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RESEARCH ARTICLE

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# BOND STRENGTH OF METAL AND CERAMIC BRACKETS BONDED TO THE SURFACE OF CAD/CAM BLOCKS

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**ABSTRACT**

**Background:** CAD/CAM crowns or veneers have been frequently founded in patientsin needed of bracket bonding and there is no conclusive evidence regarding the ideal protocol for bonding brackets to ceramic or provisional materials surfaces. **Aims:** This study evaluated the bond strength and the adhesive remnant index of metallic (Victory Series, 3M Unitek) and ceramic (Clarity, 3M Unitek) brackets bonded to the surface of different computer-aided design/computer-aided manufacturing (CAD/CAM) blocks using Transbond XT (3M Unitek) adhesive. **Settings and Design:** In vitro study. **Methods and Material:** Three types of CAD/CAM materials, namely feldspathic ceramic (FEL), lithium disilicate ceramic (LDC), and acrylic resin (AR) were randomly divided into six groups (n=12) including G1 (metallic brackets bonded to FEL ceramic blocks), G2 (metallic brackets bonded to LDC blocks), G3 (metallic brackets bonded to AR blocks), G4 (ceramic brackets bonded to FEL ceramic blocks), G5 (ceramic brackets bonded to LDC blocks), and G6 (ceramic brackets bonded to AC blocks). Subsequently, a bond strength test was carried out between the brackets and the blocks. The adhesive remnant index was also assessed. **Statistical analysis used:** Analysis of variance (ANOVA) followed by Tukey's post-hoc test. **Results:** Groups G3 and G6 showed the highest bond strengths when compared with the other groups and the highest percentage of adhesive failures (91.66% and 91.35%, respectively). The G1 group had the lowest bond strength values. **Conclusions:** Bonding of metallic and ceramic brackets to CAD/CAM acrylic resin blocks showed greater bond strength than bonding of brackets to ceramic blocks. Bonding to acrylic resin was associated with a higher percentage of adhesive fractures, which is favorable for bracket removal.



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# INTRODUCTION

Debonding of orthodontic brackets is a common concern in dental practice. It can lead to an increase in the total treatment time, additional material costs, and additional fees to the dentist (Costa *et al*., 2015). Detachment of orthodontic brackets can occur due to failure in the bonding procedure or due to the effect of masticatory forces (Costa *et al*., 2015; Abreu Neto *et al*., 2015). The approach using etch-and-rinse adhesive systems is well accepted and documented for bonding brackets on the surface of natural teeth, as it provides satisfactory adhesion (Shafiei *et al*., 2019).

Many studies have been conducted to evaluate the performance of orthodontic attachments bonded to amalgam (Wongsamut, Satrawaha & Wayakanon, 2017), porcelain (Lopes *et al*., 2020), composite resin (Hammad & El Banna, 2013), and metal (Kilponen, Varrela, Vallittu, 2019) surfaces. Until recently, a clinically acceptable bond to a surface other than tooth enamel was considered inconceivable. However, advances in materials and development of new techniques have shown that direct bonding of orthodontic attachments to other types of surfaces is also possible. To the best of our knowledge, no studies exist regarding bonding of orthodontic attachments to acrylic resin provisional restorations.

Due to the absence of adequate scientific evidence, professionals end up applying empirical protocols, which may result in failures in orthodontic treatment. In recent years, digital fabrication of provisional and permanent restorations has increased, especially with the use of computer-aided design/computer-aided manufacturing (CAD/CAM) systems (Spitznagel, Boldt &Gierthmuehlen, 2018) A major challenge while bonding orthodontic brackets to restorations, veneers, and ceramic crowns is the satisfactory adhesion and subsequent bracket removal without damaging the surface of the restorative material (Mirzakouchaki *et al*., 2016) Micromechanical bonding mechanisms are commonly used through surface blasting or acid etching, which increases the area and the surface energy (Bezerra *et al*., 2015). However, hydrofluoric acid can be harmful and aggressive to the soft tissues. Moreover, studies have suggested that mechanical polishing with diamond abrasives and airborne particle abrasion could initiate the propagation of cracks in the ceramic (Elsaka, 2011). Due to the increase in the number of adult patients seeking orthodontic treatment, certain procedures adopted in the office have to be modified to fit this new patient profile. Orthodontic treatment may serve as a pre-prosthetic activity, in which the clinicians are confronted not only with healthy dental elements, but also with extensive composite resin restorations, implants, and metal, ceramic, and provisional crowns. The literature does not present conclusive evidence regarding the ideal protocol for bonding brackets to ceramic surfaces such as lithium disilicate and feldspathic porcelain or to provisional materials such as acrylic resin, especially with respect to CAD/CAM materials. Therefore, the objective of the present in vitro study was to evaluate the bond strength and adhesive remnant index (ARI) of metallic and ceramic brackets bonded to the surfaces of different CAD/CAM blocks (feldspathic, lithium disilicate, and acrylic resin) using Transbond XT adhesive (3M Unitek, Monrovia, CA, USA). The null hypotheses of the study were as follows. H01: There is no significant difference in the bond strength between ceramic and metallic brackets when bonded to the same CAD/CAM ceramic or acrylic resin surface and H02: there is no difference in the ARI of different adhesive protocols.

# SUBJECTS AND METHODS

**Sample Preparation:** The study was performed using CAD/CAM blocks of three different materials (n=12): feldspathic ceramic (FEL) (CEREC Blocks, Dentsply Sirona, São Paulo, SP, Brazil), lithium disilicate (LDC) (E-max CAD, IvoclarVivadent, Barueri, SP, Brazil), and acrylic resin – AR (Vipi Block Trilux, VIPI, Pirassununga, SP, Brazil). Each block was cut into four rectangles using a double-sided diamond disc (Extec, Enfield, CT, USA) mounted on a hard tissue microtome (Isomet Buehler, Lake Bluff, IL, USA) at a cutting speed of 250 rpm and under constant cooling to obtain 72 specimens (10 mm × 10 mm × 3 mm). The specimens were obtained through a single cut, ensuring a flat surface.

**Surface Treatment:** The surfaces of all blocks were cleaned with pumice paste and water. Subsequently, the feldspathic porcelain blocks were conditioned with 10% hydrofluoric acid (Power C-etching, BM4, Maringá, PR, Brazil) for 60 seconds. The lithium disilicate blocks were conditioned with 5% hydrofluoric acid (Power C-etching, BM4, Maringá, PR, Brazil) for 20 seconds. The acrylic resin blocks were conditioned with 5% hydrofluoric acid for 20 seconds. All blocks were rinsed with air/water spray for 30 seconds and air-dried for 30 seconds. On each ceramic block, two layers of ceramic primer (Monobond Etch & Prime, IvoclarVivadent, Barueri, SP, Brazil) were applied and the primer coats were dried for 60 seconds. The specimens were then randomly divided into 6 groups (n=12): The G1 group consisted of metallic brackets (Victory Series, 3M Unitek, Monrovia, CA, USA) bonded to FEL ceramic blocks. The G2 group consisted of metallic brackets bonded to LDCblocks. The G3 group consisted of metallic brackets bonded to AR blocks. The G4 group consisted of ceramic brackets (Clarity, 3M Unitek, Monrovia, CA, USA) bonded to FEL ceramic blocks. The G5 group consisted of ceramic brackets bonded to LDC blocks. The G6 group consisted of ceramic brackets bonded to AC blocks. In all groups, metallic and ceramic brackets for upper premolars were bonded to the blocks using Transbond XT light-curing bonding resin, following the manufacturer's recommendations (Table 1). The brackets were placed on the surface of the blocks and the excess material was removed with a No. 05 explorer probe (Golgran, São Caetano do Sul, SP, Brazil). Light curing was carried out using a light-emitting diode curing system (Radii Cal, SDI, Bayswater, VIC, Australia) with 1100 $mW/cm^2$ intensity in four positions (on each side of the bracket) for 20 seconds each. The specimens were stored in distilled water at 37° C for 24 hours until evaluation.

**Shear Test:** The shear strength test was performed using a testing machine (EMIC DL 2000, EMIC, São José dos Pinhais, PR, Brazil) with the load applied using a blade rod at a speed of 0.5 mm/min and a load cell of 500 N. The bond strength was calculated in megapascals (MPa).

**Table 1. Distribution of materials used in the experimental groups**

| Groups | Orthodontic bracket type and adhesive system | Orthodontic bracket |
|---|---|---|
| G1 | Metal brackets for upper Victory premolar (3M Unitek, Monrovia, Calif, USA), cemented with Transbond ™ XT System, (3M Unitek, Monrovia, Calif, USA) | CAD-CAM Feldspar Ceramic Blocks. |
| G2 | | CAD-CAM Lithium Disilicate Ceramic Blocks. |
| G3 | | CAD-CAM Acrylic resin blocks |
| G4 | Clarity ceramic brackets (3M Unitek, Monrovia, Calif, USA) for upper premolar, cemented with Transbond ™ XT System, (3M Unitek, Monrovia, Calif, USA) | CAD-CAM Feldspar Ceramic Blocks. |
| G5 | | CAD-CAM Lithium Disilicate Ceramic Blocks. |
| G6 | | CAD-CAM Acrylic resin blocks |

**Table 2. Mean (± standard deviation) of shear bond strength in each group (in MPa)**

| Groups | CAD/CAM block type | Orthodontic bracket | Bond strength |
|---|---|---|---|
| G1 | Feldspathic Ceramics | Metallic | $3.89 \pm 0.70^{c}$ |
| G2 | Lithium disilicate | Metallic | $5.86 \pm 1.13^{bc}$ |
| G3 | Acrylic resin | Metallic | $9.65 \pm 2.63^{a}$ |
| G4 | Feldspathic Ceramics | Ceramic | $6.29 \pm 1{,}82^{b}$ |
| G5 | Lithium disilicate | Ceramic | $5.20 \pm 1.59^{bc}$ |
| G6 | Acrylic resin | Ceramic | $9.04 \pm 2.37^{a}$ |

*Note*: Different letters indicate a statistically significant difference ($p < 0.05$).

**Adhesive Remnant Index:** To define the location of the failure, all specimens were observed under an optical microscope (SZH-131, Olympus, Tokyo, Japan) at 100× magnification after testing. The fractures were classified as adhesive, cohesive, or mixed. Adhesive failure was defined as fracture involving the adhesive line or the adhesive-composite resin interface. Cohesive failure was defined as fracture involving only one of the substrates (ceramic or resin). Mixed failures were defined as fractures involving some of the adhesive failure interfaces in conjunction with the fracture of one or both substrates, which occurred at the adhesive line and in the ceramic or composite resin simultaneously. Fracture patterns were qualitatively assessed. Three samples from each group were prepared and observed using a scanning electron microscope to identify the fracture pattern. The samples were gold coated (Polaron SC7620, Thermo Scientific, Waltham, MA, USA) and examined using a scanning electron microscope (JEOL 5500, JEOL Inc., Peabody, MA, USA) (10 kV, 30× magnification).

**Statistical Analysis:** The data were tabulated and statistically analyzed using IBM SPSS Statistics 22.0 (IBM Corp., Armonk, NY, USA). The data were tested for normality using the Shapiro-Wilk test. Subsequently, analysis of variance (ANOVA) was performed followed by Tukey's post-hoc test.

# RESULTS

The results of the shear strength test are presented in Table 2. The group including ceramic brackets bonded to CAD/CAM acrylic resin (G3) showed the highest bond strength when compared with the other groups ($p<0.05$). However, there was no statistically significant difference between groups G3 and G6 ($p>0.05$). The G1 group showed significantly lower shear strength values when compared with the other groups ($p<0.05$). Groups G3 and G6 showed a higher percentage of adhesive failures(91.66% and 91.34%, respectively). Groups G1 and G4 showed a higher percentage of mixed failures (83.44% and 83.33%, respectively). Groups G1, G4, and G5 showed similar percentages of cohesive failures (16.56%, 16.66%, and 16.03% respectively) (Table 3). The fracture analysis is illustrated in Figure 1.

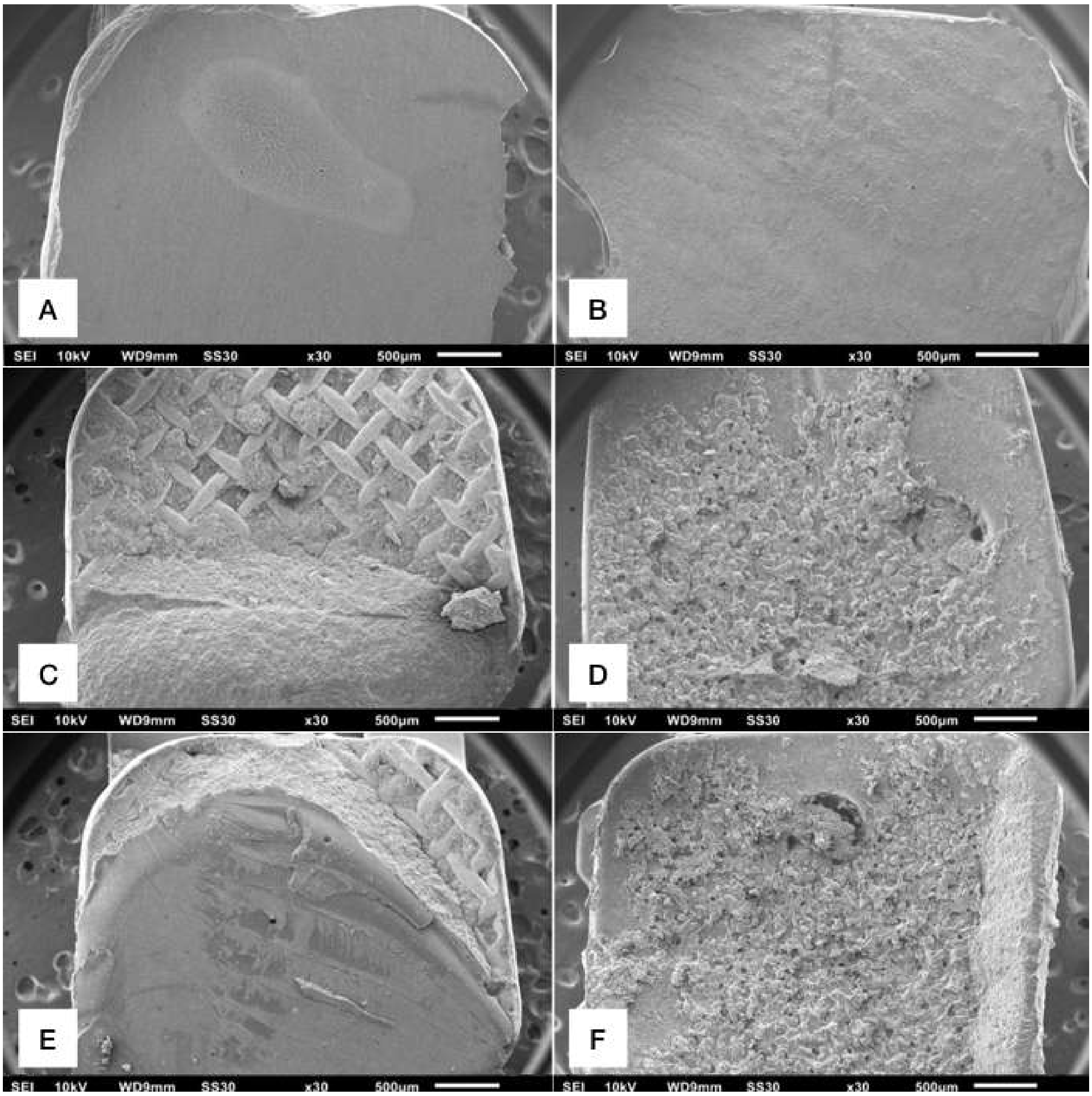


**Figure 1. Adhesive failures in groups a) G3 and b) G6, Mixed failure in groups c) G1, d) G4, and e) G5, and f) cohesive failure in group G5 observed under a scanning electron microscope at 30× magnification**

**Table 3. Fractographic analysis of the groups in percentage (evaluation of the bracket base)**

| Groups | Type of fracture (%) | | |
|---|---|---|---|
| | A | M | C |
| G1 | - | 83.44% | 16.56% |
| G2 | 50.00% | 50.00% | - |
| G3 | 91.66% | 8.33% | - |
| G4 | - | 83.33% | 16.66% |
| G5 | 8.33% | 75.00% | 16.03% |
| G6 | 91.34% | 8.33% | - |

Note: A - Adhesive Failure; M - Mixed failure; C - Cohesive failure.

# DISCUSSION

The specimens were subjected to shear test to measure the adhesive strength. The shear test is the most frequently used laboratory method to assess the bond strength of orthodontic brackets (Falkensammer et al., 2012;Oilo, 1993). Reynolds suggested that clinically acceptable bond strength should range between 5.8 and 7.8 MPa (Reynolds, 1975). In the present study, only the group containing ceramic brackets bonded to FEL presented bond strength values within this ideal range. The groups containing metallic brackets bonded to FEL and LDC had lower bond strength values than those recommended by Reynolds. On the other hand, AR groups presented higher values than this recommended range regardless of the type of orthodontic bracket. Therefore, fist hypothesiswas rejected. The higher bond strength of ceramic brackets to FEL may be explained partly by the characteristics of the orthodontic attachment. The base of the ceramic bracket is composed of polycrystalline alumina with a rough base and randomly oriented crystals or spherical glass particles that provide a favorable micromechanical interlocking with the orthodontic adhesive (Trakyali et al. 2009).On the other hand, there was no influence of the bracket type on the bond strength to LDCand RA. This finding is consistent with that reported by Willems et al., who tested the adhesive strength of several types of orthodontic brackets and concluded that the type of orthodontic bracket does not affect the quality of adhesion (Willems, Carels& Verbeke, 1997).

Ceramic surface treatment is essential for achieving ideal bond strength of orthodontic brackets bonded to ceramic surfaces. Treatment methods can be mechanical or chemical and may involve the use of hydrofluoric or phosphoric acid and adhesive agents (Buyuk&Kucukekenci).In the present study, hydrofluoric acid was used for surface treatment in all groups, with differences only in its concentration. The protocol was based on recommendations in the literature for ceramic materials, namely 5% hydrofluoric acid for lithium disilicate ceramics and 10% hydrofluoric acid for feldspathic ceramics (Mokhtarpour, Alaghehmand & Khafri 2017). The results of the present study revealed that LDCpresented with greater bond strengths than FEL in the groups that included metallic orthodontic brackets. Such a comparisons has not been reported previously for CAD/CAM blocks. However, Turk et al.(2006) observed greater bond strengths of metallic brackets with LDC than with FEL in a similar methodological design. On the other hand, Elham et al.(2010)observed that FEL presented higher bond strengths when compared to LDC. These differences may be due to the different processing methods and the structure of the two ceramics (Craig& Powers, 2002).Data regarding bonding strengths associated with CAD/CAM materials is scarce and further studies are encouraged to provide more evidence. Acrylic teeth are made of polymethylmethacrylate with long unique linear polymer chains formed after polymerization by free radicals. The high density and low porosity of this material results in reduced bonding potential at the bonding sites (Craig& Powers, 2002), resulting a deficient polymerization when compared with other materials (Maryanchik et al. 2010).In the present study, the acrylic resin groups presented a high shear resistance for metallic brackets (G3) as well as for ceramic brackets (G6).

This finding can be explained by the composition of the CAD/CAM acrylic resin blocks. CAD/CAM acrylic resin is a composite of acrylic resins and organically modified ceramic nanotechnology materials. In addition, the ceramic blocks received surface treatments according to the manufacturers' recommendations. It is possible that this finishing protocol resulted in less roughness on the block surface, which does not occur in the case of acrylic resin blocks. The ideal mode of detachment of brackets and orthodontic attachments should be adhesive failure between the adhesive and the porcelain in such a way that the entire adhesive is removed with the bracket, leaving the ceramic surface free of any resinous residues (Maryanchik et al. 2010, Anca et al. 2021).In the present study, the CAD/CAM acrylic resin groups showed the highest percentage of adhesive fractures, demonstrating that CAD/CAM acrylic resins used as provisional materials are effective for bonding of orthodontic attachments. A considerable number of studies have analyzed brackets bonded to acrylic resin. However, no previous study has investigated the behavior of orthodontic brackets bonded to CAD/CAM acrylic resin blocks. However, it was not possible to compare the results of this study with data from previous studies. Clinical trials with a low risk of bias are warranted to clarify this issue In conclusion, the present study demonstrated that the bond strength of brackets bonded to ceramic blocks depended on the surface structure of the CAD/CAM materials. Bonding of metallic and ceramic brackets to CAD/CAM acrylic resin blocks showed greater bond strength than bonding of brackets to ceramic blocks. Bonding to acrylic resin was associated with a higher percentage of adhesive fractures, which is favorable for bracket removal.

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