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ORIGINAL ARTICLE

The Effect of Different Bleaching Treatments and Thermal-Mechanical Cycling on the Shear Bond Strength of Orthodontic Brackets

Lilian Nascimento Carlos[1], Olivia Santana Jorge[1], Luiz Renato Paranhos[2], Sergio Augusto de Freitas Vincenti[1], Fernanda de Carvalho Panzeri Pires-de-Souza[1]

[1]Department of Dental Materials and Prosthodontics, University of São Paulo, Ribeirao Preto School of Dentistry, São Paulo, Brazil
[2]Department of Dentistry, Federal University of Sergipe, São Cristóvão, Brazil

ORCID IDs of the authors: L.R.P. 0000-0002-7599-0120; S.A.F.V. 0000-0002-8284-8819; F.C.P.P.S. 0000-0002-1455-1538.

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ABSTRACT

Objective: The aim of the present study was to compare the shear bond strength (SBS) of orthodontic brackets bonded to the enamel after at-home and in-office bleaching treatments.

Methods: Sixty bovine incisors were subjected to initial color readings and then classified into three groups: CP (16% carbamide peroxide), HP (35% hydrogen peroxide), and C (control). After treatments, new color readout was obtained, and orthodontic brackets were bonded to the bleached area. Half of the samples of each group (n=10) were subjected to thermal-mechanical cycling (TMC) testing (1,200,000 cycles; 44.2 N; 2 Hz/s), whereas the other half were stored in distilled water at 37 °C for 24 h. Samples were subjected to the SBS test at a speed of 0.5 mm/min. The mean SBS was analyzed (two-way ANOVA, Bonferroni test, $p<0.05$), and the fracture patterns were classified as adhesive, cohesive, and mixed types.

Results: There was no difference ($p>0.05$) in SBS values between the samples subjected to TMC and the cycled samples in any group. Samples subjected to carbamide peroxide presented lower SBS ($p<0.05$) than the non-cycled ones. Enamel adhesive fractures were higher in the bleached groups than in the control group, which presented mixed fractures prevalence, regardless of whether it was subjected to TMC or not.

Conclusion: Thermal-mechanical cycling was not significant for SBS of orthodontic brackets, but tooth bleaching was a factor.

Keywords: Mechanical stress, orthodontic brackets, shear strength, tooth bleaching

INTRODUCTION

Personal appearance care is not a recent concern, and that issue also includes smile care. There is growing demand for tooth bleaching procedures (1, 2) that can be performed in the office, by dental professionals, or self-applied with specific products in multiple and appropriate concentrations for each case (3, 4). The effectiveness of both techniques has been recognized (3, 4). However, some effects have been considered as harmful, such as the decrease in microhardness and elastic modulus of the tooth enamel, the increase in the formation and propagation of microcracks (5), as well as the increase in surface roughness of the tooth surface (4). Studies have demonstrated that solutions of 35% hydrogen peroxide change the structure and composition of the enamel (4, 6).

Address for Correspondence: Fernanda de Carvalho Panzeri Pires-de-Souza, Department of Dental Materials and Prosthodontics, University of São Paulo, Ribeirao Preto School of Dentistry, São Paulo, Brazil
E-mail: ferpanzeri@usp.br

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Bleaching or whitening products can be used before or after orthodontic treatment (7). For these treatments, the first requirement concerns the bonding of the brackets to the tooth surface. The bonding process should preserve the mechanical stability of the bracket/adhesive interface, which transfers the load generated by the archwires to the tooth (8). Poor bond strength can have adverse consequences on the cost and effectiveness of the orthodontic treatment, as well as patient comfort (9).

There is no consensus in the literature regarding the waiting time between tooth bleaching and performing any bonding procedure, and the periods vary from 24 h to 4 weeks (7, 10, 11). The decrease of the bond strength between the composite/adhesive and the newly cleared enamel may be temporary (10).

Although the bleaching effect on shear bond strength (SBS) has already been extensively studied, most of the previous studies measured the short-term adhesive bond strength and did not extend the study period to comprehend the duration of typical orthodontic treatment (12). The eating, drinking, and breathing routine can induce changes in intraoral temperature (13, 14). Thermal stresses can be pathogenic in two ways. First, mechanical stresses caused by differences in thermal expansion coefficient can directly influence crack propagation through the bonding interface between the tooth and the restorative material. Second, the changing gap dimensions are associated with volume changes that inject pathogenic oral fluids in and out of the gaps (13, 14). Despite the abundance of evidence produced by orthodontic studies, the laboratory configurations and setups used to simulate intraoral conditions are irrelevant to the actual oral environment (15-17). Thermal cycling is an in vivo process often represented in laboratory simulations (13). However, few studies have reported its effects on water sorption and solubility of composite restoratives (14).

The bond strength of the bracket can be affected by several agents (7, 18), such as the action of solvents and other components of the bleaching agents on the degradation of the bracket bond (19). In addition to that, changes in the mineral content of the bleached tooth can increase the porosity and permeability of the enamel, reducing its microhardness (20). The aim of the present study was to compare the SBS of metal orthodontic brackets bonded to the enamel subjected to at-home (16% carbamide peroxide) and in-office (35% hydrogen peroxide) bleaching treatments and thermal-mechanical cycling (TMC) tests. The study tested the null hypothesis that there would be no difference in the SBS, regardless of the type of bleaching treatment to which the enamel was subjected.

METHODS

Ethical approval

Samples used in the present study were obtained from beef packing industries as a donation. All tests were conducted in accordance with the Scientific Requirements and Research Protocols established by the World Medical Association Declaration of Helsinki.

Sample preparation

Sixty sound bovine incisors, without stains and with intact enamel surface, were selected. A circular jig was attached to the labial surface of the teeth to standardize the color readings and to define the area to be bleached (Figure 1). The outer edge of the jig was coated with colorless nail polish (Colorama; São Paulo, SP, Brazil) so that only the inner area would be subjected to any procedure.

The teeth were subjected to initial color readings using an optical reading device (Easyshade®; VITA Zahnfabrik, Bad Säckingen, Germany). It has a digital tip with 19 optical fibers that irradiate the area, and two sensors are capable of reading the color numerically. The color readings were performed in a light chamber (CL6I-45S; INTEKE HS, São Paulo, SP, Brazil) under a D65 artificial daylight source according to the CIE $L^*a^*b^*$ system (21). The system consists of three axes in color space, with a^* and b^* being perpendicular to each other representing the dimension of color tonality (green-red and blue-yellow, respectively) and L^* representing lightness, vertical to the plane a^*b^*. By assigning numerical values to these three coordinates, the CIE $L^*a^*b^*$ system can locate an object in a three-dimensional color space.

Samples were randomly classified into three groups (n=20) according to the type of bleaching treatment to which they were subjected (Table 1).

For bleaching, all the teeth were embedded in colorless and chemically activated acrylic resin (VIPI Flash; VIPI Produtos Odontologicos, Pirassununga, SP, Brazil) in a polyvinyl chloride ring (20 mm high×20 mm inside diameter), with the labial surface of the teeth perpendicular to the horizontal plane, using a parallelometer.

In the CP group, a 16% carbamide peroxide (White & Brite Night; 3M do Brasil Ltda., Sumaré, SP, Brazil) was used in daily applications of 4 h for 14 days at home. In the HP group, a 35% hydrogen peroxide (Whiteness HP; FGM Produtos Odontologicos Ltda., Joinville, SC, Brazil) was used in three 15-minute applications, with a 5-minute interval between them. In the control group (C),

Table 1. Groups studied and clinical protocols used for tooth bleaching treatments

Group	Agent	Treatment
CP	16% carbamide peroxide (White & Brite Night; 3M do Brasil Ltda., Sumaré, SP, Brazil)	Daily bleaching application, 4 h/day for 14 days
HP	35% hydrogen peroxide (Whiteness HP; FGM Produtos Odontologicos Ltda., Joinville, SC, Brazil)	Three bleaching applications lasting 15 min, with 5-minute intervals between them
C	Distilled water (control)	Storage in distilled water for 24 h

samples were stored in distilled water for 24 h (Table 1). After the bleaching treatments, new color readings were performed according to the previously described methodology to verify color change.

Bracket bonding

Sixty metal brackets with a 6 mm^2 base area (Kirium U1R Roth 022; Abzil 3M, São José do Rio Preto, SP, Brazil) were bonded to the bleached enamel surface 24 h after the bleaching procedures. The bleached area was etched with 37% phosphoric acid (Alpha-Etch; Nova DFL, Rio de Janeiro, RJ, Brazil) for 15 s, then washed with water, and dried using air jets. Then, a uniform and thin coat of primer (Transbond™ XT; 3M Unitek, Sumaré, SP, Brazil) was applied. After solvent evaporation, a small amount of adhesive (Transbond™ XT) was used on the base of the bracket, which was immediately positioned on the bleached enamel surface. To correctly adjust the bracket perpendicular to the horizontal plane, its position was checked with an acrylic positioning device (Figure 2).

A Gillmore needle (113.4 g) was used on the bracket for 5 s to standardize the force applied and its duration, so that a uniform adhesive layer would coat the enamel surface.

After a brief 3-second photoactivation (FlashLite 1401; Discus Dental, Culver City, CA, USA; power density ≥1100 mW/cm^2, wavelength range between 460 and 480 nm), the excess adhesive was removed around the base of the brackets without displacing them. Further photoactivation (FlashLite 1401) was performed for 20 s, with 10 s on each interproximal area of the tooth.

Figure 1. Circular template fixed on the vestibular surface of the tooth to standardize position of the spectrophotometer reader and region to be bleached

Samples were randomly separated into two groups (n=10) according to the treatment to which they were subjected: TMC or storage in distilled water for 24 h (control).

Thermal-mechanical cycling

Samples were subjected to 1,200,000 mechanical cycles with a load of 44.2 N at a frequency of 2 Hz/s and a rounded tip 6 mm in diameter as an antagonist (thermal-mechanical wear system-ER-11000 Plus; ERIOS, São Paulo, SP, Brazil) to simulate actual chewing conditions. The frequency used corresponded to 2 chewing cycles/s that simulated 5 years of chewing (2, 22). Thermal cycling was performed in association with mechanical cycling at temperatures of 5 °C, 37 °C, and 55 °C (±2 °C).

After thermal cycling, samples were stored on distilled water at 37 °C for 24 h after which the shear bond test was applied.

Shear bond strength

Samples were subjected to shear test in a mechanical testing machine (DL-2000; EMIC, São José dos Pinhais, PR, Brazil) at a speed of 0.5 mm/min by a chisel parallel to the long axis of the tooth, acting on the enamel/bracket interface. Shear stress was calculated by the following formula: SBS (MPa)=9.81×F (kgf)/A (mm^2), where F corresponds to the maximum bracket debonding force, and A corresponds to the area of the bracket. The SBS values were analyzed by repeated measures two-way ANOVA, Bonferroni post-hoc test ($p<0.05$).

After debonding the brackets, the fracture patterns were qualitatively analyzed under a bench magnifying glass (TL-1106; Toyo, São Paulo, SP, Brazil) at 10× magnification and classified as enamel adhesive (when all the resin remained on the brack-

Figure 2. Bracket positioned perpendicular to the horizontal plane

et), bracket adhesive (when the resin remained on the enamel surface), cohesive (when there was a fracture of the resin), and mixed (when there was a fracture of the resin and damage to the enamel). When the bracket debonding force exceeded the enamel strength, there was substrate fracture, and failure was classified as enamel fracture.

The amount of adhesive left at the enamel was classified by the Adhesive Remnant Index (ARI) as follows (23):

- score 0=no adhesive was left on the tooth
- score 1=less than half of the adhesive was left on the tooth
- score 2=more than half of the adhesive was left on the tooth
- score 3=all of the adhesive was left on the tooth, with a distinct impression of the bracket mesh.

Table 2. Mean (±standard deviation) values of the color readings

	CP	HP	C
ΔE	7.5±2.7	5.2±1.6	4.4±2.5
ΔL	3.5±1.3	0.6±2.1	-0.9±1.3
Δa	−0.5±0.8	3.2±1.2	-1.4±1.1
Δb	−6.2±3.4	−1.2±3.8	-3.8±2.2

Table 3. Comparison of the mean SBS (MPa) (±standard deviation) for the cycled and non-cycled groups (two-way ANOVA, Bonferroni test, p<0.05)

CP	229.68±86.3^{aA}	189.59±80.4^{aB}
HP	326.94±34.8^{aA}	319.47±139.1^{aA}
C	233.45±69.5^{aA}	313.14±100.7^{aA}

Different letters indicate significant differences (p<0.05)
TMC: thermal-mechanical cycling

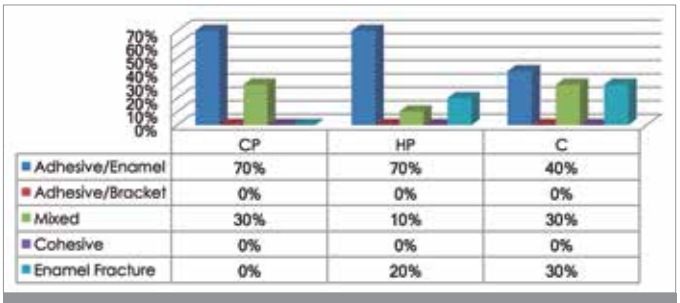

Figure 3. Fracture pattern distribution of samples in group without TMC observed after shear bond strength test

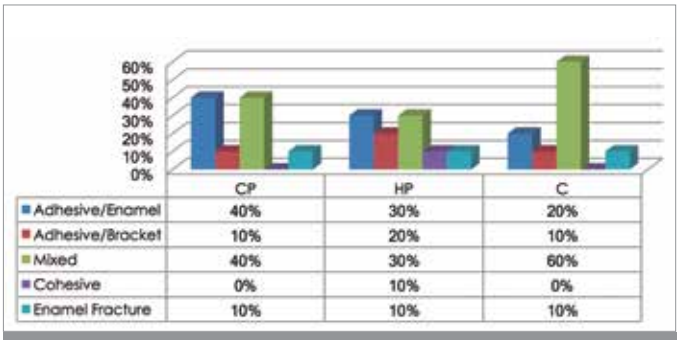

Figure 4. Fracture pattern distribution of samples in group with TMC observed after shear bond strength test

RESULTS

Table 2 shows the color change values (ΔE) of the studied groups (at-home tooth bleaching, in-office tooth bleaching, and control) and the delta values relative to the coordinates analyzed after performing the bleaching treatments.

All treatments produced an enamel color change. The most significant difference was found in the HP group, whereas the least was in the control group.

Table 3 shows the comparison of the mean SBS (two-way ANOVA, Bonferroni test, p<0.05). There was no significant difference (p>0.05) on SBS of the cycled groups, regardless of the type of bleaching tested. When not submitted to TMC, the at-home bleaching had the lowest mean SBS, which was significantly different (p<0.05) from the control and HP groups, which presented no difference (p>0.05) between them.

Before the SBS test, only one sample of the groups that were not submitted to TMC presented bond failure when subjected to the at-home bleaching. The other groups showed no failures. However, failures occurred in all the groups subjected to TMC, with three in the at-home bleaching group, four in the control group, and four in the in-office bleaching group.

Figure 3 and 4 show the fracture patterns observed after the SBS tests. For the non-cycled groups (samples not subjected to TMC), the authors found that enamel adhesive fracture occurred in 70% of the samples for both bleached groups, whereas this type of fracture occurred in 40% of the samples in the control group. There was neither bracket adhesive fracture nor cohesive type. Mixed fracture occurred in 10% of the samples in the HP group,

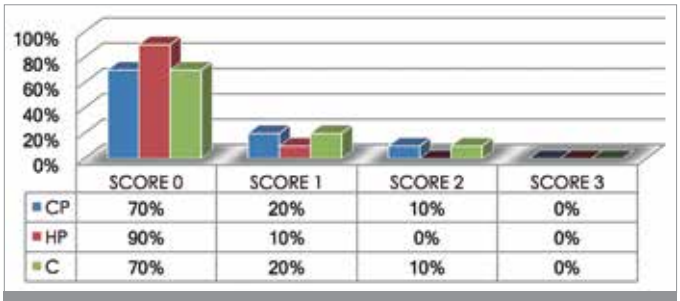

Figure 5. Distribution of Adhesive Remnant Index (ARI) of samples in group without TMC observed after shear bond strength test

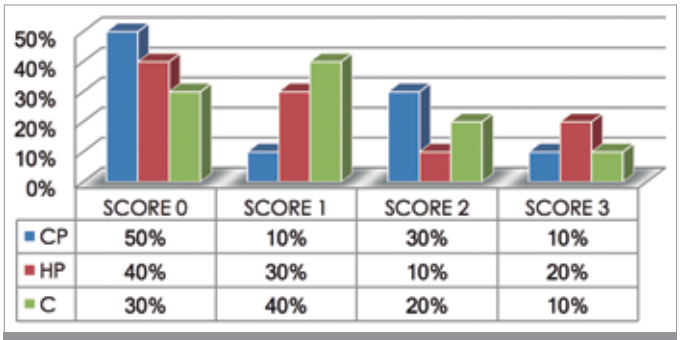

Figure 6. Distribution of Adhesive Remnant Index (ARI) of samples in group with TMC observed after shear bond strength test

whereas this type of fracture occurred in 30% of the samples in the other groups. There was no enamel cohesive fracture in the CP group. However, this type of fracture was observed in 20% of the samples in the HP group and 30% in the control group.

When submitted to TMC, there was balance in the type of fracture that occurred in the groups subjected to bleaching treatments because 30% of enamel adhesive and mixed fractures occurred in the samples submitted to HP and 40% of these same types of fractures after CP, followed by 10% of bracket adhesive fracture and 10% of enamel cohesive fracture.

After in-office bleaching, there were 20% bracket adhesive fracture and 10% cohesive and enamel fractures. The most prevalent fracture in the control group was the mixed type, followed by enamel adhesive fracture; those with the lowest prevalence were the bracket adhesive and cohesive enamel fractures.

Figure 5 and 6 show the distribution of the ARI scores in percentage. For the non-cycled groups, the highest incidence of ARI=0 occurred for both the bleaching treatments performed, being higher for the HP group, indicating that no adhesive was left on the enamel surface.

When subjected to TMC, higher percentages of scores 1, 2, and 3 were observed for all the groups tested. Samples from the control group presented the highest incidence of ARI=1, followed by ARI=0, 2, and 3, respectively. The HP group had a lower percentage of ARI=0 than the CP group when not subjected to TMC. Samples bleached in the office presented, in descending order, the scores 0>1>3>2; the ones bleached at home had the following sequence: 0>2>3=1.

DISCUSSION

The aim of the present study was to evaluate the SBS of orthodontic brackets on the enamel bleached by both at-home and in-office techniques subjected to TMC, starting from the null hypothesis that these factors would not be able to modify the enamel/bracket bonding. The authors observed that when subjected to TMC, the SBS presented no difference ($p>0.05$), regardless of the type of bleaching treatment performed. However, when not subjected to TMC, the at-home bleaching showed the lowest mean SBS, which was significantly different ($p<0.05$) from the control and HP groups. Thus, TMC was significant only for the CP group; therefore, the hypothesis of the study was partially accepted.

Studies had shown that the bond strength of composite resins to enamel decreases when tooth bleaching is performed in both at-home and in-office techniques (10, 24). In the present study, there were lower mean SBS for the CP group, corroborating the findings of previous studies (4, 25) that demonstrated that 10% carbamide peroxide is dissociated into 3% hydrogen peroxide and 7% urea, and afterwards, hydrogen peroxide dissociates into oxygen radicals and water. The released oxygen is responsible for bleaching the tooth by breaking down the pigment molecules in the enamel. These oxygen radicals are an inhibitory factor of resin composite polymerization, resulting in a reduction in bond strength right after bleaching (4, 18, 25).

On penetrating into the enamel microstructure and breaking down the pigment molecules, hydrogen peroxide denatures the enamel organic matrix proteins and causes roughness, fissures, and porosity in the tissue (26, 27), leaving it with a granular aspect (24). There may be a decrease in the concentration of calcium ions and enamel microhardness (11). All these factors may result in lower SBS. The concentration of these radicals in the tooth may vary according to the time during which the tooth remains in contact with the bleaching gel, justifying the lower SBS when carbamide peroxide was used in comparison with hydrogen peroxide; the results are similar to those found in a previous study (28).

Hydrogen peroxide was applied three times for 15 min, whereas carbamide peroxide was used for 14 days for 4 h/day. Therefore, the concentration of these radicals in the tooth could vary according to the period during which the enamel remained in contact with the bleaching gel, resulting in a reduction in bond strength that is time-dependent (25).

The action of the bleaching agent on the enamel surface also justifies the prevalence of the fracture patterns (11) and ARI scores. In the present study, the most susceptible area to failure was the enamel-resin interface, as well as ARI=0, indicating factors that demonstrate less bonding ability. These results were prevalent after non-cycled CP bleaching treatment, showing that the bleaching agent reduced the SBS; this corroborated the results of a previous study (28). The point that differentiates our study is that we submitted the samples to TMC, simulating chewing and subjecting the brackets to all the forces involved in this movement.

During the orthodontic treatment period, the materials must conveniently resist tension, traction, torque, and functional loads (16, 29). Mechanical laboratory tests used to evaluate the bonding effectiveness of adhesive systems to the dental structure are usually based on the application of displacement forces on the bonding interface in an attempt to simulate the loads transmitted to the bracket during treatment. Since orthodontic adhesives are routinely subjected to thermal variations in the oral cavity, it is essential to determine whether such temperature variations induce stress on the adhesive interface, influencing bond strength (12, 17).

In the present study, there was no significant difference in the SBS between samples either subjected to TMC or not in any of the groups. TMC was performed to cause fatigue at the bonding interface so that such stress would simulate the intraoral conditions that could be able to decrease the bonding of the tested materials to the enamel. However, the results indicated that the cycles tested were not sufficient to degrade and decrease bond strength; this was a fact also confirmed by the higher prevalence of the enamel adhesive fracture pattern when subjected to TMC. These findings corroborate previous studies that found no significant difference in bond strength after thermal cycling (12, 13, 17).

Despite this, the authors verified that TMC interfered in some way with the ARI scores. Non-cycled samples showed a higher percentage of ARI=0, whereas the groups subjected to TMC presented a higher incidence of an adhesive remnant on the enamel after the SBS test. This demonstrates a decrease in the bracket/adhesive bond strength, although no significant SBS results occurred.

These results may be explained by the significant mismatch of the thermal expansion coefficient between the adhesives, the metal bracket, and the enamel (15). In addition, the cyclical stress may cause any debonded regions at the interfaces to increase progressively in size (15). Thus, temperature alteration and axial load may have decreased the bond strength of thermally cycled specimens relative to those that were not cycled.

Another possible justification is the solubility of the composite. Water absorption that occurs during TMC can cause hygroscopic expansion as well as chemical degradation of materials (14, 15, 30), thereby reducing bond strength. However, as the SBS results showed no significant difference between the cycled and non-cycled samples, these justifications are not conclusive. Further studies are required for a better understanding of this mechanism.

CONCLUSION

Based on the results, the authors concluded that TMC was not a significant factor in SBS of any of the groups tested, regardless of the type of bleaching treatment previously performed. However, the at-home bleaching method significantly reduced the enamel/bracket SBS when non-cycled samples were tested.

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