advances of light curing systems, duration of curing time was reduced by increasing light power density (79).

Adhesive systems are expected to have adequate bond strength. However, high bond strength may cause enamel fracture and pulpal damage during the bonding procedure (80). Normal range for bond strength was reported as 6-8 MPa for orthodontic purposes (81). When the bond strength is more than 13.5 MPa, enamel fracture can be seen (82).

Demineralization or white spot lesions can be seen around orthodontic brackets during treatment which is caused by poor oral hygiene. Enamel decalcification can occur four weeks after orthodontic treatment (83). Gorelick et al. (84) reported that after the removal of bonded orthodontic appliances, white spot lesions were seen with 50% of the patients on at least one teeth. To prevent white spot lesions, orthodontic adhesives were developed with anti-cariogenic properties. Fluoride-releasing composite resins and resin-modified glass ionomer cements are widely used by orthodontists. Glass ionomer cements have adequate bond strength but fluoride-releasing performance is not good (85). Compared to resin-modified glass ionomer resins, fluoride-releasing composite resins have been shown to decrease white spot lesions (86). Derks et al. (85) reported that bonding materials, including fluoride had no effect on preventing demineralization. Also, a white spot lesion can be seen on the buccal side of the teeth, and orthodontists need to change the bracket position. As a result of white spot lesions on the buccal side, a decrease on the shear bond strength of brackets takes place (87).

2.6. Shear Bond Strength in Orthodontics

In orthodontic treatment, teeth alignment occurs due to the orthodontic forces. These orthodontic forces spread from the orthodontic appliances to teeth. For the realization of this force, it is expected that orthodontic adhesives be stable, have excellent bond strength, attain enough flow for penetration to the dental tissue surface, and easily apply (88).

To achieve sufficient bond strength, adhesive systems must resist functional and treatment forces during orthodontic treatment. To achieve successful direct bonding, there is a procedure involves four main steps, which are cleaning, enamel conditioning, sealing, and bonding (89). A well-prepared enamel surface is necessary for good bond strength. Enamel pellicles and residues should be removed from the tooth surfaces after preparation. This process, called enamel conditioning, can be provided with acid etching or sandblasting (1,90). However, researchers indicated that it causes lower bond strength than conventional acid etching (91). Nevertheless, as mentioned before, although bond strength is crucial to bond orthodontic appliances, more than sufficient bond strength can cause unwanted damage to the enamel surface. The bracket debonding process should be harmless to tooth tissue. Therefore, an acceptable range of bond strength is essential to minimize debonding complications (92,93).

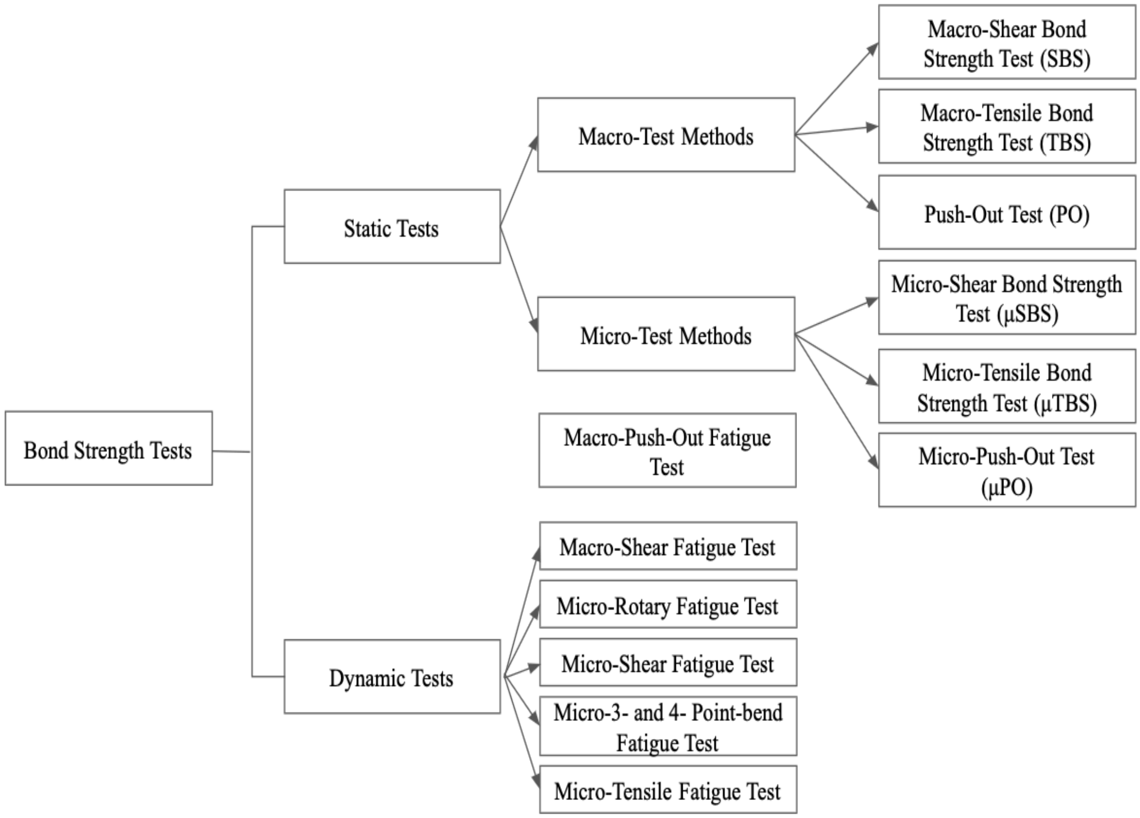
2.7. Shear Bond Strength Evaluation Methods

With the development of newer technologies, the number of new adhesive materials has increased daily. The tensile and shear bond strength tests are performed to evaluate these adhesive materials to choose the better one (94). The results of the evaluation can be influenced by passing the time between bonding and debonding, exposure to heat, etchant concentration, contamination during the bonding procedure, the properties of adhesive systems, type of curing light system, type of bracket, and the cleaning of teeth surface (34,95–98).

In vivo research is another evaluation method. However, *in vivo* evaluation of bond strength can be affected by different factors (99). These factors are the risk of blood and saliva contamination, stress caused by mastication and occlusion force, decreased adhesion due to saliva and the temperature exchange caused by food and drinks, contamination during the bonding procedure, the properties of adhesive systems, and curing light system (99).

Although the conditions are not similar to the oral environment, *in vitro* studies produce reliable evaluation results of adhesive materials introduced (100). Ferreira et al. (101) showed that there is statistically no significant difference between *in vitro* and *in vivo* studies in terms of the shear bond strength of the different adhesive systems. Whereas Pickett et al. (102) observed significantly lower shear bond strength *in* vivo conditions than *in vitro*. However, universal testing machines are used to evaluate the shear bond strength of adhesive materials *in vitro*. This machine can be used to compare orthodontic adhesives with each other. Compared to the other devices, the use of universal testing machine is much easier and has good control over study design (101).

As mentioned before, bond strength can be evaluated in the laboratory or clinically. Static and dynamic methods are part of laboratory bond strength testing (Scheme 2). When the bond area is more significant than 3 mm^2, the macro bond strength test can be calculated by shear, tensile or push-out protocol. Micro bond test methods are selected when the bond area is less than 1 mm^2 (1,103).



Scheme 2. An outline of bond strength testing methods (104).

2.7.1. Static Tests

2.7.1.1. Macro Test Methods

Macro test methods are classified as shear, tensile, and push-out test methods.

2.7.1.1.A. Macro Shear Bond Strength Test:

In the early 1960s, the macro shear bond strength method was investigated by Bowen (105,106). This method measures the shear bond strength of newly released dental adhesives. When it is desired to admeasure the bond strength of a material, the maximum stress that material can combat is produced until failure in the shear mode of loading (107).

Micro shear bond strength test is the fastest and more straightforward test method as it requires no extra testing after evaluating the shear bond strength of a material (108).

However, when the material with improved bond strength is admeasured with a shear bond strength test, it has been observed that the measurement results change due to cohesive failures in the substrate. This is because the stress was concentrated in the tooth surface (109).

2.7.1.1.B. Macro Tensile Bond Strength Test:

The macro tensile bond strength (TBS) test is used less frequently than the macro shear bond strength. It is widely used to evaluate bonding between ceramics or metal alloys to cement tissue (110).

Unlike other bond strength tests, the stress is more evenly distributed in the SBS tests. Because of this distribution, TBS tests give more reliable results when the shear bond is evaluated in hard materials that bonded cement tissue (111). In addition, bonded material should be placed perpendicular to the tensile machine; otherwise, bending stress will be released (104).

2.7.1.1.C. Push-out Test:

The push-out (PO) test calculates the fatigue resistance between dental tissue and adhesive. It is widely used to test the adherence of root canal sealers and the confinement of endodontic posts (112,113). Because the PO test relies on creating shear stress at the interface amid cement and dentin tissue (114).

To calculate the bond strength with PO test, 1-2 mm thick pieces of dentin tissue can be removed to yield a tapered cylindrical hole. The adhesive material to be evaluated is applied to the inner surface of the cylindrical cavity, and then the adhesive composite is loaded into the hole. After that composite cylinder is pushed into the dentine, and bond strength is calculated with a PO test (115). As a result of including part of the cured composite, this test method gives more reliable results than the conventional shear bond test (116). However, the PO test was never used as a universal bond strength test method (104).

2.7.1.2. Micro-Test Methods

Micro-test methods are classified into micro shear, micro tensile, and micro push-out test methods.

2.7.1.2.A. Micro-Shear Bond Strength Test

The micro-shear bond strength (μSBS) test is mostly preferred on small tooth surfaces (117). This test is used to evaluate the features including glass ionomers or dental tissue (118,119). Multiple specimens from the same tooth and different substrates are prepared to be evaluated by the μSBS test. Microcracking in the specimens can be seen without the involvement of the trimming process (118,120).

Also, the same failures seen in macro-shear bond strength are more likely to occur in micro-shear bond strength.

These are;

- Tensile stresses caused by bending force,
- The stress distribution is even more prominent compared to the SBS test,
- Measured bond strength, which underestimates the true stress the specimen resisted at the fracture.(121)

Placido et al. (122) reported that the conventional SBS test represented more efficient shear bond strength than μSBS tests. This discrepancy was associated to the comparably thicker adhesive layer and the application of loading farther from the adhesive bond.

2.7.1.2.B. Micro-Tensile Bond Strength (μTBS) Test

In 1994, a micro-tensile bond strength test was invented by Sano et al (123). Adhesive resins are placed on the full occlusal surface of teeth. Then all specimens are cured and stored in water. After that, Specimens are sectioned perpendicularly into multiple serial sections using a diamond saw. Each section has both resin composite and dentin tissue. To reduce stress in the cross-sectioned area, an hourglass shape form is given with a diamond bur (124).

The main drawback of the μTBS test is that sectioning after the bonding process makes this method more difficult, causing dehydration in some specimens and requiring sensitive work. Also, when bond strength is lower than 5 MPa, specimens may be damaged, and their geometric structure may be distorted (125,126).

The advantage of this method is that it has better control over the specimens, economic, and has minimal stress distribution. The biggest drawback is that it has good stress distribution when the bonded surface is around 1 mm^2. As a result of this, this method can avoid the failures of materials caused by adhesive bond (125,126).

2.7.1.2.C. Micro-Push-out (μPO) test

The micro-push-out test used to admeasure the bond strength of fiber posts is a adjustment of the PO test. It involves dentin specimens whose thickness are less than or equal to 1 mm^2 (127). Castellen et al. (128) investigated the bond strength between fiber posts and root dentin using four methods: hourglass microtensile, push-out, modified push-out, and pull-out. Among them, the pull-out method demonstrated the highest value of bond strength. This is followed by a modified push-out. Push-out method, on the other hand, displayed the highest cohesive failure frequency.

2.7.2. Fatigue Tests

A static bond strength test is not used very often because fast loading of the adhesives is not common in the clinic. Therefore, fatigue tests better anticipate the clinical success of dental adhesive systems results. Few fatigue tests have been used in the latter years since these tests are time-consuming and labor-intensive compared to static bond strength tests. Also, these are generally used to bond adhesive systems to dentin since it is more challenging to evaluate bonding to enamel in fatigue (129).

Some fatigue tests are;

- Macro-push-out fatigue test (130),
- Macro-shear fatigue test (131),
- Micro-rotary fatigue test (132),

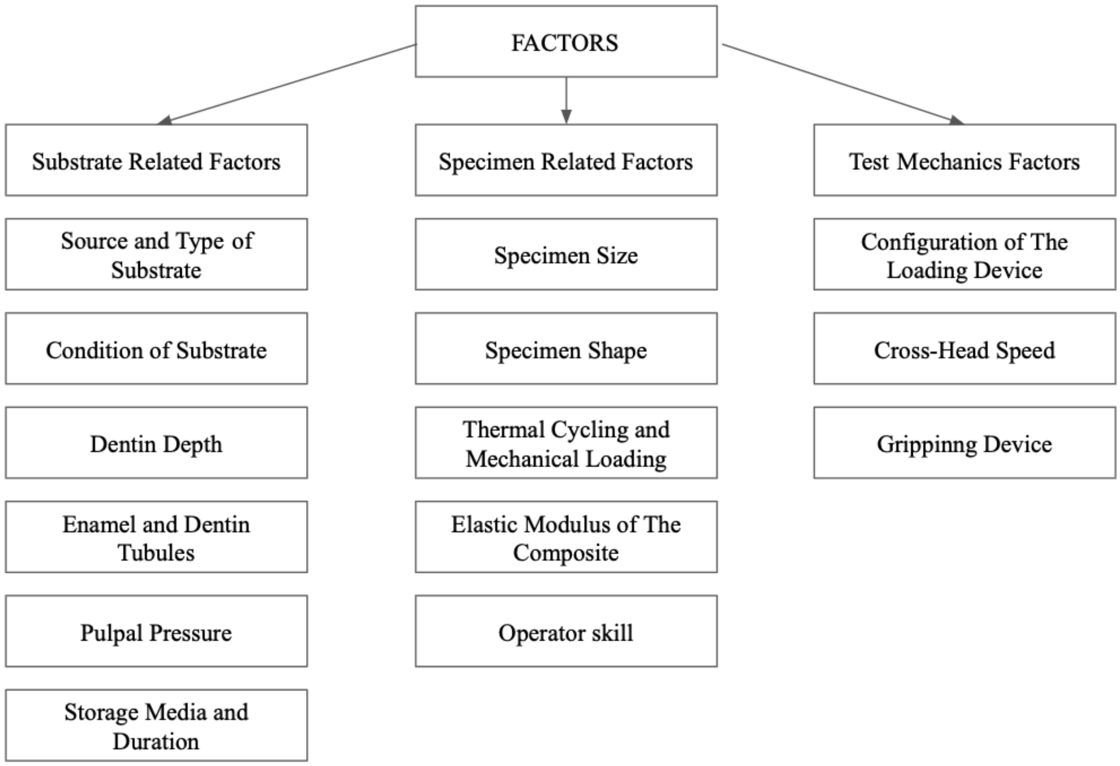
- Micro-shear fatigue test (122),
- Micro 3 and 4 point bend fatigue test (133,134),
- Micro-tensile fatigue test (135).

2.8. Bond Durability Assessment

The long-term durability of the adhesive system is essential for the success of the treatment. Recently, clinicians have preferred to evaluate their adhesive systems with *in vitro* tests. Many researchers showed that bond strength tests in the laboratory might not predict the effectiveness of adhesive clinically due to divergence in bond strength values between every research institute (136). The bond strength of some adhesive materials decreases effectiveness over time, whereas the others are more stable against environmental conditions (103).

Some researchers added 'aging' terminology to study methodology. These aging factors are thermocycling and water storage (104). Makishi et al. (137) investigated that three months in water storage, all adhesive materials showed a degradation in their structure due to aging factors.

2.9. Factors Affecting Bond Strength Measurements



Scheme 3. Factors affecting bond strength measurements (115).

2.9.1. Substrate Related factors

2.9.1.1. Source and Type of Substrate

Bovine teeth are preferred more as a specimen than human teeth due to the difficulty of teeth collection (138). Bovine teeth have larger dentinal tubules on the coronal surface than human teeth. Also, root dentin and pulp of bovine teeth have a different structures than human teeth (139). Therefore, a similar surface to human teeth should be selected when studying bovine teeth.

Ozturk et al. (140) showed that the results were significantly different between upper and lower teeth compared to shear bond strength. Moreover, they found that bond strength was altered by tooth type and adhesive system.

2.9.1.2. Condition of Substrate

Third molars are often selected to evaluate the bond strength of different adhesives, but these teeth are more absorptive and wetter than erupted teeth. Moreover, sclerotic dentin can be seen in restored teeth, carious teeth, abraded lesions (139). The success of bonding to sclerotic dentin is a challenge to overcome since tubules in the dentin are generally filled with mineral crystals (141).

2.9.1.3. Dentin Depth

The shear bond strength of dental adhesives is more likely to decrease at deeper dentin surfaces with increased permeability (142). Samimi et al. (143) investigated that the use of hydrophilic adhesive systems has been successful when it is necessary to reduce the sensitivity caused by adhesive systems at deeper dentin surfaces. In addition, in a study conducted on three different dentin surfaces with four different adhesives, the best result was obtained in superficial dentin, and the worst result was obtained in the deeper dentin according to bond strength (142).

2.9.1.4. Enamel Prisms and Dentinal Tubules

The structural feature of enamel and dentin can affect the retention of adhesive materials. Carvalho et al. (144) studied the enamel surface and found that the tensile of enamel can be affected by enamel's prismatic orientation. Another study showed that the properties of the adhesive material have a more pronounced effect on bonding to the enamel having a prismatic structure (145). Ikeda et al. (146) found that the µTBS test showed lower results when the specimen was cut perpendicularly to its long axis than in the parallel direction.

In addition, the structure of dentin is also an essential factor in reflecting the properties of adhesive materials. Eick found that bonding to the enamel can be more successful with using adhesive material, which is capable of wetting properties (147). For strong bonding to dentin, the adhesive material monomers should penetrate demineralized dentin tubules (148).

2.9.1.5. Pulpal Pressure

Pulp fluid flows from the pulp tissue through the dentinal tubules to the junction of dentin and enamel. Hegde et al. (149) found that this flows from the pulpal tissue affects the adhesion success by penetrating the structure of the adhesive material used. Another study showed that long-term flow from the pulpal tissue has a significant effect on reducing the success of adhesive materials (150).

2.9.1.6. Storage and Duration

Extracted teeth are usually stored in an aging media containing; distilled water, artificial saliva, and sodium hypochlorite (151). Other storage solutions contain glutaraldehyde, alcohols; ethanol and methanol, distilled water with thymol, and formalin (152). The main feature of storage solutions is that they prevent the growth of microorganisms and dehydration of teeth (153). However, Lee et al. (154) stated that aging media that contains sodium hypochlorite yield significantly lower bond strength than in solutions of distilled water, sodium chloride, chloramine-T, glutaraldehyde, and formalin after fourteen days. In addition, each solution can affect dentin surface moisture in different ways (155).

Storage time is also one of the critical factors affecting the bond strength of adhesive materials. De Munck et al. (156) reported that the resin-dentin bond resulted in water degradation following four years of water storage. However, another study demonstrated that six months of storage in water does not play a significant role on bond strength with using the µTBS method (151). On the contrary, when formalin and thymol solutions were chosen as storing solutions for six months, bond strength was drastically affected negatively due to the dissolution of the smear layer (157).

2.9.2. Specimen Related Factors

2.9.2.1. Specimen Size

The surface area of the specimen plays an essential role in the bond strength. Shono et al. (158) observed that the bond strength decreased when the study was carried out on the increased surface area. In addition, it is susceptible to research the micro-specimens. Phrukkanon et al. (159) observed that bond strength reduced when the bonding area was increased.

2.9.2.2. Specimen Shape

Specimen shape is another factor that affects bond strength. Various micro-specimen protocols are generally preferred to yield various specimen shapes, including; trimmed or non-trimmed specimens (160). Due to less destructive, user-friendly, and more accurate preparation, stick-shaped, non-trimmed specimens are generally preferred. Trimmed micro-specimens at the interface to hourglass-shaped specimens, on the other hand, yields higher stress concentration at the interface (160,161). It should be noted that if the trimming is not performed correctly, it will cause increased mechanical stress and attrition, yielding tooth cracks and interface failures (161,162). Furthermore, trimming mainly depends on the handling of the operator. Therefore, the use of semi-automatic trimming of micro-specimens through the application of Micro Specimen Former is recommended (162).

2.9.2.3. Thermal Cycling and Mechanical Loading

Deterioration stress occurs between the dental tissue and the adhesive material due to temperature changes in the oral environment (163). The recommended thermocycling frequency is 500 cycles according to ISO/TS specification for reliable results (115). Pitchika et al. (164) investigated that thermocycling causes a decrease in bond strength on dentin and enamel. Also, they stated that the effect is dependent on the adhesive materials.

2.9.2.4. Elastic Modulus of The Resin Composite

The elastic modulus of adhesive composites is essential in reducing stress distribution. Increased stress distribution causes the failure of the restoration and fixed orthodontic appliances (165).

2.9.2.5. Operator Skills

Operator material handling and the usage of testing apparatus were reported to play a vital role in the end result of the bond strength testing. This variation can be avoided by repetition of bind strength tests and materials (166).

3. MATERIALS AND METHODS

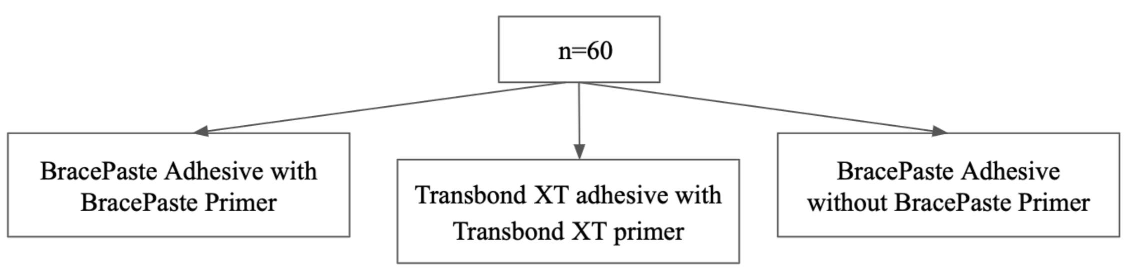
3.1. Selection of Groups

Three main groups were selected to evaluate the shear bond strength of different adhesives. In two groups, primer and adhesives were applied, while the last group only used adhesive.

- Group A - Transbond XT Adhesive and Transbond XT Primer with 37% orthophosphoric acid
- Group B - BracePaste Adhesive and BracePaste Primer with 37% orthophosphoric acid
- Group C - BracePaste Adhesives with 37% orthophosphoric acid

3.2. Sample Size

According to the statistical power analysis (G*power version 3.1) performed with the aim of determination of the sample size of our study with 0.05 alpha error probability, the SBS scores effect size of the groups were set as 0.48; and as a result of sample size analysis with the power value of 0.80, the sample size of each group was determined to be fifteen. The total sample size of our study is sixty.



Scheme 4. Sample size for each experimental group.

Figure 1. Bovine teeth before bonding.

Figure 2. Transbond XT adhesive and primer.

Figure 3. BracePaste adhesive and primer.

3.3. Preparation for Transbond XT

In this group, twenty extracted bovine teeth with the absence of caries cracks were selected. Remnants and debris were removed with a dental scaler. Nonfluorinated pumice was used to remove debris and saline from all selected bovine teeth. After that, all the samples were preserved in distilled water for one week. Then all teeth were cleansed with water and air-dried. After that, 37% orthophosphoric acid was used for 15 seconds to treat the Buccal surface of each tooth, later rinsed with water for 30 seconds and dried with air for 10 seconds. After etching, the enamel had an opaque appearance. Transbond XT Primer (3M Unitek, Monrovia, CA, USA) was applied using a micro-brush. Valo Ortho Cordless Curing Light was applied for 3 seconds on each tooth. After that, Transbond XT Light Cure Adhesive Paste (3M Unitek, Monrovia, CA, USA) was used to apply to the Mini master series upper central brackets (American Orthodontics, Mini master series, 0.22 slot). The metal brackets were laid on the prepared teeth' surface, positioned to where they had to be, and pressed tightly. The residues occurred following the pressure was removed with an explorer. Valo curing unit (Ultradent Products Inc., South Jordan, UT, USA) was applied to each tooth for

3 seconds. Specimens were stored in distilled water after bonding and stored in the drying oven for 24 hours. All teeth we selected were embedded in an acrylic block.

3.4. Preparation for BracePaste with Primer

In this group, twenty extracted bovine teeth with the absence of caries cracks were selected. Remnants and debris were removed with a dental scaler. Nonfluorinated pumice was used to remove debris and saline from all selected bovine teeth. After that, all the samples were preserved in distilled water for one week. Then all teeth were cleansed with water and air-dried. After that, 37% orthophosphoric acid was used for 15 seconds to treat the Buccal surface of each tooth, later rinsed with water for 30 seconds and dried with air for 10 seconds. After etching, the enamel had an opaque appearance. BracePaste Primer (American Orthodontics) was applied using a micro-brush. Valo Ortho Cordless Curing Light was applied for 3 seconds on each tooth. After that, BracePaste Light Cure Adhesive Paste (American Orthodontics) was used to apply to the Mini master series upper central brackets (American Orthodontics, Mini master series, 0.22 slot). The metal brackets were laid on the prepared teeth' surface, positioned to where they had to be, and pressed tightly. The residues occurred following the pressure was removed with an explorer. Valo curing unit (Ultradent Products Inc., South Jordan, UT, USA) was applied to each tooth for 3 seconds. Specimens were stored in distilled water after bonding and stored in the drying oven for 24 hours. All teeth we selected were embedded in an acrylic block.

3.5. Preparation for BracePaste Adhesive without Primer

In the last group, twenty extracted bovine teeth with the absence of caries cracks were selected. Remnants and debris were removed with a dental scaler. Nonfluorinated pumice was used to remove debris and saline from all selected bovine teeth. After that, all the samples were preserved in distilled water for one week. Then all teeth were cleansed with water and air-dried. After that, 37% orthophosphoric acid was used for 15 seconds to treat the Buccal surface of each tooth, later rinsed with water for 30 seconds and dried with air for 10 seconds. After etching, the enamel had an opaque appearance. BracePaste Light Cure

Adhesive Paste (American Orthodontics) was used to apply to the Mini master series upper central brackets (American Orthodontics, Mini master series, 0.22 slot). The metal brackets were laid on the prepared teeth' surface, positioned to where they had to be, and pressed tightly. The residues occurred following the pressure was removed with an explorer. Valo curing unit (Ultradent Products Inc., South Jordan, UT, USA) was applied to each tooth for 3 seconds. Specimens were stored in distilled water after bonding and stored in the drying oven for 24 hours. All teeth we selected were embedded in an acrylic block.

Figure 4. Samples after polymerization.

3.6. Adhesive Systems Used

3.6.1. Etch and Rinse Adhesive System

To apply etch and rinse adhesive system, first of all, the teeth that we will use for research were cleansed with water. 37% orthophosphoric acid was used for 15 seconds to treat the Buccal surface of each tooth, later rinsed with water for 30 seconds and dried with air for 10 seconds. Transbond XT Primer and Transbond XT Adhesive (3M Unitek, Monrovia, CA, USA) were applied on the tooth surface. The metal brackets were laid on the prepared teeth' surface, positioned to where they had to be, and pressed tightly. The residues occurred following the pressure was removed with an explorer. To polymerize the samples, Valo curing unit (Ultradent Products Inc., South Jordan, UT, USA) was applied for 3 seconds.

3.6.2. Light Curing Units

In this study, Valo Ortho Cordless Curing Light which has 3200 light intensity (mW/cm^2) and 395-480 wavelength(nm) (Ultradent Products Inc., South Jordan, UT, USA), was used (mW/cm^2) to polymerize specimens on each group. Valo Ortho Cordless Curing Light was positioned close to the bracket and polymerized in extra power mode.

Figure 5. Valo Ortho Cordless curing unit.

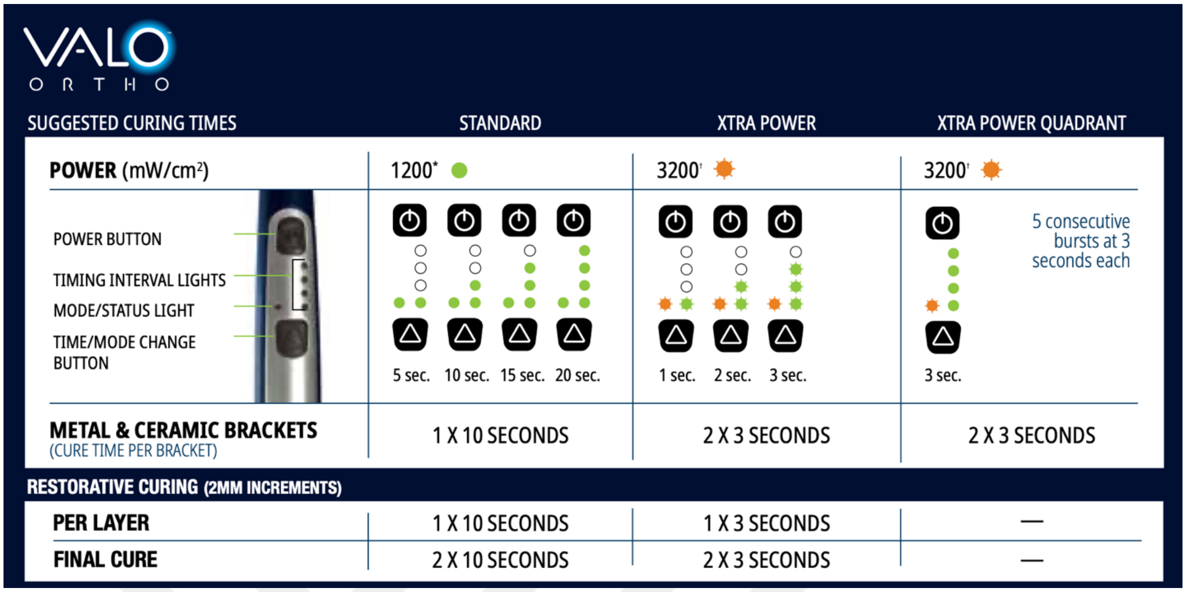


Figure 6. Valo Ortho Cordless curing light instructions.

Table 2. List of studied adhesive systems.

Material	Description	Composition
Transbond XT Primer (3M Unitek, Monrovia, CA, USA)	Conventional Adhesive Primer	Bisphenol A Diglycidyl Ether Dimethacrylate (BIS-GMA) Triethylene Glycol Dimethacrylate 4-(dimethyl amino)-benzene ethanol DL-Camphorquinone Hydroquinone
Transbond XT Light Cure Adhesive (3M Unitek, Monrovia, CA, USA)	Conventional Adhesive Adhesive	Silane Treated Quartz Bisphenol A Diglycidyl Ether Dimethacrylate (BIS-GMA) Bisphenol ABis(2-Hydroxyethyl Ether) Dimethacrylate Silane Treated Silica Diphenyliodonium Hexafluorophosphate
BracePaste Primer (American Orthodontic)		BIS-GMA and BIS-EMA particles Ethoxylated Bisphenol A dimethacrylate Tetramethylene Dimethacrylate Diphenyl(2,4,6-trimethylbenzoyl phosphine oxide
BracePaste Adhesive (American Orthodontic)		Silanated Quartz Silanated Silica

3.7. Statistical Analysis

Statistical analysis of our study was done with NCSS (Number Cruncher Statistical System) 2007 Statistical Software (Utah, USA) package program.

In the data evaluation, the distribution of variables was investigated using the Shapiro-Wilk normality test, besides the descriptive statistical methods, such as mean, standard deviation, median, and interquartile range. To evaluate the repetitive measurements of variables with normal distribution, one-way variance analysis in Tukey multiple comparison tests was applied in subgroup comparisons. Results were evaluated at the $p < 0.05$ significance level.

4. RESULTS

Shear bond strength results of brackets bonded with Transbond XT Adhesive with Primer and BracePaste using Valo curing unit with or without BracePaste Primer are indicated in Table 3.

Table 3. Mean and standard deviation of shear bond strength values for Transbond XT.

Transbond XT	**MAX. STR (MPa)**	**MAX. LOAD (N)**
1	12.07178	162.24474
2	9.17957	123.37346
3	11.88018	159.66965
4	11.29314	151.77983
5	12.29600	165.25822
6	9.59179	128.91362
7	13.27597	178.42897
8	13.69720	184.09036
9	7.85578	105.58163
10	13.89680	186.77299
11	11.03747	148.34360
12	11.74801	157.89320
13	11.55712	155.32770
14	13.45092	180.78043
15	12.16991	163.56358
16	11,46170	154.04523
17	13.84444	186.06927
18	12.89261	173.27673
19	12.71001	170.82254
20	8.67538	116.59711
Average	**11.72929**	**157.64164**
Standard Deviation	**1.74027**	**23.38923**

Table 4. Mean and standard deviation of shear bond strength values for BracePaste with BracePaste Primer.

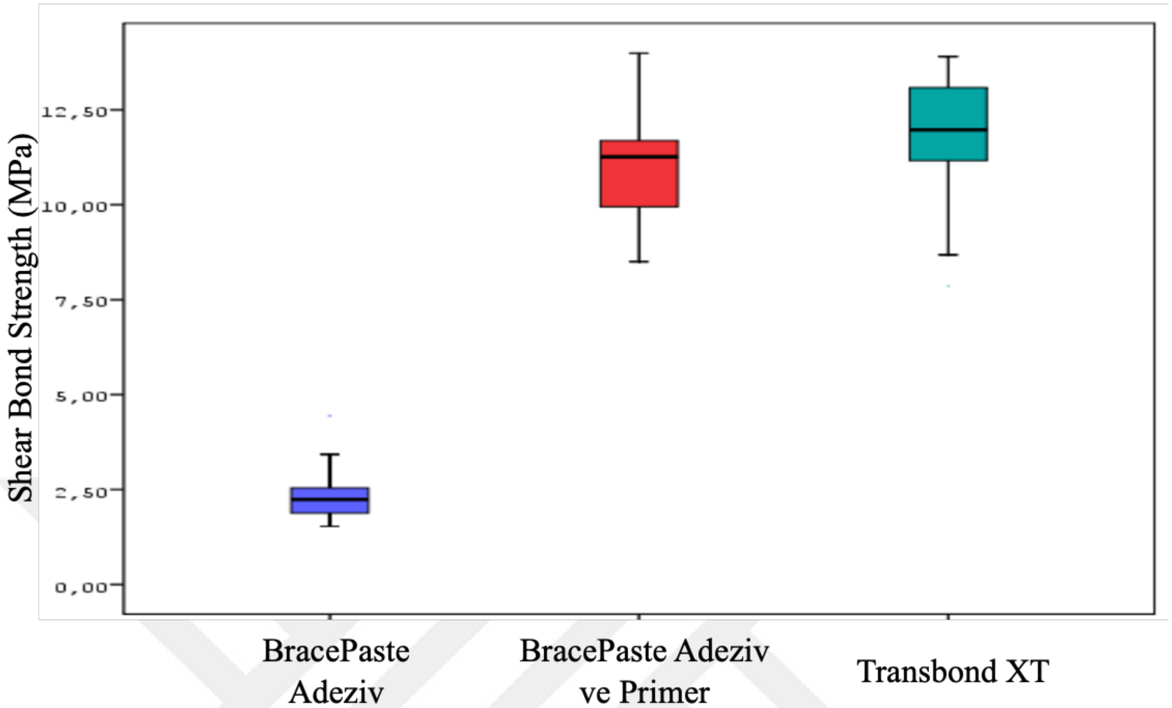
BracePaste with primer	**MAX. STR (MPa)**	**MAX. LOAD (N)**
1	8.84123	118.82615
2	11.63009	156.30840
3	8.50236	114.27177
4	11.66110	156.72513
5	13.99065	188.03436
6	9.46644	127.22890
7	10.01786	134.64001
8	9.72642	130.72304
9	11.40984	153.34822
10	10.31791	138.67265
11	13.35698	179.51779
12	11.16697	150.08409
13	9.89461	132.98360
14	11.34705	152.50429
15	12.69607	170.63513
16	10.88484	146.29224
17	10.56306	141.96754
18	11.57025	155.50417
19	11.72080	157.52757
20	13.52812	181.81792
Average	**11.11463**	**149.38065**
Standard Deviation	**1.50836**	**20.27236**

Table 5. Mean and standard deviation of shear bond strength values for BracePaste without BracePaste Primer.

BracePaste without primer	MAX. STR (MPa)	MAX. LOAD (N)
1	4.45032	59.81229
2	1.92224	25.83492
3	4.42902	59.52598
4	1.75584	23.59855
5	1.53497	20.62998
6	1.78788	24.02905
7	2.08814	24.02905
8	2.65358	35.66408
9	2.51242	33.76687
10	1.72857	23.23204
11	1.83698	24.68894
12	2.08035	27.95991
13	2.25059	30.24798
14	1.93190	25.96477
15	2.46899	33.18329
16	2.53886	34.12222
17	2.22633	29.92119
18	2.22832	29.94858
19	2.32330	31.22511
20	3.43422	46.15594
Average	**2.40914**	**32.37885**
Standard Deviation	**0.81208**	**10.91436**

The shear bond strength of the three groups was analyzed with the Universal test machine. Our study indicates no statistically significant difference between Transbond XT Adhesive with Transbond XT Primer and BracePaste Adhesive with BracePaste Primer has been found in terms of shear bond strength at the $p<0.05$ significance level. When comparing BracePaste Adhesive with BracePaste Primer to BracePaste Adhesive without BracePaste Primer, there is a statistically significant difference between them at the $p>0.05$ significance level.

Figure 7. Instron 3345 (Universal Testing Machine).



Scheme 5. Bar graph of shear bond strength in MPa for Transbond XT Adhesive with primer, BracePaste Adhesive with BracePaste Primer and BracePaste Adhesive without BracePaste Primer.

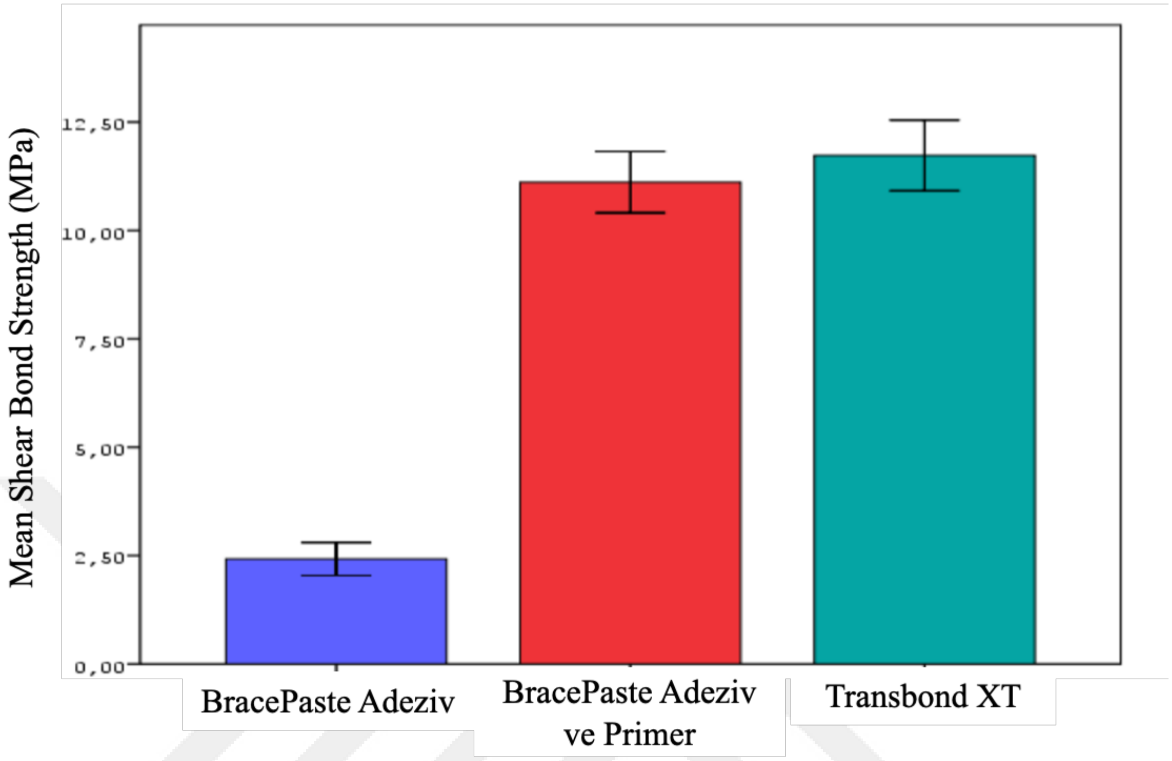
The shear bond strength was measured for sixty samples in three groups. Transbond XT Adhesive with primer group showed a mean SBS of 11.73 ± 1.74 MPa, BracePaste Adhesive with BracePaste Primer group showed a mean SBS of 11.11 ± 1.51 MPa, and BracePaste Adhesive without BracePaste Primer group showed a mean SBS of 2.42 ± 0.81 MPa. The standard deviation values and mean shear bond strength values are shown in Table 6.

Table 6. Mean difference of shear bond strength ± STD values (MPa).

	N	**Shear Bond Strength ± STD (MPa)**	**Median**	**Min.**	**Max.**
Transbond XT	20	11.73 ± 1.74	11.98	7.86	13.90
BracePaste with primer	20	11.11 ± 1.51	11.26	8.50	13.99
BracePaste without primer	20	2.42 ± 0.81	2.24	1.53	4.45

Table 7. Tukey Multiple Comparison Test

Tukey Multiple Comparison Test	**p value**
BracePaste with BracePaste Primer/ Transbond XT	0.357
BracePaste with BracePaste Primer/ BracePaste without Primer	0.0001



Scheme 6. Graphical view of mean shear bond strengths (MPa) of Transbond XT Adhesive with primer, BracePaste Adhesive with BracePaste Primer, and BracePaste Adhesive without BracePaste Primer.

When the shear bond strength results in the three groups are analyzed, there is a statistically significant difference among shear bond strength scores of Transbond XT, BracePaste with primer, and BracePaste without primer at the $p=0.0001$ significance level. The group of BracePaste without primer is statistically significantly lower than BracePaste with primer group in terms of shear bond strength ($p=0.0001$). There is no statistically significant difference between the shear bond strength of Transbond XT and BracePaste with primer ($p < 0.005$).

5. DISCUSSION

One of the crucial factors determining the success and duration of orthodontic treatment is the adhesive system used. Therefore, orthodontists look at the result of *in vitro* studies, and one of the methods is preferred to choose adhesive material. Adhesive systems in dentistry have advanced much compared to the past and continue to evolve. Conventional etch and rinse adhesive systems are widely used and referred to as the gold standard.

The other factor for good bonding is choosing brackets with a significant base. Orthodontic brackets must withstand undesirable forces during the orthodontic treatment. Also, they must have enough MPa resistance. Reynolds indicated that 5.9-7.8 MPa resistances are adequate to resist the masticatory forces (167). Cucu et al. (168) stated that there is no statistically significant difference between mini and standard-size braces compared to shear bond strength *in vitro*. Knox et al. (169) used the brackets with size 60-80-100 gauge single mesh bases, a double mesh base, and an integrated metal base to find the significance between the bracket base and shear bond strength. They discovered that bracket base design might improve the shear bond strength. Pham et al. (170) concluded that bracket base shape could change the shear bond strength between dental tissue and brackets on bovine teeth.

Moreover, curing systems plays a decisive role in increasing the shear bond strength. Light-curing units can cause polymerization shrinkage. This can cause a decrease in the bond strength of adhesive material (171). Feilzer et al. (172) found that polymerization speed also inhibits the molecular flow of adhesive material, which can affect the adhesion.

Lovius et al. (173) reported the failure rates of rebonding brackets during the orthodontic treatment ranging between 3.5% to 23%. Debonding is usually caused by excessive forces from the patient's diet. It has been reported that the duration of orthodontic treatment can be increased from 0.3 to 0.6 months due to debonding of one bracket (174,175). Also, a study showed that when the duration of treatment was prolonged more than expected, the patient's appointment attendance every six months decreased by 23% (176). In addition, the cost of treatment is increased both for orthodontists and patient (176).

In this study, we preferred bovine teeth instead of human teeth. Extracted human teeth mimic *in vivo* with higher efficacy in *in vitro* conditions (177). However, extracted human teeth have some limitations, such as; quantity limitation, extensive caries, defect problems, and ethical aspects. Because of these reasons, bovine teeth are used as substitutes to evaluate the bond strength (177). Camargo et al. (178) found that according to dentin tubules, bovine teeth had a significantly higher mean value than human teeth. Similarly, Almeida et al. (179) and Dutra-Correa et al. (180) are concluded that bovine teeth had higher mean value in terms of dentin tubules. Schilke et al. (181) stated that bovine teeth showed no difference in shear bond strength compared to human teeth. Similarly, Lopes et al. (182) observed no statistical difference between bovine and human teeth in terms of bond strength. Furthermore, Robinson et al. (183) stated that bovine teeth can be used as a replacement of human teeth in terms of their composition and morphology.

There are various teeth storage solutions in the literature, including chloramine solutions (74), distilled water (184–187), thymol solutions (187,188), saline solutions (189). The most preferred solution is distilled water because it does not cause any damage to the enamel structure and bonding material. We preferred distilled water for our study. To prevent bacterial growth, we renewed distilled water every day.

Mui et al. (190) observed no statistically significant difference between initial bond strength and rebonding strength when the tooth surface is cleaned with a tungsten carbide bur.

Before bonding, plaque and pellicle layer should be removed from the dental surface. It improves the success of the bracket bonding on the enamel and decreases clinical failure rates (191). In addition, Lill et al. (192) found that when pumice pretreatment was omitted, shear bond strength was significantly decreased. In light of these findings, we polished teeth with pumice for 10 seconds; after this process, the teeth were cleansed with water for 15 seconds in our study.

One of the variables that were evaluated in our study is different adhesive systems. Transbond XT primer and Transbond XT Adhesive were used to assess the shear bond strength in our study. Transbond XT was preferred to correlate the shear bond strength of different adhesives in this study because it is widely used and a reliable adhesive in dentistry. In many studies, Transbond XT showed higher shear bond strength than other adhesives(193–198). Several manufacturers recommend etching for 15 seconds on the enamel. Many researchers have tried applying phosphoric acid to the enamel surface for 15-90 seconds. They concluded that longer etching time had no significant effect on shear bond strength (199–202). Several manufacturers recommend an etching time of 15 seconds on the enamel. Because of that, 37% phosphoric acid was first applied to the enamel surface for 15 seconds in our study.

The other adhesive system which was compared to Transbond XT in our study was BracePaste adhesive and BracePaste Primer. BracePaste was introduced to the dental market as being similar to Transbond XT in terms of its composition and properties consisting of Bis-GMA and Quartz Silica. The viscosity of the primer has been increased so that the position of the bracket can be easily controlled during the adhesion process. The manufacturer of BracePaste claims that it can be used with or without primer. BracePaste Adhesive was designed to reduce bracket movement and clean remnant adhesive easily before curing (203).

Adhesive resins are routinely exposed to thermal changes that can cause stresses between adhesive and bracket in the oral cavity. Therefore, the thermal cycling method is used to create a simulation area of the oral cavity. Thermal cycling stresses may affect the shear bond strength between resin and enamel. Many studies showed no statistical difference in shear bond strength with 2000 thermal cycles (204,205). Similarly, Kitayama et al. (206) found that shear bond strength was the same after the thermal cycling test. Also, Saito et al. (206) reported no significant difference in shear bond strength values for 0, 2000, and 5000 thermal cycles. A study on bovine teeth investigated that after 2000 thermal cycles, there was no significant effect on shear bond strength (207). A study on bovine teeth investigated that after 2000 thermal cycles, there was no significant effect on shear bond strength (208). Therefore, the thermocycling method was not used in our study.

The shear bond strength test or tensile bond strength test can be selected to evaluate the bond strength of different adhesives; Shear bond strength test is widely used in terms of ease to use. Because while the specimen is aligned in a tensile bond strength test machine, deleterious stress distribution can change the results (209,210). Moreover, test protocol and specimen preparation are more difficult compared to the shear bond strength test (108). Also, many studies showed that the tensile bond strength test is unsuitable for finding the accurate result of bonding strength (159,211). Millett et al. (212) investigated that the shear bond strength test had significantly higher results than the tensile test. Therefore, our study used the shear bond strength test to evaluate the shear bond strength of different adhesives. The bond strength of specimen was evaluated with Universal Testing Machine.

In our study, three groups were analyzed to compare their bond strength between the enamel surface and bracket base. There was no statistical difference between Transbond XT and BracePaste Adhesive with BracePaste Primer regarding shear bond strength. On the contrary, there was a statistical difference between Transbond XT and BracePaste Adhesive with no Primer. The mean SBS and standard deviation values for BracePaste Adhesive with BracePaste Primer group were found as 11.11 ± 1.51 MPa. In comparison, the mean SBS and standard deviation of Transbond XT had 11.73 ± 1.74 MPa for thirty samples. Reynolds considered that bond strength within the range of 6 MPa - 8 MPa as “clinically acceptable ” (167).

In our study, led curing units were used to polymerize the adhesive systems which bond the bracket to enamel tissue. Almeida et al. (213) observed in their study, which used Transbond XT Adhesive with Transbond XT Primer to evaluate shear bond strength with Valo curing unit as our study, similar to our results, Transbond XT displayed the highest shear bond strength with MPa value of 21.06.

BracePaste Adhesive without BracePaste Primer showed the lowest MPa among the other groups. The manufacturer claimed that the bond strength of BracePaste Adhesives without its Primer was sufficient to attach the teeth surface. However, our findings indicated that the mean shear bond strength in BracePaste Adhesive without BracePaste Primer was 2.24. there was a statistically significant difference compared to BracePaste Adhesive with BracePaste Primer, in which the mean shear bond strength was 11.26. Only a little research has been done with BracePaste Adhesive and Primer, so the results can be compared to other studies in which other adhesive brands were evaluated with or without Primer. Similarly, Rohmetra et al. (214) studied with Transbond XT to evaluate the difference in the shear bond strength between using primer and without primer. In his study, while the mean MPa of Transbond XT with primer was 11.82, Transbond XT without primer had 7.55 MPa. Also, in one study, Transbond XT with Transbond XT Primer had 16.77 MPa, and Transbond XT without Transbond XT Primer had 11.59 MPa, like our results.

Although BracePaste Adhesive is a new adhesive system in orthodontics, it has been compared with Transbond XT regarding the shear bond strength. Because Transbond XT is considered as the gold standard in orthodontics. Samaneh et al. (203) correlated the shear bond strength of different adhesive systems. Unlike our study, they found that the shear bond strength of Transbond XT was higher than BracePaste Adhesive.

Transbond XT is widely used to bond the orthodontic brackets to the enamel tissue. In our study, the mean shear bond strength for Transbond XT showed statistically similar score with BracePaste Adhesive with BracePaste Primer. On the contrary, Hellak et al. (215) investigated in their study, where the shear bond strength of three adhesives systems was evaluated, that the mean SBS score of Transbond XT was 15.49, and it was the highest score among the three adhesive systems. Abdelnaby et al. (216) conducted a study where they investigated the shear bond strength of four adhesive systems, and they found that Transbond XT showed the highest mean value of shear bond strength.

In vitro studies have certain limitations compared to *in vivo* studies due to the difficulties of oral cavity simulation. Because it is hard to achieve the same condition that the oral cavity has, such as; saliva, pH, temperature changes, and occlusal forces. Therefore, our results should be reevaluated to have relevant results with *in vivo* studies.

6. CONCLUSION

All in all, our study indicates no statistically significant difference between the mean shear bond strength of Transbond XT with Transbond Primer and BracePaste Adhesive with BracePaste Primer.

Furthermore, we found a statistically significant difference between the mean shear bond strength of BracePaste Adhesive with BracePaste Primer and BracePaste Adhesive without BracePaste Primer.

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