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CO2 laser irradiation for debonding ceramic orthodontic brackets

Denise Souza Matos [1], Erika Calvano Küchler [2], Maria Cristina Borsatto [2], Mirian Aiko Nakane Matsumoto [2], Fernanda Vicioni Marques [2], Fábio Lourenço Romano [2]

[1]School of Dentistry of University Center of Patos de Minas, Patos de Minas, MG.

[2]Department of Child Clinic, School of Dentistry of Ribeirao Preto, University of São Paulo, Ribeirão Preto, SP.

Correspondence: Fábio Lourenço Romano, School of Dentistry of Ribeirão Preto, University of São Paulo; Av. do Café, s/n Monte Alegre, Ribeirão Preto – SP, Brazil, 14040-904
e-mail: fabioromano@forp.usp.br

This study evaluated shear bond strength (SBS), adhesive remnant index (ARI) and fracture mode of chemically and mechanically retained ceramic brackets bonded with different composite resins and irradiated with CO2 laser. The null hypothesis was that ceramic brackets bonded with different composite resins and irradiated with CO2 laser would have similar SBS values. Ninety human premolars were divided into four experimental groups according to the combination of type of composite resin (Transbond XT and Z 250) and type of ceramic bracket (Fascination and Mystique), and two control groups (n=15). In the four experimental groups, the brackets were irradiated with CO2 laser at 10 W for 3 seconds before SBS testing. Enamel surface ARI was calculated after debonding under electron microscopy scanning. ANOVA and the Mann-Whitney test were used for statistical analysis. The laser groups had lower SBS values than the non-irradiated groups (control) ($p<0.05$). The mechanically retained brackets (Mystique) had the higher ($p<0.05$) and Z250 had the lower SBS values after CO2 laser irradiation. The groups bonded with Z250 had the highest ARI. Adhesive fractures were the most prevalent. The null hypothesis was rejected. CO2 laser decreased SBS efficiently and facilitated debonding of mechanically and chemically retained ceramic brackets.

Key Words: orthodontic, ceramic brackets, CO2 laser, shear bond strength.

Introduction

The first esthetic brackets were introduced in Orthodontics by Newman in 1965 (1), but the first ceramic brackets appeared only in the 1970s. There are two types of ceramic brackets according to their structure: 1) monocrystalline and 2) polycrystalline. Retention may be mechanical or chemical. Ceramic brackets have high hardness, high tensile strength, low fracture resistance and low friction properties. However, the use of ceramic brackets, which have a low level of deformation, may lead to problems, as their debonding often causes irreversible damage to tooth surfaces (2).

The use of heat transfer to soften the luting agent may make debonding of ceramic orthodontic brackets safe. Moreover, the type of luting agent and the temperature of the pulp chamber should be carefully considered to prevent iatrogenic effects (3-7). Several researchers have explored the use of lasers for that purpose (6-16).

CO2 laser, developed by Patel et al. (17) in 1964, has been used in surgical procedures and extensively studied in Dentistry as a tool to inhibit demineralization (17). However, the use of CO2 laser for debonding ceramic brackets has not been fully explored. The several protocols and types of equipment used have a great variation of power and wavelengths (6, 8-12, 15, 18, 19, 20). Several methods have been used to evaluate debonding of ceramic brackets with the application of CO2 laser, but lack of standardization indicates that further studies should focus on the equipment used. Moreover, studies should develop and consolidate protocols to confirm the effectiveness and efficiency of this technique (6, 15, 20).

This study evaluated shear bond strength (SBS), adhesive remnant index (ARI) and fracture mode of chemically and mechanically retained ceramic brackets bonded with different composite resins and irradiated with CO2 laser. The null hypothesis was that ceramic brackets bonded with different composite resins and irradiated with CO2 laser would have similar SBS.

Materials and method

This study was approved by the local Research Ethics Committee (protocol number CAAE 0054.0.138.000-11).

Ninety sound human premolars were used. Their crowns were embedded in pink self-curing acrylic resin (Jet Clássico, São Paulo, SP, Brazil), and the buccal surface of each tooth was pressed onto a glass slide before setting. After that, the same surface was prepared with 400, 600 and 1200 grit wet sandpaper (3M, Sumaré, SP, Brazil) in a polishing machine (DP-902, Struers A/S, Copenhagen, Denmark) to obtain an enamel area of about 5 mm for bracket bonding.

The roots of the teeth were then placed at the center of PVC tubes (Tigre, Rio Claro, SP, Brazil), and the tube was filled with self-curing acrylic resin. An L-shaped glass spreader (90° bend) was used to position the buccal surface of each tooth perpendicular to the base of the tube.

Specimens were randomly divided into four test groups (L) and two control groups (C) (n=15) according to the two types of brackets, Mystique (M) (Dentsply Sirona, York, UK) and Fascination (F) (Dentaurum Inc. Langhorne, PA), and the two composite resins, Transbond XT (T) (3M Unitek, Monrovia, CA), and Z250 (Z) (3M ESPE, Dental Products Division St. Paul, MN) (Table 1). The number of specimens was defined according to ISO TR 11405. Both types of brackets were polycrystalline and had a 0.022 x 0.028-inch slot, but the Mystique brackets had a mesh base.

Table 1: Groups and characteristics of the material

Group	Composite	Ceramic bracket	Type of retention	CO_2 laser irradiation
1 - TMC (Control)	Transbond XT*	Mystique◦	Mechanical	No
2 - TFC (Control)	Transbond XT	Fascination◦◦	Chemical	No
3 - TML	Transbond XT	Mystique	Mechanical	Yes
4 - ZML	Z 250**	Mystique	Mechanical	Yes
5 - TFL	Transbond XT	Fascination	Chemical	Yes
6 - ZFL	Z 250	Fascination	Chemical	Yes

* 3M Unitek, Monrovia, CA, USA
** 3M ESPE, St. Paul, MN, USA
◦ GAC, New York, NY, USA
◦◦ Dentaurum, Ispringen, BW, Germany

Before bracket bonding, fluoride-free pumice paste with water and a low speed handpiece were used for specimen prophylaxis for 10 seconds. Specimens were then rinsed for 10 seconds and dried using a syringe for 10 more seconds. After prophylaxis, enamel was etched with 37% phosphoric acid for 15 seconds, then rinsed and dried for 15 seconds. Brackets were bonded according to manufacturer's specifications. Before bonding, the following agents were used: XT Primer (3M Unitek, Monrovia, CA) for Transbond XT; and Single Bond 2 (3M ESPE, Dental Products Division St. Paul, MN) for Z250. These bonding agents, Primer XT and Single Bond, were light activated for 20 seconds after application and before the application of the cementing agents, Transbond XT and Z250, which were then applied to the base of the brackets using an insertion spatula to cover the entire surface with a uniform layer about 1 mm thick. After positioning the bracket, light manual pressure was applied, and marginal excesses were removed with an insertion spatula. Light activation was performed for 10 s on each surface (upper, lower, right and left), at a total of 40 s, using an XL 1500 halogen-curing unit (3M/ESPE, St. Paul, MN, USA) at a standard 1 mm from the bracket, measured using a millimeter ruler. Light intensity, measured using a radiometer (Demetron, Danbury, CT, USA), reached 400 mW/cm2. After bonding, the specimens were kept intact and at a distance from each other inside plastic boxes according to study group for 30 minutes for the initial polymerization. After that, they were stored in distilled water at 37° C for 24 hours to simulate oral conditions.

Specimens in control groups 1 and 2 underwent SBS testing in a universal test machine (Emic DL 500, São José dos Pinhais, Brazil) at a speed of 0.5 mm/min with an active chisel tip positioned at/against the resin-enamel interface. Laser groups also underwent SBS testing, but were irradiated at the center of the ceramic bracket with a CO2 laser unit (Shanghai Jue Hera Technology Development Shanghai, PR, China) immediately before the test. Laser parameters were 10.6-µm wavelength, 10-W power for 3 seconds, and pulse duration of 0.01 s at a distance of 4 mm, standardized using an orthodontic wire coupled to the active tip of the unit.

After SBS testing, the adhesive remnant index (ARI) for the enamel of all specimens was estimated using a stereoscopic loupe (Carl Zeiss, Goettingen, NI, Germany) at 16 X magnification and classified according to the scores recommended by Artun and Berglund (1984) (21):

0 – no composite resin adhered to enamel;
1 – less than half of all composite resin adhered to enamel;
2- more than half of all composite resin adhered to enamel;
3- all composite resin adhered to enamel.

The buccal surfaces of all the specimens were evaluated and analyzed under a scanning electron microscope (SEM), and fracture mode was classified as follows:

- Adhesive fracture (Ad): Fracture occurring between composite resin and enamel.
- Cohesive resin fracture (CR): Fracture occurring between bracket and composite resin and composite resin remaining adhered to enamel.
- Cohesive enamel fracture (CE): Fracture occurring on the tooth surface with partial removal of enamel.
- Mixed cohesive/adhesive fracture (CR/Ad): Fracture between the bracket and the composite resin with composite resin remaining adhered to the tooth surface and fracture between the composite resin and enamel.
- Mixed cohesive enamel/adhesive fracture (CE/Ad): Partial removal of tooth structure and fracture between the composite resin and enamel.
- Mixed cohesive enamel/resin fracture (CR/CE): Composite resin remaining adhered to tooth surface and partial removal of tooth structure.

Figure 1 show a diagram of the method used.

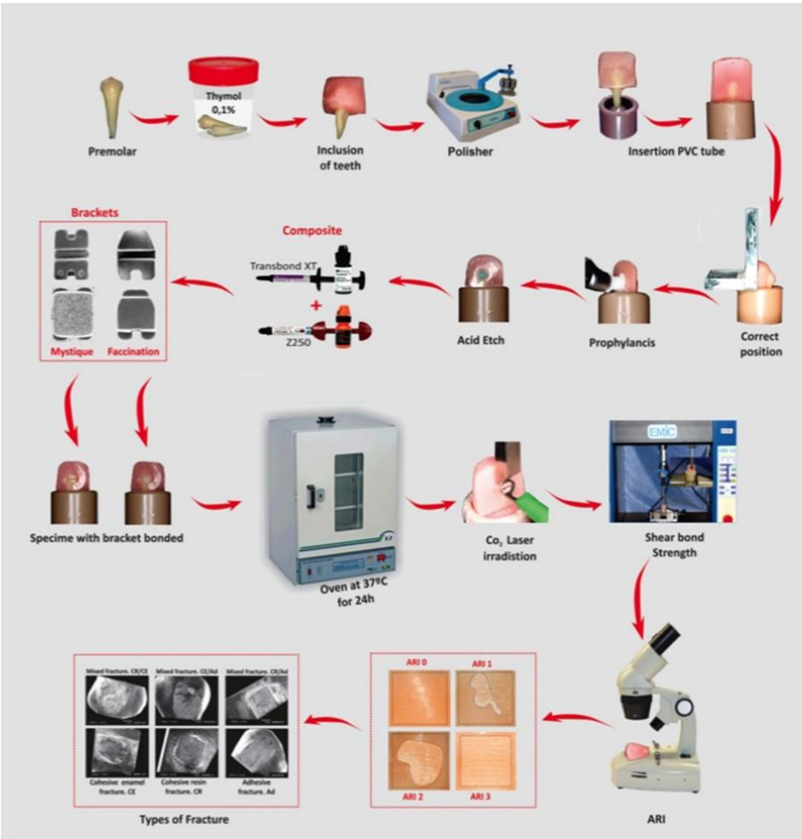

Figure. 1: Study flowchart. Diagram shows method used in study.

Statistical analysis

SBS values were analyzed using ANOVA and the post-hoc Tukey test. ARI was analyzed using the Mann-Whitney test. The level of significance was set at 5%.

Results

SBS values were statistically lower in the laser groups than in the control groups, regardless of composite resin (Table 2). The analysis of groups with the same brackets revealed no statistically significant differences between types of composite resin ($p>0.05$) (Table 2). The mechanically retained Mystique brackets, both in the control and laser groups, had statistically higher values than the chemically retained Fascination brackets (Table 2) ($p<0.05$).

Table 2: SBS (MPa) and ARI values.

SBS					
			Ceramic brackets		
	Composites		Mystique		Fascination
Control groups	Transbond XT	TMC	7.63 (1.3) bA	TFC	4.45 (0.68) bB
Laser groups	Transbond XT	TML	3.45 (0.68) aA	TFL	0.92 (0.18) aB
	Z 250	ZML	3.52 (1.04) aA	ZFL	0.28 (0.70) aB
Note: Equal letters, lowercase between lines and uppercase letters between columns indicate statistical similarity.					
ARI					
Control groups	Transbond XT	TMC	0.60 (0.98) a	TFC	1.53 bc
Laser groups	Transbond XT	TML	1.20 (1.08) abc	TFL	1.60 (1.30) c
	Z 250	ZML	1.86 (0.99) c	ZFL	2.66 (0.48) d
Note: Equal letters indicate statistical similarity					

The chemic0ally retained Fascination brackets that were bonded with Z250 had the lowest bond strength values after CO2 laser irradiation. In the three groups of mechanically retained Mystique brackets, the lowest SBS values were found for the group in which Transbond was used after laser irradiation.

Table 2 shows that the TMC control group had the lowest mean ARI (zero). The best results were found in the ZFL and ZML laser groups, both bonded with Z250.

Of the 90 specimens, 79 underwent SEM evaluation, because 11 were lost during cutting and preparation. Specimen surfaces were evaluated and classified according to the type of fracture (Table 3).

Table 3: Types of fracture after debonding.

Groups	Ad	CR	CE	Mixed CR/Ad	Mixed CE/Ad	Mixed CR/CE
TFC	6	4	-	4	-	-
TMC	8	2	2	2	-	-
TML	6	5	-	4	1	-
ZML	2	4	3	2	3	1
TFL	3	5	1	2	1	-
ZFL	1	8	-	3	1	-

Ad: Adhesive fracture
CR: Cohesive resin fracture
CE: Cohesive enamel fracture
Mixed CR/Ad: Mixed cohesive/adhesive fracture
Mixed CE/Ad: Mixed cohesive enamel/adhesive fracture
Mixed CR/CE: Mixed cohesive enamel/resin fracture

Adhesive fractures were the most frequent. The second most frequent type was the cohesive resin fracture, found mostly in the Z250-Fascination-laser (ZFL) group. In this group, there was less damage to tooth surface and a predominance of scores 2 and 3. The group with the greatest damage to tooth surface was the Z250-Mystique-laser (ZML) group, which had 3 cohesive enamel fractures, 3 mixed CE/Ad and 1 mixed CR/CE. Groups Transbond-Mystique-control (TMC), Transbond-Mystique-laser (TML), Transbond-Fascination-laser (TFL) and ZFL also had damage to enamel, but on a smaller scale (Figure 2).

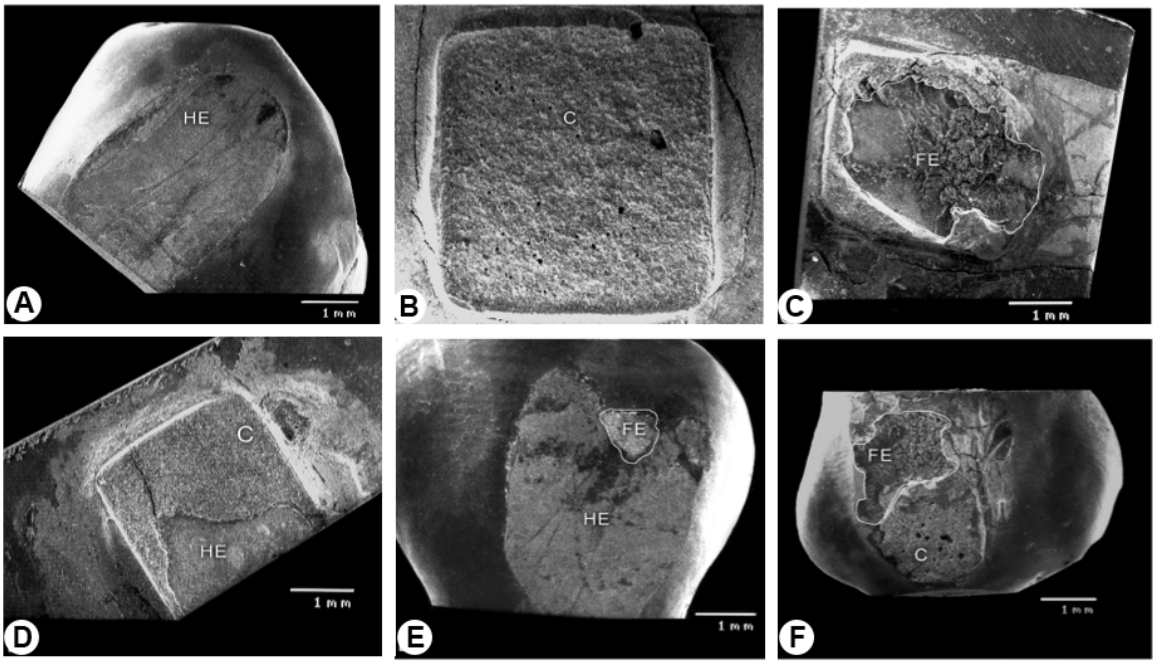

Figure. 2 - Types of fracture and distribution. **A**- Adhesive fracture (Ad); **B** - Cohesive resin fracture (CR); **C** - Cohesive enamel fracture (CE); **D** - Mixed cohesive/adhesive fracture (Mixed CR/Ad); **E** - Mixed cohesive enamel/adhesive fracture (Mixed cohesive enamel/adhesive fracture); **F** - Mixed cohesive enamel/resin fracture (Mixed CR/CE). HE Intact Enamel. C – Composite. FE - Fractured Enamel.

Discussion

Studies about the application of CO2 laser have used a wide variation of power parameters and provided little information about irradiation duration, which may raise concerns about pulp overheating and the lack of standardization of the procedure. In this study, brackets were irradiated with CO2 laser at 10 W for 3 seconds and at a pulse interval of 0.01 second. This protocol was also adopted by Macri (2012) (6), and pulp chamber temperature reached 4.7^{o} C, which does not exceed the limit of 5.5^{o} C recommended by Zach and Cohen (1965) (3).

Our study revealed a reduction in the force required to debond brackets after CO2 laser irradiation, as well as lower SBS values in the laser groups. In the Mystique groups (TML and ZML), adhesive values were 50% lower when laser was used, regardless of type of composite resin. A larger reduction, over 90%, was found in the Fascination groups. This accentuated reduction confirms findings reported by Romano et al. (2017) (15), but not by any other authors, regardless of method used. A decrease in adhesion after irradiation, although to a lesser extent, was also found in other studies that used lower intensity laser irradiation (9,11). Debonding seems to be facilitated by the heat generated by laser. As it reaches the bracket and the composite resin, it breaks chemical bonds and makes removal of the orthodontic bracket easier, as demonstrated in other studies (2, 4, 6, 9, 15).

SBS values of chemically and mechanically retained brackets found in the literature (12, 23) are different from those found in our study, in which the highest SBS values were found in groups of mechanically retained brackets. Our result may be explained by the fact that studies use different methods and bracket brands, as well as laser frequency variations. Moreover, as the chemically retained Fascination brackets are more translucent than the mechanically retained Mystique brackets, laser light passes through their structure more easily and weakens the composite resin more effectively.

This study used two luting composite resins, Transbond XT and Z250. In the groups with the same type of bracket, SBS values were not statistically different. Both composite resins had a suitable quantity of filler particles in their compositions, which promotes adhesion to the enamel and may explain our results. Maybe the type of luting material used did not affect debonding procedures. The results reported by Rueggeberg and Lockwood (1990, 1992) (4, 5) and Mimura et al. (1995) (22) differed from ours, as they found that different forces and temperatures were needed to debond brackets in a study that compared other materials.

Kitahara-Céia et al. (2008) (23) evaluated ARI in specimens prepared with mechanical retention, mechanical retention with polymer mesh base and chemical retention, and found higher scores for mechanical retention. Ahari et al. (2011) (12) used the chemically retained Fascination brackets and the mechanically retained Inspire Ice brackets, both debonded with CO2 laser at 188 W output power for 5 seconds. They found that most scores of 3 were in the group that used mechanically retained brackets irradiated with laser, followed by the control group with the same type of bracket. In our study, the group that had the highest mean ARI was ZFL, which had chemically retained brackets, whereas the group that had the lowest mean was TMC, which had mechanically retained brackets. Although these results are not in agreement with other studies, differences may be explained by the fact that mechanically retained brackets have higher SBS values. ARI mean values in the other groups were similar to each other, and inversely proportional to mean bond strength. Associations have been found in similar evaluations, but have not been definitely established.

Tehranchi et al. (2010) (11) used a polycrystalline ceramic bracket and the chemically activated No-mix composite resin and found that mean ARI in the group that received CO2 laser applications as an auxiliary method to bracket debonding was significantly higher than in the control group. A similar result was found in our study, in which ARI in the control groups was lower than in the laser groups (Table 2).

The test specimens examined under SEM were classified according to fracture mode, and the most prevalent type of fracture was adhesive. This result is in agreement with those reported by Theodorakopoulou et al. (2004) (24) and Liu et al. (2005) (25), but differs from those found by Rueggeberg and Lockwood (1990) (4), who had a higher prevalence of cohesive fractures when using two-paste resins.

Damage to tooth structure (cohesive enamel fractures, cohesive and mixed cohesive resin/enamel and cohesive enamel/adhesive fractures) was found in 15% of the specimens, similar to what Liu et al. (2005) (25) found. This suggests that enamel fractures resulted from SBS testing, as the highest values were found for the specimens with damage to the tooth surface in both control and laser groups.

CO2 laser decreased the adhesion of ceramic brackets to enamel, facilitating bracket debonding. Mechanically retained ceramic brackets had greater adhesion to enamel than chemically retained brackets. Adhesion values were similar for both composite resins, with or without laser irradiation. Adhesive fractures, which do not damage enamel structure, were the most frequent.

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Resumo

O objetivo do estudo foi avaliar a resistência de união ao cisalhamento da colagem (RCC), o índice de remanescente de adesivo (IRA) e o modo de fratura de bráquetes cerâmicos com retenção química e mecânica colados com diferentes compositos e irradiados com laser de CO2. A hipótese nula testada foi que bráquetes colados com diferentes compósitos e irradiados com laser de CO2 apresentam valores semelhantes de RCC. Noventa pré-molares humanos foram divididos em 6 grupos (n=15): 2 controles e 4 experimentais que se diferenciaram pelo tipo de bráquete ceramic (Fascination and Mystique) e pelo compósito de fixação (Transbond XT e Z 250). Nos quatro grupos experimentais, os bráquetes foram irradiados com laser de CO2 com 10W por 3 segundos anteriormente ao teste de RCC. O IRA das superficies de esmalte foram avaliados após a descolagem e submetidos a análise em microscopia electrônica de varredura (MEV). Para análise estatística foram utilizados ANOVA e o teste de mann-Whitney. Os grupos laser mostraram valores de RCC menores que os grupos não irradiados (controles) ($p<0.05$). Os bráquetes com retenção mecânica (Mystique) mostraram alta RCC ($p<0.05$) e o compósito Z 250 obteve os mais baixos valores de RCC após irradiação com laser. Os grupos colados com o compósito Z 250 apresentaram os mais altos escores do IRA. O modo de fratura mais prevalente foi a adesiva. A hipótese nula foi rejeitada. O laser de CO2 foi eficaz para diminuir os valores de RCC e facilitou a descolagem dos bráquetes cerâmicos de retenção química e mecânica

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