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Bond strength of different bracket bonding materials to the enamel subjected to thermal cycling[1]

Resistência de união de diferentes materiais de colagem de bráquetes ao esmalte submetidos à ciclagem térmica

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ABSTRACT

Objective
The aim of this study was to evaluate in vitro the shear bond strength of metallic orthodontic brackets to enamel using different bonding materials followed by thermal cycling.

Methods
A fluid composite resin (Transbond XT / 3M Unitek) and a resin-modified glass ionomer (Fuji Ortho LC / GC America Inc.) were evaluated. Eighty sound human premolars were randomly divided into eight experimental groups (n = 10), according to the material used and the number of thermal cycles: zero, 1000, 2000 and 3000 cycles. Bracket bonding was performed on the buccal surface of the teeth. After 24 hours, they were subjected to thermal cycling at temperatures ranging between 5° C and 55° C for 15 seconds each immersion. Shear bond strength was performed using a universal testing machine with a chisel-type tip at a speed of 0.5 mm / min. The bond strength data was analyzed using two-way ANOVA.

Results
No difference on shear bond strength was observed regarding the number of thermal cycles for each specimen (p = 0.873). A significant difference was found in shear bond strength between the bonding materials (p = 0.022), with significantly higher values for Transbond XT regardless of the number of thermal cycles.

Conclusion
The number of thermal cycles did not significantly affect the bond strength of the adhesive materials investigated. The bonding agent Transbond XT showed higher bond strength than Fuji Ortho LC regardless of the number of thermal cycles.

Indexing terms: *Glass ionomer cements. Resin cements. Shear bond strength.*

RESUMO

Objetivo
Avaliar *in vitro* a resistência de união por cisalhamento de bráquetes ortodônticos metálicos ao esmalte utilizando diferentes materiais para colagem em função da quantidade de ciclos térmicos.

Métodos
Foram avaliados um sistema de união com resina composta fluida (Transbond XT/3M Unitek) e um ionômero de vidro modificado por resina (Fuji Ortho LC/GC America Inc.). Oitenta pré-molares humanos hígidos foram aleatoriamente divididos em oito grupos experimentais (n=10), de acordo com os tipos de material e quantidade de ciclos térmicos: zero, 1000, 2000 e 3000 ciclos. A colagem dos bráquetes foi realizada na face vestibular dos dentes. Após 24 horas, foram submetidos à ciclagem térmica com temperaturas de imersão entre 5ºC e 55ºC por 15 segundos. Os testes de resistência de união foram feitos em máquina de ensaios universal com ponta tipo cinzel com velocidade de 0,5 mm/min. Os dados foram submetidos à ANOVA a dois critérios.

Resultados
Não houve diferença na resistência de união entre bráquetes e o esmalte em função do número de ciclos térmicos (p = 0,873). Houve diferença significativa na resistência de união proporcionada entre os materiais para colagem (p = 0,022), sendo que valores significativamente superiores foram obtidos com a utilização do Transbond XT, independentemente do número de ciclos térmicos.

Conclusão
A quantidade de ciclos térmicos não influenciou significativamente a resistência de união dos materiais. Transbond XT mostrou maior resistência de união do que o cimento Fuji Ortho LC, independentemente da quantidade de ciclos térmicos.

Termos de indexação: Cimentos de Ionômeros de vidro. Cimentos de resina. Resistência ao cisalhamento.

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INTRODUCTION

High flow composite resins are among the most widely used materials for bonding orthodontic appliances, due to a combination of uncomplicated clinical applicability as well as their low viscosity (flow type resins), which allows penetration of the material into the etched enamel and the bracket mesh[1]. However, they have a high modulus of elasticity and may cause high polymerization shrinkage stress and bond failures[1], in addition to being susceptible to the moisture present in the oral cavity[2].

Glass ionomer cement is also a material used for bonding orthodontic brackets. It features both chemical bonding to enamel as well as anticariogenic properties, in addition to being easily removed from the enamel surface, therefore preventing damage[3]. In order to facilitate clinical application and handling, resin components were added to the material, resulting in the so-called resin-modified glass ionomer cement, which shows more favorable clinical outcomes when compared to conventional glass ionomer[4].

Regardless of the material used for bonding, one should consider several factors that can lead to bond failure of orthodontic brackets to enamel, thus increasing the duration of the treatment, potential damage to the enamel surface and increased chair time due to the need for repeated procedures[5-6]. Among these factors, there are some that can influence bond strength at the time of bonding of the brackets to enamel - etching time, application of the adhesive system and curing time[1] – as well as factors inherent to the oral cavity, such as pH variations, incident masticatory stress, the patient's own occlusion and its sliding mechanics[7].

Bond strength must be high enough to provide bracket stability throughout the course of orthodontic treatment; although towards the end of treatment, such property may no longer be so important due to lighter forces, considering that the final movements are aimed at leveling the teeth within the dental arch. It should be considered that any material present in the oral cavity for a long period of time may have lost some of its mechanical properties due to imbibition, solubility and fatigue, thus reducing bond strength and introducing the need for further visits to reattach the appliances at this stage[8].

In laboratory tests, thermal cycling is used to simulate the normal aging experienced by materials in clinical practice, by subjecting them to repeated temperature fluctuations in hot and cold water and reproducing the thermal changes that occur in the oral cavity[7,9-10]. Although several studies have evaluated the bond strength of brackets bonded to enamel immediately or within the first few hours or weeks after bonding to enamel[1,5,11-12], there are only a few studies[7,13-15] that have investigated the effect of bonding material aging in terms of the number of thermal cycles on the bond strength and fracture mode, thus suggesting the need for further studies on this matter. Therefore, the objective of this study was to evaluate *in vitro* the effect of the number of thermal cycles on the shear bond strength and fracture mode of metallic orthodontic brackets bonded to enamel using either a composite resin or a resin-modified glass ionomer bonding system.

METHODS

This study was approved by the Research Ethics Committee of the São Leopoldo Mandic Dental School and Research Center (registration number 2012/0031). Eighty sound human upper and lower permanent premolars donated by the teeth bank of the São Leopoldo Mandic Dental School were used. Prophylaxis was performed on the coronal aspect of the teeth using rubber cups (KG Sorensen, Barueri, São Paulo, Brazil) and pumice (extra fine pumice stone, SS White, Rio de Janeiro, Rio de Janeiro, Brazil) and water for 10 seconds at low speed.

The teeth were embedded using standard cylindrical PVC molds (PVC tubes, Tiger, Joinville, Brazil). The latter were positioned vertically and filled with colorless acrylic resin (Vipi Flash, Pirassununga, Brazil) manipulated according to the manufacturer's directions and immediately poured into the PVC pipe. The tooth root was completely immersed into the resin, leaving the buccal surface of the tooth at a right angle with the horizontal plane. Once the acrylic resin was polymerized, a mark was made on the central area of the buccal surface of each tooth to optimize accuracy when bonding the brackets.

The materials used in the study, composition and / or specification, manufacturer and batch number are shown in Chart 1. The brackets were bonded following etching with 37% phosphoric acid for 15 seconds, rinsing with distilled water for 15 seconds and drying with compressed air for 5 seconds.

Chart 1. Materials used, composition and / or specification, manufacturer, batch number.

Materials	Composition / Specification	Manufacturer (city, state, country)	Batch number
Composite resin (Transbond XT)	Primer: camphorquinone, TEGDMA, Bis-GMA Composite resin: Bis-GMA, silane, n-dimethylbenzocaine, phosphorus hexafluoride, silica	3M Unitek (Monrovia, California, United States of America)	Primer: 712-034 Resin: 182301
Resin-modified glass ionomer (Fuji Ortho LC)	Net: polyacrylic acid, HEMA, UDMA, water Powder: glass aluminosilicate	GC America Inc., (Alsip, Illinois, United States of America)	1003161
Phosphoric acid (Condac)	37% phosphoric acid	FGM (Joinville, Santa Catarina, Brazil)	68059
Metal bracket Abzil Kirium Line Roth	Stainless Steel	Abzil Ind. E Com. Ltda (São José do Rio Preto-SP-Brazil)	1111800272

The materials for orthodontic bonding were handled according to the manufacturer's standards. For the composite resin group a uniform layer of *primer* was applied onto the tooth surface with a disposable brush (KGbrush, Cotia, Brazil), followed by a light jet of air for 5 seconds. A small amount of resin was applied to the base of the bracket, which was immediately placed on the tooth surface and light-cured. For the resin-modified glass ionomer, the powder and the liquid were mixed in a proportion of 1 measure of powder for two drops of liquid. The cement was mixed for 20 to 25 seconds on a glass plate using a spatula (spatula n. 24, Duflex, SS White, Rio de Janeiro, Brazil). A portion of this mixture was placed at the base of the bracket, which was positioned onto the tooth surface and light-cured.

The brackets were positioned onto the most central and flat portion of the buccal surface. Light manual pressure was applied and the excess cement was removed with a dental probe (exploratory probe n. 47, Duflex, SS White, Rio de Janeiro, Brazil). Light curing was performed using a halogen light curing unit (Demetron, LC Kerr Corporation, Orange, California, USA) for 40 seconds, 10 seconds on each side of the tooth (incisal, cervical, distal and mesial). Irradiance was measured every five brackets using a radiometer system (Newdent Equipment Ltd, Ribeirão Preto, SP, Brazil). The average irradiance was measured at 483mW / cm^2.

The teeth were stored in distilled water in an incubator (Odontobrás ECB1.3 Digital, Ribeirão Preto, Brazil) at 37ºC for 24 hours. The specimens were then randomly divided into eight groups according to the number of thermal cycles (Table 1).

The number of thermal cycles (1000, 2000 and 3000) was defined according to those commonly used in the literature, simulating aging for less than a year[16-18], whereby 10,000 (ten thousand) cycles corresponded to one year of aging[19]. A thermocycling equipment was used (Elquip, São Carlos, Brazil) set at 15-second dips to 5 seconds of transfer time. The immersion temperatures ranged from 5° C to 55° C. At the end of the thermocycling period, the shear bond strength tests were performed.

Table 1. Groups studied according to orthodontic bonding materials and number of cycles.

Groups	Number of Teeth	Sticking materials	Number of thermal cycles
1	10	Transbond XT	none (control)
2	10	Fuji Ortho LC	none (control)
3	10	Transbond XT	1000 cycles
4	10	Fuji Ortho LC	1000 cycles
5	10	Transbond XT	2000 cycles
6	10	Fuji Ortho LC	2000 cycles
7	10	Transbond XT	3000 cycles
8	10	Fuji Ortho LC	3000 cycles

The test specimens were taken to a universal testing machine (Emic DL2000, São José dos Pinhais, Brazil) for shear bond strength testing. A chisel-type tip was chosen to apply force to the contact interface between the orthodontic bracket and the enamel surface at a speed of 0.5 mm per minute. A digital caliper (Mitutoyo MIP / E 103, Suzano, Brazil) was used to measure the width and height of the metal bracket to calculate the bonding area between the material and the enamel. This area measured 10,88mm^2.

Bond strength value was calculated according to the following formula[6]: R = F / A, where:

R: corresponded to the shear strength in Megapascal (MPa);

F: was the load required to break the tooth-resin-bracket bond;

A: corresponded to the bonding area, represented by the bracket base area (10.88 mm^2).

Upon failure, the specimens were examined under a stereoscopic loupe (eikonal, São Paulo, Brazil) at 10 times magnification to define the adhesive remnant index (ARI). For the classification of the ARI, the following scores were used: 0 = no material adhered to the tooth; 1 = less than half the material adhered to the tooth; 2 = more than half the material adhered to the tooth and 3 = all the material adhered to the tooth, including the bracket mesh imprint.

ARI assessment was performed by a calibrated examiner with experience in this type of methodology.

Data homogeneity was verified using the Shapiro-Wilk test, given the assumptions for parametric statistical analysis. Bond strength data were evaluated using two-way analysis of variance (ANOVA). The ARI was displayed as a table containing median values and a graph showing distribution frequencies. The differences between the groups were analyzed using the Kruskal-Wallis test. The significance level was 5%, using the Minitab 16 program for the implementation of statistical calculations.

RESULTS

The two-way ANOVA showed no significant interaction between the factors *material for bracket bonding to enamel* and *number of thermal cycles* (p = 0.439). No difference in bond strength was observed between brackets and the enamel in terms of the number of thermal cycles to which the specimens were submitted (p = 0.873). A significant difference in bond strength was observed between the materials for brackets bonding (p = 0.022), where the higher values were obtained for the composite resin Transbond XT, regardless of the number of thermal cycles, as illustrated in Table 2.

Table 2. Mean and standard deviation of the shear bond strength values (MPa), in terms of the adhesive system used and number of thermal cycles

Thermal cycling	Transbond XT	Fuji Ortho LC	Overall mean
0	17.59 (6.34)	17.82 (4.02)	17.71 (5.17) *
1000	19.53 (7.84)	14.26 (6.37)	17.03 (7.49) *
2000	18.74 (9.81)	14.54 (5.37)	16.64 (8.00) *
3000	17.85 (5.06)	14.46 (5.92)	16.16 (5.63) *
Overall mean	18.37 (7.22) A	15.30 (5.46) B	-

Note: Mean followed by different letters indicate significant difference. Overall mean with an asterisk indicate no difference.

The Kruskal Wallis test showed no significant difference between groups (p = 0.6619) and the ARI (Table 3).

Table 3. Median and Kruskal Wallis test result for the adhesive remnant index, according to the adhesive system used and number of thermal cycles.

Group	Median
Transbond - control	1
Fuji Ortho - control	0.5
Transbond - 1000 cycles	0
Fuji Ortho - 1000 cycles	0
Transbond - 2000 cycles	0
Fuji Ortho - 2000 cycles	0
Transbond - 3000 cycles	0
Fuji Ortho - 3000 cycles	1

Figure 1 illustrates the percentage of scores for the ARI, according to the adhesive system and number of thermal cycles. In 40-80% of the specimens from all the experimental conditions, no adhesive remained on the tooth structure (score 0), except when the adhesive system with composite resin Transbond XT was not thermocycled and when the Fuji Ortho LC material was subjected to 3000 cycles, where there was a higher percentage of the ARI score 1, i.e., less than half the adhesive remained on the tooth structure. ARI score 1 was observed in all groups, representing 20-60% of the shear bond strength test failures.

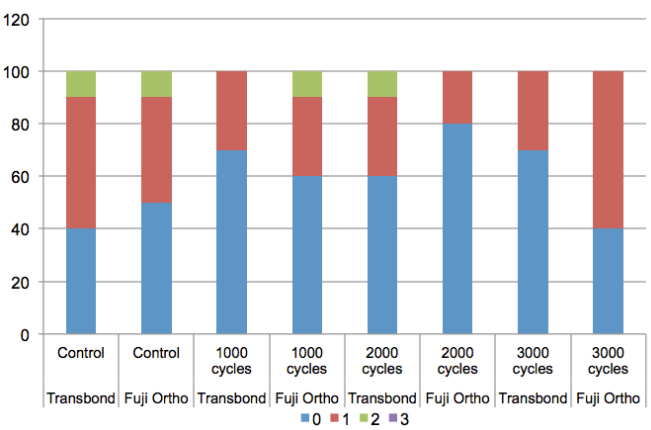

Figure 1. Bar chart showing the percentage of scores obtained for the adhesive remnant index, according to the adhesive system and number of thermal cycles.

In 10% of specimens bonded with Transbond XT or Fuji Ortho LC and not thermocycled, the presence of more than half of the adhesive was observed on the tooth surface (score 2). In no experimental condition was the adhesive fully retained on the enamel.

DISCUSSION

Thermocycling, among many methods, is considered a valid approach to simulate material aging *in vitro*[7,9-10,13,17]; however, there is no consensus in the literature on the number of cycles, temperature or immersion times[9-10]. Therefore, estimates of values close to *in vivo* conditions are extremely varied and the choice of such parameters is commonly based on convenience[7,9-10]. In a literature review by Morresi et al.[10], it was concluded that authors barely offer a rationale for the choice of temperature and, due to the great variability of cycles, temperature, immersion time and intervals between immersions, the data become practically incomparable.

In this study, the samples were submitted to 1000, 2000 and 3000 thermal cycles, with immersion temperatures between 5° C and 55° C, 15-second dips and a 5-second interval between immersions, in order to allow comparisons with other studies that used similar conditions[7,12,14-15,17]. In addition, the simulated aging corresponded to less than a year, since 10,000 (ten thousand) cycles would be needed to simulate one year of aging[19], which poses great difficulties in terms of laboratory testing, since this would require months to be achieved.

The results showed no significant effect of the number of thermal cycles and materials used for bracket bonding, nor was there any difference in bond strength between brackets and enamel in terms of the number of thermal cycles within the same bonding material group. These results are similar to those found by Aguilar et al.[17] who noted that 3000 thermal cycles between 5° C and 55° C and intermediate temperature of 37° C did not affect the bond strength of the materials used (Scotchbond MP, OptiBond FL, Amalgambond Plus and OptiBond dual cure). These authors suggested that the most important factor in material degradation could be the water, since no difference in bond strength was observed between the thermocycled and water-stored control specimens. Furthermore, they stated that water absorption during thermocycling may counterbalance the shrinkage caused by polymerization, thus reducing shrinkage stress, which could lead to bond failure[17].

The resin matrix of the composite resin absorbs less water than glass ionomer and is more resistant to hydrolytic degradation for being less hydrophilic and absorbing less water over time[20]. Furthermore, glass ionomer cements feature rapid water imbibition in addition to leaching several components, such as organic molecules, silicate, fluoride, calcium and other ions[8]. However, another factor to be considered is temperature fluctuation, to which the specimens were subjected, as well as the distinct linear thermal expansion coefficients of the materials used. It is known that differences between thermal expansion coefficient of the tooth substrate and the material can result in detachment and gap formation, where glass ionomer holds an advantage over resin as it has a linear thermal expansion coefficient closer to that of the enamel [21]. Another factor to consider is fatigue, where the influence of occlusal loads in a clinical situation could lead to further degradation, reducing bond strength values.

This study also found a statistically significant difference in bond strength values between the bonding materials tested, with higher values observed for the composite resin Transbond XT, regardless of the number of thermal cycles. This finding corroborates those by other studies, independently of whether a thermal cycling step was included or not[22-23]. Nonetheless, other studies have reported no difference between these materials[4,23]. Moreover, it has been demonstrated that a bonding strategy such as prior conditioning of the enamel surface or the use of a self-etching *primer* demonstrated significant difference in bond strength values[11,24-26]. It has been speculated that lower bond strength values should be observed when a modified glass ionomer is used without etching the enamel prior to bracket bonding, which has been considered a relevant factor that could affect the performance of this material, which adheres to enamel chemically and hence bond strength values are not of the same magnitude as those observed for composites[27].

Glass ionomer has been demonstrated to yield lower bond strength values than composites *in vitro*[22-23] and, therefore, its use has been questioned. Nevertheless, the performance of this material *in vivo* has been shown to be comparable to those of composites with regards to adhesion and failure rates[4,23] and with the potential advantage of inhibiting demineralization around orthodontic brackets[3,28]. It should be highlighted that a classic study by Reynolds[29] reported that clinically acceptable bond strength values should range between 6 and 8 MPa. The values obtained in this study exceeded those figures, thus enabling both materials to be indicated for bracket bonding. Furthermore, the ARI values were not accompanied by the presence of bonding material to the tooth, thus potentially preserving tooth substrate by avoiding the need to remove adhered resin.

Considering that the mean bond strength values observed in this study were higher than those regarded as clinically acceptable and that both materials showed low levels of adhesive residue, they could both be used in orthodontic practice to bond orthodontic brackets to enamel.

CONCLUSION

The number of thermal cycles did not influence the bond strength of the adhesive materials investigated. Moreover, the composite resin Transbond XT showed higher bond strength than the resin-modified glass ionomer Fuji Ortho LC, regardless of the number of thermal cycles. Regarding the adhesive remnant index, most specimens from all groups had no adhesive residue on the tooth after bracket removal.

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