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"JÚLIO DE MESQUITA FILHO"
Instituto de Ciência e Tecnologia
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# Effectiveness of different orthodontic adhesives and a universal bonding resin on the bond strength of brackets to different ceramics

Eficácia de diferentes adesivos ortodônticos e uma resina de ligação universal na resistência adesiva de bráquetes à diferentes cerâmicas

**Serpil ÇOKAKOĞLU[1], Işıl KARAOKUTAN[2]**

1 - Pamukkale University, Faculty of Dentistry, Department of Orthodontics. Denizli, Turkey.
2 - Pamukkale University, Faculty of Dentistry, Department of Prosthodontics. Denizli, Turkey.

## ABSTRACT

**Objective:** The aim of this study was to evaluate the effectiveness of different adhesives on the shear bond strength (SBS) of brackets bonded to different ceramic materials. **Material and Methods:** Fifty disk-shaped specimens were produced from lithium disilicate (IPS e.max CAD) and monolithic zirconia (Cercon) materials. Each specimen was polished with a three-step diamond polishing system. The polished ceramic surfaces were conditioned with universal bonding resin (Assure Plus) without pre-treatment, except for two specimens. Central brackets were bonded onto different ceramic specimens with different adhesives as follows: group 1: conventional adhesive onto the lithium disilicate; group 2: one-step adhesive onto the lithium disilicate; group 3: conventional adhesive onto the monolithic zirconia; group 4: one-step adhesive onto the monolithic zirconia. After thermal cycling, the specimens were subjected to the SBS test. The adhesive remnant index (ARI) scores were also recorded to evaluate bond failure type. Kruskal–Wallis and Mann-Whitney U tests were used for statistical analysis. **Results:** There were statistically significant differences among the SBS values ($p<0.05$). The monolithic zirconia group with universal bonding resin and conventional orthodontic adhesive demonstrated the highest SBS value (6.34 MPa) and ARI scores. The lithium disilicate group showed the lowest SBS value (2.17 MPa) with the same protocol. No adhesive remained on the lithium disilicate specimens. **Conclusion:** One-step adhesive and universal bonding resin combination should not be considered as an alternative for lithium disilicate and monolithic zirconia restorations. Conventional adhesive and universal bonding resin application can be effective on non-pretreated ceramic surfaces during orthodontic bonding.

## KEYWORDS

Bracket; Ceramics; Hydrophilic bonding resin; One-step adhesive.

## RESUMO

**Objetivo**: o objetivo deste estudo foi avaliar a eficácia de diferentes adesivos na resistência ao cisalhamento (SBS) de bráquetes colados a diferentes materiais cerâmicos. **Material e métodos**: Cinquenta espécimes em forma de disco foram produzidos a partir de materiais de dissilicato de lítio (IPS e.max CAD) e zircônia monolítica (Cercon). Cada amostra foi polida com um sistema de polimento de diamante de três passos. As superfícies cerâmicas polidas foram condicionadas com resina de ligação universal (Assure Plus) sem pré-tratamento, exceto para dois corpos-de-prova. Bráquetes centrais foram colados em diferentes corpos de prova cerâmicos com diferentes adesivos da seguinte forma: grupo 1: adesivo convencional sobre dissilicato de lítio; grupo 2: adesivo de uma etapa sobre o dissilicato de lítio; grupo 3: adesivo convencional sobre zircônia monolítica; grupo 4: adesivo de uma etapa sobre a zircônia monolítica. Após a ciclagem térmica, os corpos-de-prova foram submetidos ao teste SBS. Os escores do índice de remanescente adesivo (ARI) também foram registrados para avaliar o tipo de falha de adesão. Os testes U de Kruskal-Wallis e Mann-Whitney foram usados para análise estatística. **Resultados**: Houve diferenças estatisticamente significativas entre os valores de SBS ($p<0,05$). O grupo de zircônia monolítica com resina de colagem universal e adesivo ortodôntico convencional demonstrou o maior valor de SBS (6,34 MPa) e escores de ARI. O grupo de dissilicato de lítio apresentou o menor valor de SBS (2,17 MPa) com o mesmo protocolo. Nenhum adesivo permaneceu nas amostras de dissilicato de lítio. **Conclusão**: A combinação de adesivo de uma etapa e resina de ligação universal não deve ser considerada como uma alternativa para restaurações de dissilicato de lítio e zircônia monolítica. A aplicação de adesivo convencional e resina de colagem universal podem ser eficazes em superfícies de cerâmica não pré-tratadas durante a colagem ortodôntica.

## PALAVRAS-CHAVE

Bráquete; Cerâmica; Resina de ligação hidrofílica; Adesivo de uma etapa.

## INTRODUCTION

Adequate bracket bond strength during fixed orthodontic treatment is crucial for successful treatment results. The orthodontic treatment demands of adult patients with porcelain restorations necessitate finding an effective bonding protocol for the different ceramic materials used [1].

All ceramic materials can reflect the natural appearance of teeth, and their optical properties are similar to tooth structure [2]. With the recent increase in patients' aesthetic expectations and the development of CAD/CAM technology, new restorative materials have been introduced to the market. Lithium disilicate ceramics (LDCs) have been used for many years due to their high aesthetic characteristics [3]. However, their brittle character due to their glassy structure limits the use of these materials. Yttrium-stabilized tetragonal zirconia polycrystals (Y-TZP) have been used as an alternative to LDCs due to their superior mechanical properties, but they are very opaque and need veneering material to provide aesthetic and optic properties [4]. In Y-TZP applications, delamination of veneering porcelain is a major problem [5]. To overcome this problem, monolithic zirconia materials have been developed in recent years. They do not require veneering material and can be processed as a full contour. They can be used in both the posterior and anterior regions owing to their improved aesthetic and mechanical properties [6].

In clinical practice, adequate bonding to porcelain surfaces is generally achieved as a result of many applications, such as hydrofluoric acid (HF) etching, sandblasting, silane application, or a combination of them [7]. The routine bonding procedure on silica-based ceramics involves the use of HF followed by silane as a coupling agent for methacrylate terminal groups of an orthodontic adhesive [8], but this protocol results in inadequate bond strength on non-silica-based ceramics [9]. Bonding procedures that eliminate one or more steps have gained popularity among orthodontists [10,11]. Recently, a new protocol facilitating the clinical application of unidose hydrophilic bonding resin on enamel surfaces was introduced [12]. The newest version of universal bonding resin also eliminates the need for HF conditioning by replacing sandblasting on different surfaces such as feldspathic, lithium disilicate, or zirconia ceramic.

According to the manufacturer's instructions, bonding to feldspathic, lithium disilicate or zirconia ceramic includes the following steps; sandblasting, rinsing and drying, followed by the application one coat of porcelain conditioner, gentle air-drying, followed by the application of one coat of universal bonding resin, lightly air-dying and light-curing. The bracket is then bonded by use of orthodontic adhesive. Moreover, this resin allows the clinician to bond directly to all surfaces and is adaptable to all the light-cured and chemically cured orthodontic adhesives [13].

In clinical practice, one of the easiest ways of effective bonding may be the use of a one-step orthodontic adhesive with integrated primer applied to acid-etched enamel surfaces due to its adequate bond strength [14] and other characteristic material properties, such as low shrinkage stress and elastic modulus [15]. The development of these new adhesive materials raises the question of whether the combination of one-step adhesive and universal bonding resin could be effective for bonding metallic brackets to different ceramic materials in a unidose manner.

In the literature, only a few studies have investigated the effects of universal bonding resin (Assure Plus) on the shear bond strength (SBS) of brackets bonded to lithium disilicate and monolithic zirconia surfaces with additional applications [16-20]. However, to date, no study has investigated whether a unidose universal bonding resin is effective on different ceramic surfaces when using different orthodontic adhesives.

The aim of this study was to evaluate the bonding effectiveness of different adhesive materials on the SBS of brackets bonded to different ceramic materials. For this purpose, the null hypothesis was that there were no differences between the SBSs of brackets bonded with universal bonding resin and conventional or one-step orthodontic adhesive.

## MATERIALS AND METHODS

This in-vitro study was approved by the Ethical Committee of Pamukkale University, (Ethical approval No. 22.12.2020-24).

### Specimen preparation

A total of 50 disk-shaped (5 mm diameter, 2 mm thickness specimens were fabricated from lithium disilicate (IPS e.max CAD Ivoclar Vivadent, Schaan, Liechtenstein) and monolithic zirconia (Cercon, Dentsply Sirona, Hanau, Germany) materials (n=25). The acquired 3D images were processed into a standard tessellation language (STL) file, and the data were used to mill the specimens. After milling, the lithium disilicate specimens were crystallized in an Ivoclar Vivadent ceramic furnace (Programat P300) at 840°C according to the manufacturer's instructions. For the monolithic zirconia specimens, X, Y, and Z coordinates were entered into 3Shape software as 1.240, 1.240, and 1.234, respectively, and then the specimens were milled. After milling, the specimens were sintered in an inLab Profire furnace (Dentsply Sirona, Hanau, Germany) at 1500°C for 135 minutes according to the manufacturer's instructions. One surface of the specimens was glazed and then polished with a three-step diamond polishing system (Eve Diapol System, EVE Ernst Vetter GmbH, Keltern, Germany). To evaluate surface morphology, one specimen was randomly selected from each ceramic groups and cleaned with ultrasonic bath, dried with absorbent paper, and then coated with a thin Au-Pd layer (200-300 nm) for examination by scanning electron microscopy (SEM; Zeiss Supra 40 VP, Carl Zeiss AG, Germany).

The remaining specimens in ceramic groups were further divided into two subgroups (n=12) according to the different orthodontic adhesives during the bonding procedure:

- Group 1: Brackets were bonded with conventional orthodontic adhesive onto the lithium disilicate specimens.
- Group 2: Brackets were bonded with one-step orthodontic adhesive onto the lithium disilicate specimens.
- Group 3: Brackets were bonded with conventional orthodontic adhesive onto the monolithic zirconia specimens.
- Group 4: Brackets were bonded with one-step orthodontic adhesive onto the monolithic specimens.

### Bonding procedure

Before bonding procedure, specimens were embedded in chemically polymerized acrylic resin (Meliodent, Heraeus Kulzer, South Bend, IN, USA) and kept in a glass bottle with a screw cap until the aging process was carried out. The ceramic and bonding materials used in this study are demonstrated in Table I. A thin layer of universal bonding resin (Assure Plus, Reliance Orthodontics Products, IL, USA) was applied on the ceramic surfaces without pre-treatment of ceramic specimens. Then, the metal maxillary central incisor brackets with a .022-inch slot (Natural Orthodontic Products, FL, USA) were bonded onto the ceramic surfaces with conventional (Transbond XT, 3M Unitek, Monrovia, Calif, USA) or primer-integrated one-step orthodontic adhesive (GC Ortho Connect, GC Orthodontics, Tokyo, Japan), and standardized stable pressure (300 gf) using a gauge (Morelli, Dental Morelli Ltd., Brazil) was applied for 10 seconds to obtain a uniform adhesive thickness in each placement. All brackets were bonded to the surfaces by the same clinician. The excess adhesive was removed with a scaler, and polymerization using an LED device (Valo, standard mode, 1000 mW/cm$^2$; Ultradent) was performed for 15 seconds from the mesial and distal sides of the brackets.

### Thermal cycling and SBS test

All specimens were thermocycled (Julabo, FT400, Germany) for 1000 cycles between 5 and 55°C at an interval of 30 seconds. After

**Table I -** Ceramic and bonding materials and their compositions

| Material | Composition | Manufacturer |
|---|---|---|
| IPS e.max CAD (Lithium disilicate) | SiO2 57-80% | Ivoclar Vivadent, Schaan, Liechtenstein |
| | Li2O 11-19% | |
| | K2O 0-13% | |
| | P2O5 0-11% | |
| | ZrO2 0-8% | |
| | ZnO 0-8% | |
| | Colorants 0-12% | |
| Cercon HT (Monolithic zirconia) | Zirconium oxide | Dentsply Sirona, Hanau, Germany |
| | Yttrium oxide 5% | |
| | Hafnium oxide < 3% | |
| | Aluminium oxide, Silicon oxide, other oxides < 2% | |
| Assure® Plus Universal Bonding Resin | BisGMA 30-50% | Reliance Orthodontic |
| | Ethanol 30-50% | Products, Itasca, IL, USA |
| | 2-Hydroxyethyl Methacrylate 10-30% | |
| | 10-Methacryloyloxydecyl Dihydrogen Phosphate 5-10% | |
| Transbond XT (conventional orthodontic adhesive) | Silane treated quartz 70-80% | 3M Unitek, Monrovia, Calif, USA |
| | Bisphenol A diglycidyl ether dimethacrylate 10-20% | |
| | Bisphenol A dimethacrylate 5-10% | |
| | Silane treated silica <2 | |
| | Diphenyliodonium hexafluorophosphate <1 | |
| | Triphenylantimony <1 | |
| GC Ortho Connect (one-step orthodontic adhesive) | 4,4'-isopropylidenediphenol, ethoxylated and 2-methylprop-2-enoic acid 25-50% | GC Orthodontics, |
| | 7,7,9(or 7,9,9)-trimethyl-4,13-dioxo-3,14-dioxa-5,12-diazahexadecane-1,16- | Tokyo, Japan |
| | diyl bismethacrylate 25-50% | |
| | methacryloyloxydecyl dihydrogen phosphate 1-5% | |
| | 6-tert-butyl-2,4-xylenol <0.5% | |

thermocycling, the SBS test was performed using a universal testing machine (Instron 1075, Norwood, MA, USA) at a speed of 0.5 mm/min. The knife-edge blade of the machine was located parallel to the ceramic surface and bracket interface until debonding occurred (Figure 1). The SBS value was calculated as MPa dividing the force in N by the bracket base surface area (11.78 $mm^2$). After the SBS test, the specimens were examined under a stereomicroscope (Nikon, SMZ 1500, Tokyo, Japan) at 10x magnification. The remnant adhesive on the surface was scored according to the adhesive remnant index (ARI) as follows [21]:

- ARI 0: No adhesive left on the ceramic surface
- ARI 1: Less than half of the adhesive left on the ceramic surface
- ARI 2: More than half of the adhesive left on the ceramic surface
- ARI 3: All adhesive remained on the ceramic surface with a distinct impression of bracket base

## Statistical analysis

Power analysis (G*Power, version 3.1.9.2) showed that 9 specimens for each group would give more than 80% power at the 95% confidence level with an effect size (f=0.62) based on a previous study [22]. The data were analyzed with SPSS (version 23.0; IBM Corp, Armonk, NY, USA). The Kolmogorov-Smirnov test was used to determine normal distribution. Kruskal–Wallis and Mann-Whitney U tests were used in the absence of normal distribution and the significance level was accepted as $p<0.05$.

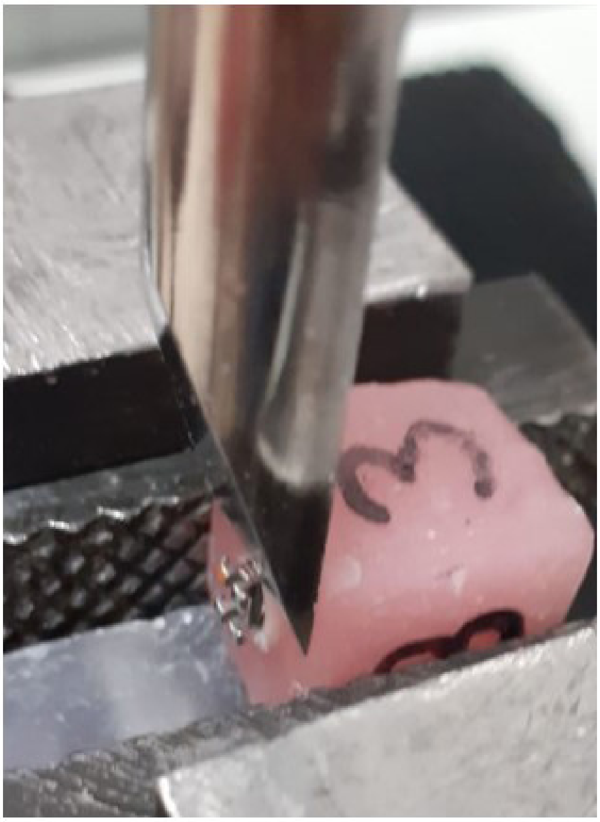

**Figure 1 -** The SBS test.

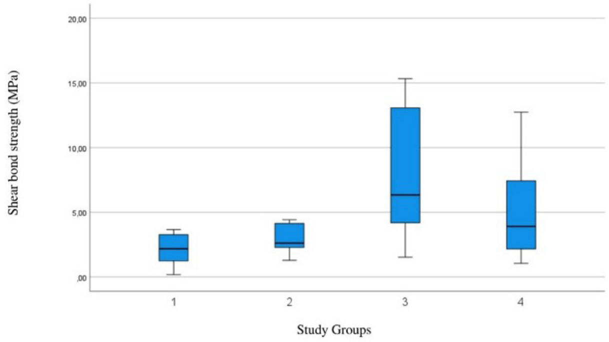


**Figure 2 -** The box plot showing the SBS of the study groups. Group 1: Lithium disilicate (e.max CAD) + Assure + Transbond; Group 2: Lithium disilicate (e.max CAD) + Assure + GC Ortho Connect; Group 3: Monolithic zirconia (Cercon); + Assure + Transbond; Group 4: Monolithic zirconia (Cercon); + Assure + GC Ortho Connect.

**Table II -** Comparison of shear bond strength values of study groups

| | n | Median (MPa) | Min (MPa) | Max (MPa) | IQR (MPa) |
|---|---|---|---|---|---|
| Group 1 | 10 | 2.17 [a] | 0.18 | 3.66 | 2.37 |
| Group 2 | 10 | 2.61 [a] | 1.28 | 4.42 | 2.06 |
| Group 3 | 12 | 6.34 [b] | 1.53 | 15.33 | 10.35 |
| Group 4 | 12 | 3.91 [ab] | 1.05 | 12.74 | 5.85 |

Group 1: Lithium disilicate (e.max CAD) + Assure + Transbond; Group 2: Lithium disilicate (e.max CAD) + Assure + GC Ortho Connect; Group 3: Monolithic zirconia (Cercon); + Assure + Transbond; Group 4: Monolithic zirconia (Cercon); + Assure + GC Ortho Connect. Median values significantly different are followed by different letters ($p < 0.05$).

## RESULTS

### Shear bond strength

The SBS of the study groups are demonstrated as box plots in Figure 2. There were significant differences between the SBS of brackets bonded to ceramic materials with different adhesive materials ($p<0.001$) (Table II). The SBS values of brackets bonded to lithium disilicate specimens was lower than that of monolithic zirconia. The metal brackets bonded to monolithic zirconia with universal bonding resin and conventional orthodontic adhesive (Group 3) showed significantly higher SBS values than those of brackets bonded to lithium disilicate, irrespective of adhesive materials ($p<0.05$). On the other hand, the SBS values of brackets bonded to monolithic zirconia specimens with universal bonding resin and one-step orthodontic adhesive (Group 4) did not differ from those of the other study groups.

### SEM evaluation

The SEM images are shown in Figure 3A and 3B. After polishing with a three-step diamond polishing system, the monolithic zirconia specimen surface showed more irregularities than lithium disilicate specimen.

### Adhesive remnant index

The distribution and comparisons of the "Adhesive Remnant Index" (ARI) scores of the ceramic groups are shown in Table III. Among the lithium disilicate groups, all specimens had an ARI score of 0. The monolithic zirconia specimens had higher ARI scores than the lithium disilicate specimens. In Group 3, half of the specimens had an ARI score of 0, approximately 30% of the specimens had ARI scores of 1, and 20% of the specimens had an ARI score of 2. Among all the groups, the most adhesive remained in this group. Most of the specimens in Group 4 had an ARI score of 0. ARI scores of 1 and 2 were observed in one specimen each. None of the specimens had an ARI score of 3.

After the SBS test, representative stereomicroscobe images of the specimens are shown in Figures 4-6.

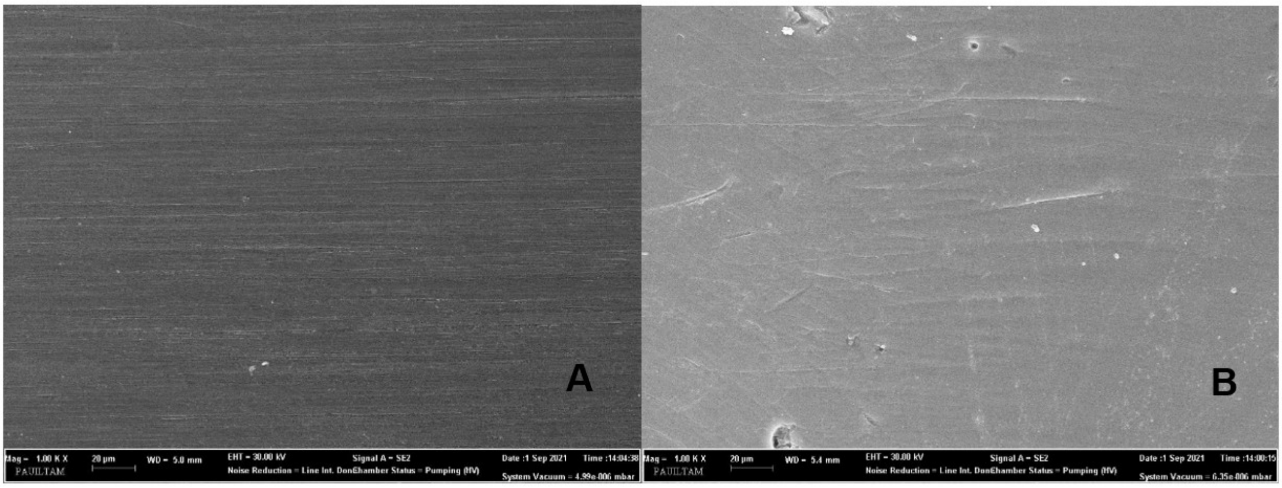


**Figure 3 -** Lithium disilicate specimen (A), monolithic zirconia specimen after polishing (B).

**Table III -** Distribution of adhesive remnant index (ARI) scores of study groups

| Ceramic material | Adhesive material | ARI scores | | | |
|---|---|---|---|---|---|
| | | 0 (%) | 1 (%) | 2 (%) | 3 (%) |
| Lithium disilicate | Transbond | 10 (100) | --- | --- | --- |
| (e.max CAD) | GC Ortho Connect | 10 (100) | --- | --- | --- |
| | Total | 20 (100) | --- | --- | --- |
| Monolithic zirconia | Transbond | 6 (50) | 4 (33.3) | 2 (16.7) | --- |
| (Cercon) | GC Ortho Connect | 10 (83.3) | 1 (8.3) | 1 (8.3) | --- |
| | Total | 16 (66.7) | 5 (20.8) | 3 (12.5) | --- |
| | Transbond | 16 (72.7) | 4 (18.2) | 2 (9.1) | --- |
| Total | GC Ortho Connect | 20 (90.9) | 1 (4.5) | 1 (4.5) | --- |
| | Total | 36 (81.8) | 5 (11.4) | 3 (6.8) | --- |

Group 1: Lithium disilicate (e.max CAD) + Assure + Transbond; Group 2: Lithium disilicate (e.max CAD) + Assure + GC Ortho Connect; Group 3: Monolithic zirconia (Cercon); + Assure + Transbond; Group 4: Monolithic zirconia (Cercon); + Assure + GC Ortho Connect.

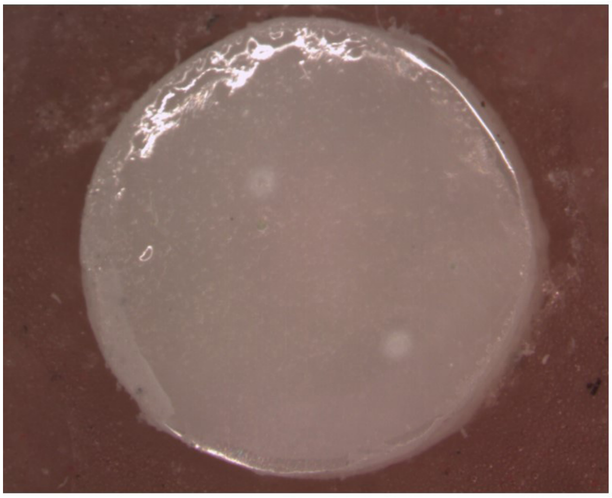

**Figure 4 -** ARI score of 0.

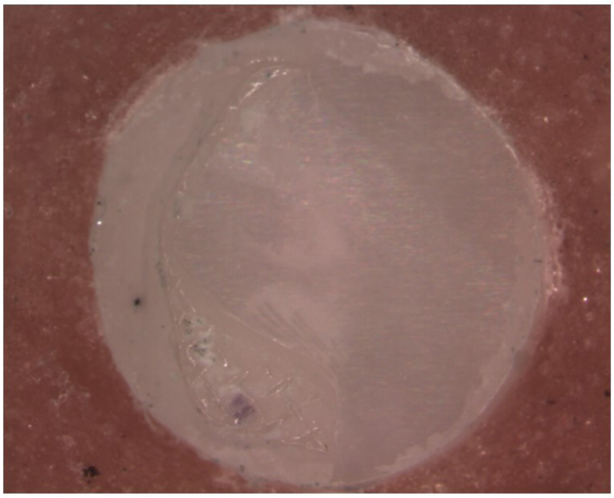

**Figure 5 -** ARI score of 1.

## DISCUSSION

This study compared the SBSs of metal brackets bonded with two different resins to lithium disilicate and monolithic zirconia specimens after the application of universal bonding resin (Assure Plus). The combination of one-step adhesive and universal resin bonding

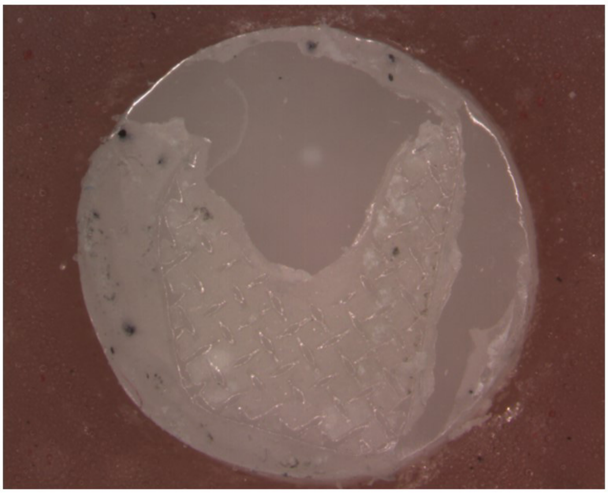

**Figure 6 -** ARI score of 2.

has not been studied in this context so far in the literature. Based on the results of this study, the null hypothesis, that there would be no significant differences in the SBSs of brackets bonded with different adhesive materials, was rejected.

The standard orthodontic bonding protocol for glass-ceramic materials such as lithium disilicate involves HF etching followed by the application of universal or ceramic primer (silane) [23]. However, acid etching that reacts with the silica phase of ceramic material for mechanical retention can cause irritation in soft tissues in the absence of a high-vacuum suction system in clinical conditions [24]. The newest version of universal bonding resin eliminates the need for HF etching and its possible risks during the bonding procedure of ceramic materials. The manufacturer clearly recommends sandblasting and the application of a silane as a pre-treatment before the use of bonding resin.

It is also important to prevent surface damage during the debonding of brackets from different ceramic surfaces. To this end, the use of silane to increase the bond strength is questionable due to cohesive bond failure during the debonding procedure [18]. The sandblasting of ceramic surfaces with aluminum oxide particles was not considered in this study due to the inconvenience of its intraoral conditions although the application of MDP-containing primer after sandblasting has been suggested for zirconia surfaces in previous studies [9,25-27]. Therefore, the effectiveness of different adhesive materials on the SBSs of metal brackets bonded to lithium disilicate and monolithic zirconia surfaces were evaluated without pre-treatment of ceramic specimens.

According to our findings, the lowest SBS values were observed on lithium disilicate surfaces treated with MDP-containing bonding resin and conventional orthodontic adhesive. Similarly, Di Guida et al. [28] evaluated the effects of another one-bottle primer and adhesive (MDP) on lithium disilicate (IPS e.max) during the bonding procedure. The metal brackets bonded with MDP monomer yielded the lowest SBS value (1.14 MPa) among the surface pre-treatment methods, including HF etching, silane application, and their combinations. Moreover, the findings of this study revealed that one-step adhesive slightly improved the adhesion due to its MDP composition. The MDP mechanism of this adhesive on the lithium disilicate surface resulted in higher SBS values compared with conventional adhesive. The glassy matrix may be dissolved with the combination of universal bonding resin and one-step orthodontic adhesive and thus cause the formation of more retentive areas. Nevertheless, the MDP-containing hydrophilic bonding resin showed an inadequate bond strength on lithium disilicate surfaces irrespective of orthodontic adhesives. Di Guida et al. [28] suggested a minimum of 5 MPa for glass-ceramic surfaces, which is within close range of Reynold's findings [29] which explained that SBS values between 6 and 8 MPa were clinically acceptable. In another study, Naseh et al. [18] compared the SBSs of brackets bonded to lithium disilicate (IPS e.max) surfaces treated with sandblasting and HF etching followed by Assure Plus or conventional primer (Transbond XT) with the same conventional orthodontic adhesive. In their study, no significant differences were found between lithium disilicate groups. Contrary to our findings, universal bonding resin (Assure Plus) provided the highest SBS when adequate surface preparation was achieved in the lithium disilicate samples.

Monolithic zirconia ceramic does not contain a glassy phase, unlike lithium disilicate material, and HF etching does not increase bond strength [7]. The combination of sandblasting and primers or silanes has been recommended to obtain adequate bond strength on zirconia surfaces [26]. In clinical practice, the final alignment of all-ceramic restorations should be done after cementation, which has led to the development of polishing systems suitable for many materials. Amaya-Pajares et al. [30] stated that lithium disilicate and monolithic zirconia ceramics showed rougher surfaces after adjustment and polishing. Moreover, Amer and Rayyan [31] concluded that mechanical roughening of glazed monolithic zirconia was effective during surface treatment and can be an alternative to sandblasting in clinical practice. In this study, the SBS of brackets bonded to monolithic zirconia was higher compared with lithium disilicate surfaces. This can be explained by the polishing step that increased the surface roughening. The polishing step did not influence the surface roughness of lithium disilicate, while it had an effect on the monolithic zirconia surface. In a recent study, Abuelenain et al. [32] explained that the mechanical roughness achieved using Soflex discs only was greater on lithium disilicate ceramics (IPS e.max) compared with zirconia-reinforced ceramics. This meant that various polishing systems had different impacts on ceramic materials.

The SBS findings for polished monolithic zirconia surfaces demonstrated clinically adequate bond strength values with hydrophilic resin and conventional orthodontic adhesive. Moreover, the SBS values were influenced by different monomer types of adhesives. The structures of conventional and one-step orthodontic adhesives depend on bisphenol A-glycidyldimethacrylate (Bis-GMA) and urethane dimethacrylate (UDMA) monomers, respectively. The higher filler content of conventional orthodontic adhesive resulted in the highest SBS values of brackets bonded to monolithic zirconia surfaces due to the bracket bond strength depending on the filler level of the orthodontic adhesive [33].

In clinical practice, the bond strength should be strong enough to keep the brackets in the mouth during treatment but should also leave the ceramic surface undamaged and leave less remnant adhesive during the debonding process. Two samples of each lithium disilicate group were debonded at the beginning of the SBS test during this study. However, the remaining samples provided the required sample size in terms of SBS results [34]. For these groups, no adhesive remnant was found on the ceramic surfaces, and bond failures were observed at the ceramic-adhesive interfaces.

Based on the findings of this study, higher ARI scores were related to higher SBS values, especially in the monolithic zirconia groups. Regarding the adhesive type, bond failures were found in many specimens within the adhesive itself when conventional adhesive was used. On the other hand, the one-step orthodontic adhesive bond failures were generally found at the adhesive-ceramic surface interface. In the present study, different ARI scores may be due to less filler reinforcement of the one-step adhesive, which tends to lower ARI scores [33]. Although higher ARI scores may cause more adhesive removal during debonding, this condition can be accepted as safer in terms of surface damage in clinical practice [18].

It is important to point out that shear bond strength measurement assumes a uniform interfacial shear stress, whereas there are heterogeneous stress distributions with protocol used during the assessment of the bonding effectiveness of adhesive materials. For this reason, debonding force is the more appropriate variable to report, but the use of bond strength (shear or tensile) is embedded in the literature [35]. This situation could be considered as a limitation of this study. Another limitation was that nature of debonding force applied during the universal test could not be restricted to shear modes due to the complexity of oral environment [36]. Taking these limitations into consideration, the SBS of brackets bonded to lithium disilicate surfaces with universal bonding resin was inadequate when conventional or one-step orthodontic adhesive was used. Therefore, the surface of IPS e.max CAD should be roughed with the appropriate etching method. However, the combination of conventional orthodontic adhesive and universal bonding resin can be used as an alternative during the bonding of metallic brackets to monolithic zirconia surfaces without pre-treatment. Future studies must be performed to improve the SBS of brackets bonded to lithium disilicate surfaces according to different pre-treatment methods when Assure Plus resin is used with conventional or one-step orthodontic adhesive.

## CONCLUSION

The use of universal bonding resin (Assure Plus) with conventional (Transbond XT) or one-step (GC Ortho Connect) orthodontic adhesive seems to produce clinically inadequate bond strength on lithium disilicate. However, the use of Assure Plus and Transbond XT can be an alternative for bonding brackets to monolithic zirconia without pre-treatment in clinical conditions.

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## Authors' Contributions

SÇ, IK: designed the study and wrote the manuscript.

## Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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The authors declare that no financial support was received.

## Regulatory Statement

The authors declare that the approval of the ethics committee was required for this in vitro study (Ethical approval No. 22.12.2020-24).

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**Serpil Çokakoğlu**
**(Corresponding address)**
Pamukkale University, Faculty of Dentistry, Department of Orthodontics, Denizli, Turkey.
Email: serpilcokakoglu@gmail.com

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