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Effect of shear bond strength of metallic orthodontic brackets bonded with and without dental adhesive

Efeito da resistência ao cisalhamento de braquetes ortodônticos unidos com e sem adesivo dentário

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ABSTRACT

Objective: The aim of this study was to evaluate the shear bond strength (SBS) of two materials for bonding orthodontic brackets on dental enamel before and after thermocycling. **Material and Methods:** Forty bovine incisors were divided into four groups (n=10). All teeth were etched with 35% phosphoric acid (3M Espe). For bonding of the brackets, G1 and G2 received orthodontic composite resin (Fill Magic Ortodôntico) and G3 and G4, an adhesive (ScotchBond) was used before the orthodontic resin Transbond XT (3M Unitek). G1 and G3 were kept at 37ºC for 24h and G2 and G4 were submitted to thermocycling (5000 cycles, at 5ºC - 55ºC) prior to SBS testing, performed by a universal machine (EMIC) at 1 mm/min, with a 50kgf load cell. Results were analyzed with two-way ANOVA, followed by Tukey's test (p=0.05). Adhesive surfaces were evaluated through stereomicroscopy and classified according to the type of failure presented. **Results:** Surface treatment with dental adhesive presented higher SBS values, regardless thermocycling (G3: 12.01 MPa; G4: 12.36 MPa) and the lowest values occurred in G2 (8.89 MPa). For groups without adhesive and with thermocycling, a higher number of completely adhesive failures between composite and enamel were present. For groups in which dental adhesive was used, regardless thermocycling, the failures were mainly adhesive between composite and the bracket. **Conclusion:** Surface etching of enamel with 35% phosphoric acid with or without adhesive showed a positive effect on SBS. The application of adhesive on enamel surface contributed to the maintenance of SBS values after thermocycling.

KEYWORDS

Aging; Orthodontic brackets; Composite resins; Shear strength.

RESUMO

Objetivo: O objetivo desse estudo foi avaliar a resistência ao cisalhamento de dois materiais para fixação de braquetes ortodônticos ao esmalte dentário antes e após a termociclagem. **Material e Métodos:** Quarenta incisivos bovinos foram divididos em quatro grupos (n=10). Todos os dentes foram condicionados com ácido fosfórico a 35% (3M Espe). Para a fixação dos braquetes, G1 e G2 receberam a resina composta ortodôntica (Fill Magic Ortodôntico) e G3 e G4, um adesivo dentário (ScotchBond) foi usado antes da resina ortodôntica Transbond XT (3M Unitek). G1 e G3 foram mantidos a 37ºC por 24h e G2 e G4 foram submetidos à ciclagem térmica (5000 ciclos, de 5ºC - 55ºC) anterior ao teste de resistência ao cisalhamento, realizado por máquina universal (EMIC) a 1 mm/min, com célula de carga de 50kgf. Os resultados foram analisados com ANOVA 2-fatores, seguida do teste de Tukey (p=0,05). As superfícies adesivas foram avaliadas através de estereomicroscopia e classificadas de acordo com o tipo de falha presente. **Resultados:** O tratamento de superfície com adesivo dentário apresentou maiores valores de resistência ao cisalhamento, independente da termociclagem (G3: 12,01 MPa; G4: 12,36 MPa) e os menores valores ocorreram para G2 (8,89 MPa). Para os grupos sem adesivo e com termociclagem, o maior número de falhas predominantemente adesivas entre resina composta e esmalte estava presente. Para os grupos em que o adesivo dentário foi utilizado, independente da termociclagem, as falhas foram principalmente adesivas entre resina composta e o braquete. **Conclusão:** O condicionamento superficial do esmalte com ácido fosfórico a 35% com ou sem adesivo mostrou um efeito positivo sobre a resistência ao cisalhamento. A aplicação de adesivo na superfície do esmalte contribuiu para a manutenção dos valores de resistência ao cisalhamento após a termociclagem.

PALAVRAS-CHAVE

Envelhecimento; Braquete ortodôntico; Resinas compostas; Força de cisalhamento.

INTRODUCTION

The concept of adhesion of dental materials to enamel was first introduced in 1955 by Michael G. Buonocore [1] and only in 1979 there was a description of bonding orthodontic brackets to enamel with photocured composite resins [2]. The development of bonding materials and orthodontic brackets has contributed to simplifying the process of bonding, with the reduction of operatory steps, and consequently, reducing time [3-5].

The adequate bonding of orthodontic brackets to teeth structure is a prerequisite for a successful orthodontic treatment. However, to achieve adequate bonding without damaging tooth structure can be challenging [4,6], thus, the bonding system used to bond orthodontic brackets to teeth structure must not fail during the period of orthodontic treatment [4]. One of the methods of enamel treatment is the etching of the surface with phosphoric acid, which can be combined with different adhesive systems and composite resins [7]. An acceptable bonding system must resist to the forces applied by orthodontic wires, such as shear, in an oral environment where restorations are aged [8,9].

Shear bond strength (SBS) testing is directly linked to the evolution of bonding materials, since it is the most efficient and used method to quantify the bonding resistance of orthodontic brackets to human enamel [10]. The influence of each variable involved (surface treatment, adhesive systems and aging) must contribute to the achievement of an ideal bonding, with the primordial intention of obtaining clinical success.

The purpose of the present study was to evaluate the (SBS) of metallic orthodontic brackets to bovine enamel using different adhesive systems and composite resins before and after thermocycling. The null hypothesis was that neither surface treatments nor in vitro aging would affect SBS.

MATERIAL AND METHODS

Teeth preparation

For the confection of the specimens, recently extracted bovine teeth were used. Teeth were obtained in a certified slaughterhouse. Criteria for inclusion of teeth included absence of abnormalities on the surface of enamel, absence of fractures or surface cracks. All teeth were analyzed under stereomicroscopy (Discovery V20, Zeiss, Göttingen, Germany) and a total of 40 teeth were chosen. Crowns were separated from roots at the enamel-cement joint, using a circular saw (Edenta, Labordental, SP, Brazil) under constant water cooling. Cleaning of the enamel surface was performed using rubber cups, pumice and water for 20 s, for the removal of surface debris. All teeth were dried for 20 s and posteriorly, sterilized in autoclave (Cristófoli Equipments of Biosecurity Ltda, Campo Mourão, Paraná, Brazil) with 134ºC for 15 min.

Sample preparation

To standardize the enamel parallel surface, the lingual surface was embedded in acrylic resin (Jet, Clássico, SP, Brazil) at the center of a PVC tube (Polyvinyl chloride, Tigre, Joinville, Brazil), leaving the buccal surface exposed. Using a glass plate, the enamel surface was correctly positioned and held down until final setting of the acrylic. All enamel buccal surfaces were polished with #600 and #1200 silicon carbide sandpaper (Norton Abrasives, Guarulhos, SP, Brazil) using a politrix (EcoMet 250 Grinder Polisher, Buehler, Lake Buff, Illinois, USA), under water cooling. Before the bonding of the orthodontic brackets, all surfaces were cleaned with isopropyl alcohol to remove any debris from the polishing of the surfaces.

Experimental groups and bonding procedure

The division of the groups, as well as the materials used in this study and their composition are described in Table I.

Table I - Experimental groups and materials used.

Group	Enamel etching	Adhesive system and cementation agent	Composition	Thermocycling
G1	35% phosphoric acid (Scotchbond Etchant, 3M Espe Dental Products, St Paul, Mn, USA)	Fill Magic Ortodôntico (Vigodent/Coltene, RJ, Brazil)	bisphenylglycidyl dimethacrylate (BisG-MA), ethoxylated bisphenol-A dimethacrylate (Bis-EMA), UDMA, triethylene glycol dimethacrylate (TEGMA), ethyl 4-dimethylaminobenzoate (EDAB), BHT, photoiniciator, resin load, ytterbium fluoride and pigments	Without
G2				With
G3		Adhesive: Adper Scotchbond (3M Espe Dental Products, St. Paul, MN, USA) + Transbond™ XT (3M Unitek, Mn, CA, USA)	Primer: triethylene glycol dimethacrylate (TEGDMA), bisphenylglycidyl dimethacrylate (BisGMA) Adhesive paste: silica, Bis-GMA, silane, N-dimethylbenzocaine, hexa-fluoride-phosphate	Without
G4				With

All enamel surfaces were etched using 35% phosphoric acid (ScotchbondTM Etchant, 3M Espe, St. Paul, MN, USA) for 30 s, following by rinsing and complete air drying using triple syringe, free of oil. Specimens were randomly divided into two groups (n=20) according to the adhesive system and composite resin used: half of the specimens received orthodontic resin (Fill Magic Ortodôntico, Vigodent/Coltene) and the other half received the application of dental adhesive (Adper Scothbond, 3M Espe, St. Paul, MN, USA) and orthodontic resin (Transbond™ XT, 3M Unitek, Monrovia, CA, USA). According to the manufacturer, the orthodontic resin Fill Magic does not require dental adhesive. A single type of NiCr metallic bracket was chosen (Orthodontic Bracket M.B.T. Prescription Standard, Dental Morelli Ltda, Sorocaba, SP, Brazil; 9.75mm^2 base area; -6º torque and 0º angulation; lot: 1663210). All procedures were performed by a single operator.

In groups G3 and G4, a thin layer of dental adhesive (ScotchBond, 3M Espe, St. Paul, MN, USA) was actively applied using a microbrush (Vigodent, Rio de Janeiro, RJ, Brazil) on the dry enamel surface for 20 s and photocured for 40 s with light emitting diode (LED) (high intensity of 1000 mW/cm^2; wavelength ranging from 440 to 480 nm - Radii-Cal, SDI, Dublin, Ireland).

Brackets were kept stable using orthodontic tweezers (serial number: 75.01.022; Morelli Ortodontia, Sorocaba, SP, Brazil) to receive a single increment of composite resin. Then, they were positioned on the enamel surface, held down using a 750 g load for 10 s, to ensure that the base of the bracket was parallel bonded to the enamel surface and that enough pressure was present to eliminate the excess of composite resin. Lateral excesses were removed using a microbrush and the set was photocured for a total of 50s, 10s on each lateral side (0º, 90º, 180º and 270º) and 10 s on the upper face (buccal) of the bracket.

Thermocycling

Half of the specimens of each group (n=10) was kept in distilled water in a stove (Olidef, Ribeirão Preto, SP, Brazil) at 37 ºC for 24 h, before shear bond testing. The other half was submitted to thermocycling (n=10), in a thermocycler (Nova Ética, São Paulo, SP, Brazil), with a total of 5000 cycles, with temperature ranging from (5 ± 1) ºC to (55 ± 1) ºC, with 30 s of immersion in each bath and 15 seconds of water drainage, forming a thermal cycle.

Shear bond strength test

After either being kept in water at 37 ºC for 24 h or being thermocycled, all specimens were submitted to shear bond testing in a universal testing machine (EMIC DL-1000, EMIC, São José dos Pinhais, PR, Brazil), with a 50 kgf load cell. A 0.45 mm wire was used for the test, being placed on the enamel-adhesive interface (Figure 1), in incise-gingival direction, at 1 mm/min crosshead speed. SBS is the maximum load needed for debonding or initial failure (either on the adhesive system or on the tooth structure), being recorded in Newton (N), and then converted into megapascal (MPa = $N.mm^{-2}$) according to the following ratio: SBS = N/A, in which SBS is the shear bond strength (MPa), N is the debonding load required (Newton) and A is the bonding area developed on the bracket ($9.75mm^2$ - according to the manufacturer's instructions).

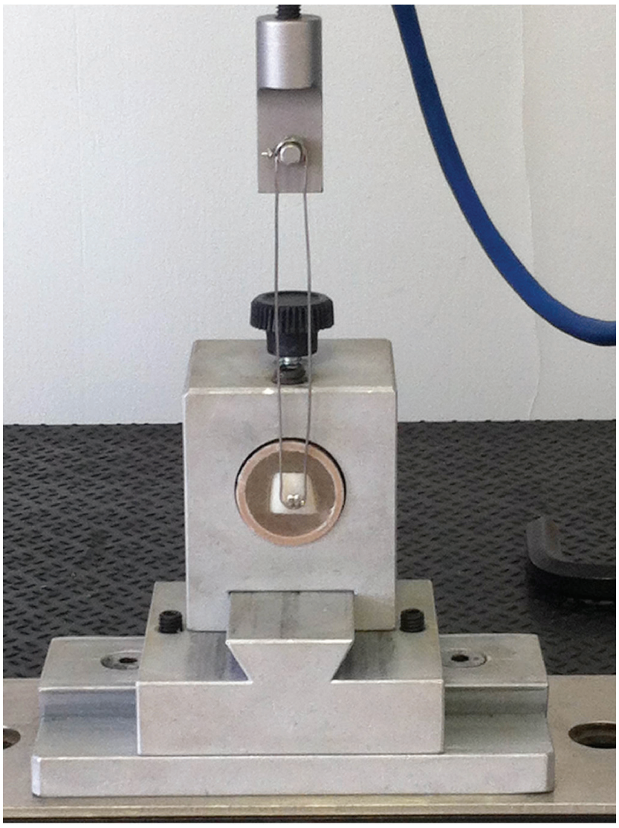

Figure 1 - Sample held in position for the SBS test.

Analysis of the failure mode

After shear bond testing, enamel surface was analyzed under optical stereomicroscope (Discovery V20, Zeiss, Göttingen, Germany) with 10× magnification to identify the failure mode. Failures were classified according to the composite resin - enamel interface or the enamel-orthodontic bracket interface, as following: completely adhesive, between composite resin and enamel; predominantly adhesive, between composite resin and orthodontic bracket; and completely adhesive, between composite resin and orthodontic bracket.

Statistical analysis

The data were analyzed with the statistical software program MINITAB 17.0 (Minitab, PA, USA). First, the data of descriptive statistics, including mean value and standard deviation, were calculated for all groups. A two-way analysis of variance (ANOVA) test was used for multiple comparisons of SBS between groups and the post hoc Tukey's test were conducted (α=0.05).

RESULTS

Descriptive statistical analysis (mean and standard deviation) of SBS (MPa) results for all groups are showed in Table II and Figure 2. Two-way ANOVA (Table II) showed a significant interaction effect for the "adhesive system" factor, which indicated that there was alteration in the SBS according to the type of adhesive (p = 0.022). For the factor "thermocycling" there was not significant interaction (p = 0.168), as well as in the interaction adhesive system + thermocycling concomitantly.

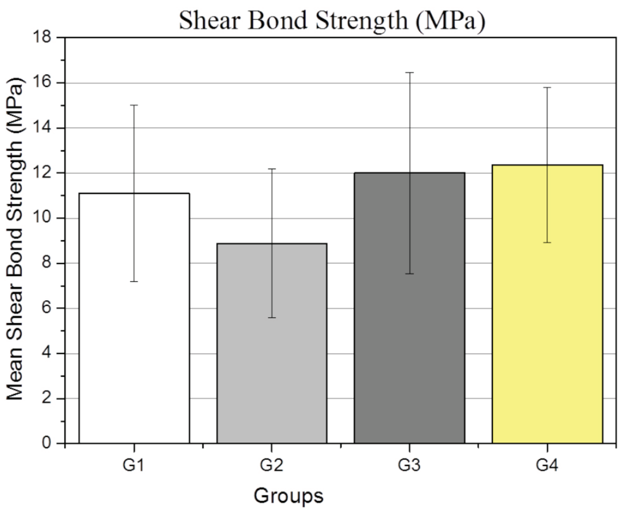

Figure 2 - Mean shear bond strength for the different groups.

Post-hoc Tukey test showed differences between groups (p = 0.345) (Table II). For the groups comparing adhesives, without considering thermocycling, G3 presented the highest SBS values (12.01 ± 4.46 MPa), being statistically similar to the group without adhesive (G1), which presented lower SBS values (11.09 ± 3.91 MPa). When the interaction between "adhesive system" and "thermocycling" factors are compared, groups G1 and G4 showed statistically different values. G4 presented higher SBS values (12.36 ± 3.43 MPa) when compared to the other groups.

Table II - Descriptive statistics of shear bond strength (SBS) among experimental groups (MPa).

Shear Bond Strength (SBS)			
		Range	
Groups	Mean and SD (MPa)	Lower limit (MPa)	Upper limit (MPa)
G1	11.09 ± 3.91[A]	5.14	20.02
G2	8.89 ± 3.29[AB]	5.89	13.51
G3	12.01 ± 4.46[AB]	7.41	21.40
G4	12.36 ± 3.43[B]	7.18	19.61

*Same superscript letters indicate statistical equality.

Results of failure analysis are shown in Table III and in Figure 3. In Figure 3, letter A represents a completely adhesive failure between composite resin and enamel; B represents predominantly adhesive failure, between composite resin and orthodontic bracket and C represents a completely adhesive failure, between composite resin and orthodontic bracket.

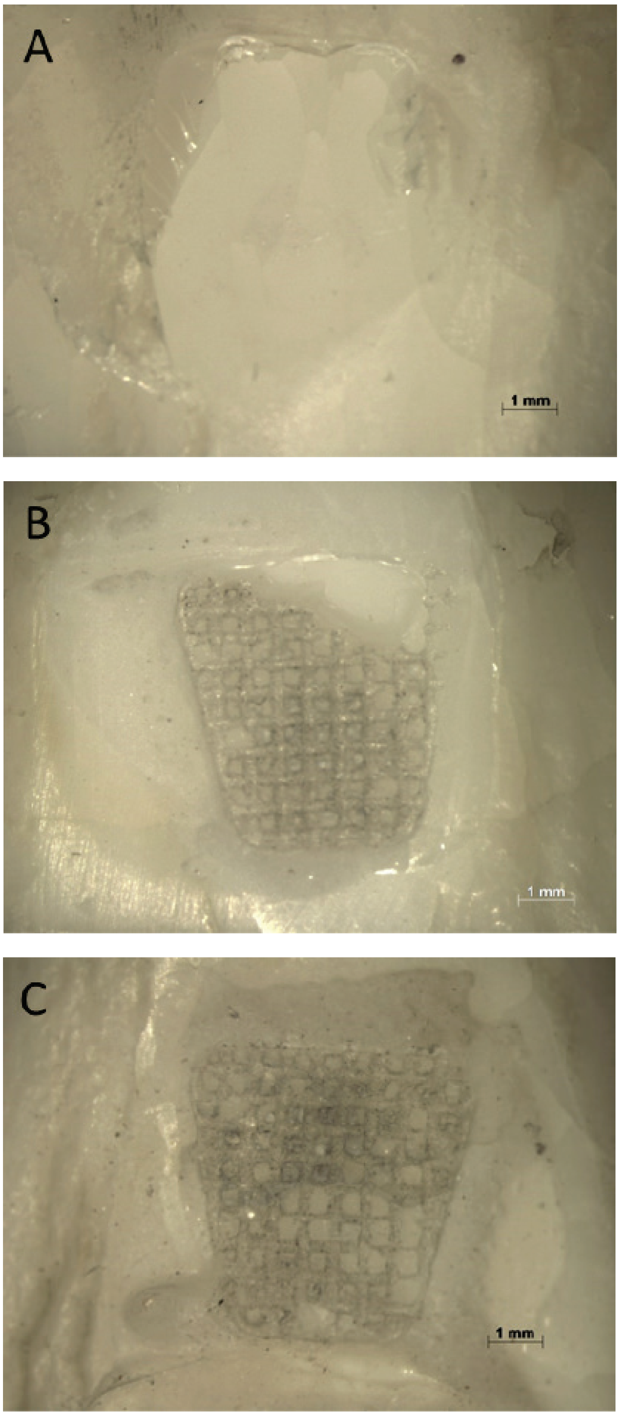

Figure 3 - View of types of failures under stereomicroscope (10× magnification).

Table III - Frequencies of the failures on the adhesion interface (in %).

Groups	Completely adhesive failure between composite resin and enamel	Predominantly adhesive failure between composite resin and orthodontic bracket	Completely adhesive failure between composite resin and orthodontic bracket
G1	1	3	6
G2	7	1	2
G3	3	7	0
G4	3	7	0

*Same superscript letters indicate statistical equality.

Most of the failures in G1 was completely adhesive between composite resin and orthodontic bracket and in G2, completely adhesive between composite resin and enamel. Groups G3 and G4 presented the same frequency of failures. Thermocycling was the factor that diminished SBS between composite resin and enamel only for the group that did not receive the application of adhesive system.

DISCUSSION

Once the findings of the present study showed that acid etching on enamel surface, on the absence of adhesive, presents clinically acceptable bond strength, but lower in relation to its application, the first null hypothesis was partially accepted. In addition, current findings in the literature highlighted the potential influence of thermocycling/aging [11,12] and the type of adhesive system on bond strength [13], denying the second null hypothesis. Therefore, SBS was affected by both factors: "adhesive system - cementation agent" and "aging - thermocycling".

There is lack of consensus when regarding the usage of adhesive systems in the bonding of orthodontic brackets to enamel [14,15], thus it is indispensable the usage of a material that adequately bonds the bracket to enamel, however not causing any damage to enamel surface. For this matter, in this present study, 35% phosphoric acid was used, since it is responsible for the dissolution of apatite crystals and the creation of microporosities on the surface morphology [16]. In a previous study, it was demonstrated that for enamel demineralization, the application of 35% wt and pH < 1.0 phosphoric acid is needed [17].

In addition to acid etching of enamel surface, a dry, clean, free of saliva operative field is mandatory, so that the performance of adhesive systems is not affected [18]. It is known that cross-linking methacrylates are the main adhesive-resin component of a bonding system and those are responsible for the bond strength and the integrity of the adhesive layer, although presenting hydrophobic characteristics [19]. The most common are 2,2-bis[4-(3-methacryloyloxy-2-hydroxypropoxy)phenyl]propane (Bis-GMA), triethyleneglycol dimethacrylate (TEGDMA) and urethane dimethacrylate (UDMA) [20]. These components are found in the composition of two materials used in this present study, as described by the manufacturers (Table I).

Contact with liquids (such as water) with the composite resin, as well as the thermal shock and the storage period may cause degradation of the resinous matrix [21], which can lead to leaching of these monomers [22]. The main purpose of the adhesion process is based on reliability and durability of the union between substrates, as well as enhance interface chemistry and the capacity of reaction between adhesives and teeth surface. This reaction occurs when the substrate is exposed after the removal of barriers and the adhesive systems applied on the enamel surface are capable of forming direct connections with the substrate [23].

The capacity of shear bond resistance of orthodontic brackets is also dependent on the adhesive system used, even when the bonding agent is absent [24]. It is important to consider that for a successful orthodontic treatment, the maintenance of brackets in the oral cavity for a long period of time is mandatory [25], and this way the aging simulation through thermocycling was proposed. Based on the results of this present study, the higher SBS values were from the group that received bonding of composite resin after the use of the dental adhesive, immediately or after aging. However, the results were statistically similar with or without the use of adhesive after thermocycling. This fact shows that it is possible to bond orthodontic brackets effectively, causing less damage to tooth structure [6] and maintaining the effective union between tooth structure and bracket during the orthodontic treatment [26].

Failure analysis can be related to SBS values, since when the bracket was bonded using an orthodontic composite resin after the usage of a bonding system [3,13,27], regardless thermal aging, bond strength was higher, with a higher quantity of predominantly adhesive failures between composite resin and orthodontic bracket (Table II). Unlike the behavior of the groups without adhesive system, the findings of this study showed that thermocycling was an important factor in diminishing SBS values (8.89 ± 3.29 MPa) and in the presence of a higher quantity of completely adhesive failures between composite resin and enamel, which indicates that the usage of dental adhesive is crucial for maintaining the composite resin on the enamel, enabling a possible reduction of damage chances to tooth structure.

CONCLUSIONS

- The presence of dental adhesive for the bonding of orthodontic brackets enhances SBS when compared to orthodontic brackets bonded without dental adhesive;

- The presence of dental adhesive contributes to the maintenance of SBS values after thermocycling;

- Enamel surface etching and bonding of orthodontic brackets with composite resin caused less tooth structure damage and presented acceptable bond strength values between orthodontic bracket and tooth structure.

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