J Dent Mater Tech 2024; 13 (1): 19-25
https://doi.org/10.22038/jdmt.2024.74474.1585

J Dent Mater Tech

Original Article

Open Access

The Effects of different recycling methods on the shear bond strength of ceramic brackets

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Abstract

Objective: This study aimed to evaluate the effect of different recycling (also known as reconditioning) methods on the shear bond strength (SBS) of ceramic brackets.

Methods: Fifty mechanically retentive polycrystalline ceramic brackets and 50 mandibular bicuspids were used in this study. The teeth were divided into 5 groups and bonded with new (group 1) or reconditioned brackets. The reconditioning methods were sandblasting (group 2), sandblasting + silane (group 3), hydrofluoric (HF) acid + silane (group 4), and Er:YAG laser (group 5). The SBS of brackets were assessed and the adhesive remnant index (ARI) scores were determined. Statistical analysis was performed using one-way ANOVA, Tukey, and chi-square tests at $P<0.05$.

Results: The highest SBS value was observed in brackets treated with sandblasting + silane (19.26 ± 3.30 MPa), which was comparable to both the control (19.01 ± 3.12 MPa) and sandblasting (16.98 ± 3.13 MPa) groups. Treatment with hydrofluoric acid + silane (9.46 ± 3.43 MPa) and Er:YAG laser (9.71 ± 1.23 MPa) yielded significantly lower SBS values than the other study groups ($P<0.05$). The highest overall ARI scores were observed in the HF acid + silane and Er:YAG laser group, indicating more adhesive remnants on the enamel surface.

Conclusions: Sandblasting, with or without silane treatment, effectively restored the bond strength of ceramic brackets to almost initial values. Although recycling with hydrofluoric acid + silane or Er:YAG laser produced lower bond strengths, they still surpassed the clinical threshold of 7.8 MPa, making them viable options for bracket reconditioning in clinical settings.

Keywords: Bond strength, Ceramic, Erbium laser, Orthodontic brackets, Recycling, Silane

Introduction

Brackets are passive components of fixed orthodontic appliances that transmit forces to the teeth. Orthodontic brackets can be manufactured from metal, ceramic, and plastic materials. Plastic and ceramic brackets have become popular choices due to their esthetic appeal. However, plastic brackets, made of polycarbonate, have limitations such as poor strength and suboptimal dimensional stability (1). Ceramic brackets, made of aluminium oxide, combine the durability of metal brackets with esthetic advantages. They are resistant to staining, maintain their integrity over long periods, and are suitable for patients with allergies or those undergoing magnetic resonance imaging (MRI) (2). Ceramic brackets bond to enamel through mechanical retention (indentations and undercuts) or chemical retention with silanes (3, 4).

To ensure adequate attachment of ceramic brackets, a bond strength of 6-8 MPa is necessary (2). However, excessive bonding strength can cause damage to the tooth or restoration surface during the debonding process. Early debonding of orthodontic brackets is unpleasant in clinical settings. It is a common consequence of poor bonding technique, which may occur due to several factors including contamination with saliva, moisture, or oil during bonding, over-etching the enamel surface, and using faulty or expired bonding materials. Applying heavy forces on the bracket or moving it during adhesive setting, as well as inadequate light curing, can also contribute to early detachment, necessitating bracket rebonding. Bracket replacement

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Accepted: 3 February 2024. Submitted: 19 August 2023.

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also becomes necessary in cases of improper bracket positioning.

Rebonding can be done using a new bracket or recycling (also known as reconditioning) the old one. Recycling ceramic brackets can save costs and reduce the need for new ones, benefiting both the patient and the clinician. To avoid any legal concerns, recycling can be done in the clinic, by reusing the same bracket for the same patient (5). During the recycling process, it is important to remove adhesives from the bracket base without causing damage to its structure (3).

There are several methods used for recycling ceramic brackets, such as using silica coating, burning technique, burning and silane, burning and ultrasonic cleaning, hydrofluoric acid application, hydrofluoric (HF) acid and silane, silane application, sandblasting, sandblasting and hydrofluoric acid, sandblasting and silane, and lasers including erbium, chromium-doped yttrium, scandium, gallium, garnet (Er,Cr:YSGG) and erbium-doped yttrium aluminum garnet (Er:YAG) (2, 3, 6-10). These methods help in effectively recycling the brackets.

It has been observed that the burning technique for debonding results in a much lower bond strength (2). Sandblasting, also known as airborne particle abrasion, is used for recycling brackets. It is done with aluminium oxide particles to clean the surfaces of materials, resulting in micromechanical roughening, increased surface area, and improved wettability. Sandblasting can be done with different particle sizes of aluminium oxide, such as 25 µ, 50 µ, and 110 µ.

Using silane as an adhesive booster is a simple and quick method for rebonding debonded brackets. It enhances bond strength by forming chemical bonds between the ceramic base and adhesive resin and also improves surface wettability (6, 11). However, a previous study found that silanization of rebonded brackets decreased shear bond strength (9). On the other hand, Gaffey et al. (6) suggested that recycling ceramic brackets with a silane coupling agent can result in clinically acceptable bond strength.

Hydrofluoric acid 9.6% is commonly used to etch ceramic crowns for bracket bonding. It creates micro porosities on the surface, allowing for a mechanical interlock with the composite resin. Nevertheless, some studies suggested that hydrofluoric acid treatment of sandblasted brackets may reduce bond strength, and thus, it is not advised (6, 9).

Lasers are a modern tool used in many dental treatments. Er:YAG and Er,Cr:YSGG lasers emit light at wavelengths that are strongly absorbed by water. The Er:YAG laser has a wavelength of 2940 µm, while the Er,Cr:YSGG laser emits 2780 µm. These lasers can effectively target the adhesive without damaging the surrounding tooth or the ceramic bracket (12-14). Both Er:YAG and Er,Cr:YSGG lasers have higher absorption in composites compared to ceramic materials (15). Previous studies showed that the shear bond strength of recycled brackets is equal to that of new brackets, with minimal or no damage to the ceramic bracket base (10, 15). This suggests that laser recycling could be a viable option for ceramic brackets.

The purpose of this study was to compare the efficiency of different methods for recycling ceramic brackets including sandblasting with or without silane coupling agent, hydrofluoric acid and silane application, and Er:YAG laser treatment.

Materials and methods

Sample collection and preparation

A total of 50 mandibular premolar teeth were collected from Maharishi Markandeshwar College of Dental Sciences and Research. The inclusion criteria consisted of intact, non-carious, non-hypoplastic premolars without any restorations or developmental defects. Teeth were extracted for orthodontic purposes and stored in a 10% formalin solution for four months. The study received approval from the Maharishi Markandeshwar ethical committee, under the ID code of 913.

The selected teeth were then randomly allocated to five groups (n=10) and mounted on acrylic blocks with different colors to distinguish one group from another. To clean the buccal surface of the premolars, a non-fluoridated pumice slurry and a rubber cup were used for 15 seconds (2, 15).

Bracket preparation

For this study, 50 mandibular bicuspid mechanically retentive polycrystalline ceramic brackets (Ortho Organizer, California, USA) were used. To simulate debonded brackets, 40 brackets were attached with Enlight composite (Ormco, Washington DC, USA) to an unetched and slightly wet enamel surface, allowing for easy removal of the bonded bracket (2, 9). Excess composite around the bracket base was removed using an explorer and the composite was cured for 20 seconds. The brackets were gently removed from the tooth surface using tweezers. Figure 1 displays the armamentarium used in this study.

Grouping and reconditioning methods

The teeth were randomly assigned into five groups according to the conditioning method applied as follows:

Group 1 (Control): New brackets were used in the control group.

Group 2 (Sandblasting): Deboned brackets were blasted with 25 µm aluminium oxide particles using a handpiece at a 10 mm distance. Sandblasting was continued until the composite was fully removed from the bracket base and was no longer visible to the naked eye. The bracket was then rinsed with air and water for 15 seconds to clear the residue (7, 9).

Group 3 (Sandblasting + silane): After sandblasting, silane (ESPE Sil; 3M ESPE, Minnesota, USA) was applied to the bracket base and left to dry for 1 minute (2, 6).

Group 4 (Hydrofluoric acid + silane): Brackets were treated with 10% HF acid (Condictionador De Porcelana, Angelus, Brazil) for 2 minutes, rinsed and dried. Then, the silane was applied to the bracket base and left to dry for 1 minute (6).

Group 5 (Er:YAG laser): Brackets were exposed to an Er:YAG laser (Light Walker DT, Fotona, Gruibingen, Germany) at 2940 nm wavelength, 280 mJ pulse energy, 20 Hz repetition rate, and pulse width of 250 µs, using air and water spray. During laser irradiation, the bracket base was placed perpendicular to the handpiece at a distance of 6 mm and the irradiation was performed for 10 seconds continuously in the scanning mode. Protective glasses were used during this process (10, 15).

Bonding process

The same bonding protocol was applied for all groups. Teeth were etched with 37% phosphoric acid (Meta Etchant; Meta Biomed, South Korea) for 15 seconds, rinsed with water for another 15 seconds, and dried until a chalky appearance was achieved. A thin coating primer (Ortho Solo, Ormco, Washington DC, USA) was applied on the enamel surface and the adhesive was placed on the bracket base. The bracket was pressed on the tooth surface and after removing the excess material, it was cured for 40 seconds from the mesial, distal, occlusal, and gingival directions. Samples were then immersed in distilled water for 24 hours before SBS testing.

Shear bond strength testing

An Instron machine was used for SBS testing. The tooth was placed in the device and the load was applied in the occlusogingival direction at the bracket tooth interface with a crosshead speed of 0.5 mm/min. The shear force required to debond each bracket was recorded in Newton (N) and converted to megapascals (MPa).

Scoring of remnant adhesive

The amount of adhesive left on each tooth surface was assessed after debonding using a stereomicroscope (Vaiseshika, India) at 10 x magnification (Figure 2). The remained adhesive was scored according to the the Artun and Bergland adhesive remnant index (ARI) scoring system (15, 16). The ARI scores were described as follows:

Score 0: No adhesive was left on the tooth.

Score 1: ≤50% of adhesive was left on the tooth.

Score 2: ≥50% of adhesive was left on the tooth.

Score 3: All adhesive remained on the tooth surface with a distinct impression of the bracket base.

Statistical analysis

The statistical analyses were performed using SPSS software (SPSS Inc., Chicago, IL, USA, version 16.0).

Figure 1. The armamentarium used in the study

Figure 2. The stereomicroscope used for scoring Adhesive Remnant Index (ARI)

Table 1. The mean and standards deviation (SD) of shear bond strength values in the study groups

Group		Mean ± SD	Min - Max
1	Control	19.01 ± 3.12[a]	11.66 - 22.44
2	Sandblasting	16.98 ± 3.13[a]	11.94 -21.00
3	Sandblasting + Silane	19.26 ± 3.30[a]	12.55 - 24.61
4	Hydrofluoric acid + Silane	9.46 ± 3.43[b]	5.50 - 16.88
5	Er:YAG laser	9.71 ± 1.23[b]	8.22 – 12.05
P-value		0<0.001	

The Kolmogorov-Smirnov test was used to examine if variables follow a normal distribution. Since the SBS data were normally distributed (P>0.05), a one-way analysis of variance (ANOVA) was used for group comparisons, followed by Tukey's post-hoc test for detailed analysis. The chi-square test was applied to compare ARI scores among the groups. A P-value less than 0.05 was considered statistically significant.

Results

SBS

Table 1 presents the mean and standard deviation (SD) of bond strength values in the study groups. Group 3 (sandblasting + silane) exhibited the highest SBS value (19.26 ± 3.30 MPa), whereas group 4 (HF acid + silane) displayed the lowest SBS among the study groups (9.46 ± 3.43 MPa).

ANOVA revealed a statistically significant difference in SBS between the study groups (P<0.001; Table 1). According to Tukey's post hoc test, groups 1, 2, and 3 showed significantly greater SBS values compared to groups 4 and 5 (P<0.05). Neither the difference between groups 1, 2, and 3 nor the difference between groups 4 and 5, was statistically significant (P>0.05; Table 1).

ARI

Figure 3 illustrates the ARI scores observed in the study groups. The samples showed an ARI score of 1 (58%), 0 (34%), and 2 (8%) in descending order of frequency. The ARI score of 3 was not detected in any of the samples. ARI score 2 was only observed in a total of 4 samples, belonging to groups treated with hydrofluoric acid plus silane and the Er:YAG laser group.

According to the chi-square test, there was a statistically significant difference between the study groups concerning the ARI scores (P<0.001).

Discussion

This study aimed to evaluate and compare the SBS values of debonded mechanically retentive polycrystalline ceramic brackets that were recycled using different methods. The goal was to find a recycling method for debonded ceramic brackets that provides sufficient bond strength without causing enamel damage. Human-extracted teeth were used in this study

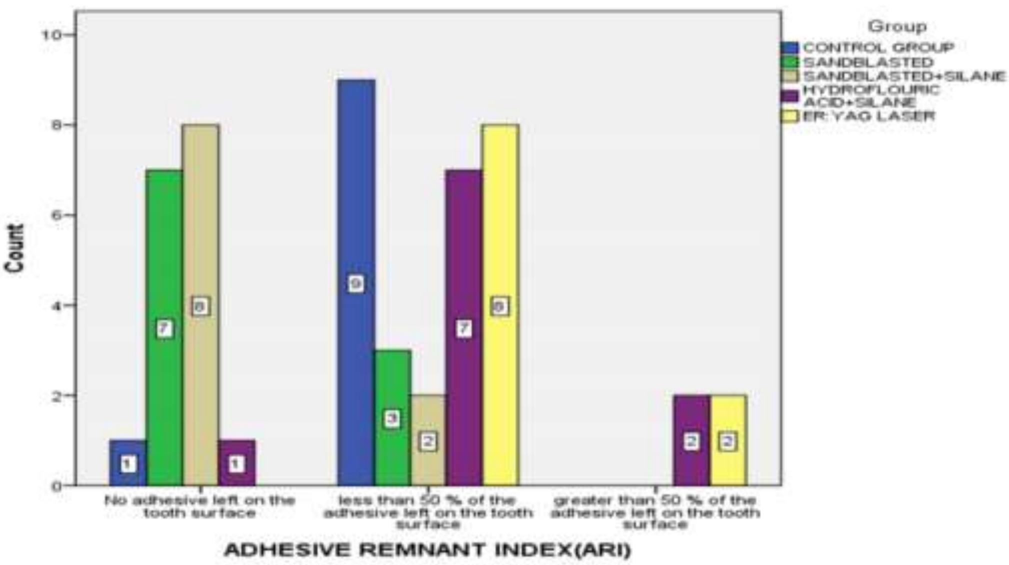

Figure 3. The adhesive remnant scores observed in the study groups

because the quantitative results of bovine teeth may differ from those of human teeth. The teeth were stored in a 10% formalin solution, which is considered the best storage media for in vitro studies. The International Organization for Standardization suggests performing bond strength experiments at a maximum of 6 months after tooth extraction (15, 18). Accordingly, bond strength measurements were conducted within 4 months post-extraction in the present study.

The success of orthodontic treatment relies on achieving adequate bond strength between brackets and enamel. It is assumed that a shear bond strength value of 5.9 to 7.8 MPa is considered the minimum requirement in clinical practice (19). In the present study, the shear bond strength of all groups exceeded this threshold range. The highest bond strength value was found in the sandblasting + silane group (19.26 ± 3.30 MPa), which was comparable to the control (19.01 ± 3.12 MPa) and sandblasting (16.98 ± 3.13 MPa) groups. This suggests that sandblasting is an effective method for recycling ceramic orthodontic brackets.

The outcomes of this study align with several studies that indicated the efficacy of sandblasting in removing adhesive remnants and providing micromechanical retention on bracket basses (2, 9). The shear bond strength of the sandblasting + silane group in this study was higher than the values reported in previous studies. This can be attributed to the use of a 25 µ aluminium oxide particle size for sandblasting, resulting in less residual bond material, and the formation of a new type of mechanical retention on the bracket base. Montero et al. (5) stated that as the size of the aluminium oxide particle decreases, the shear bond strength increases.

In contrast to the outcomes of this study, Yousef et al. (18) found that the use of aluminium oxide (50 µm) with silane resulted in a significantly lower SBS value of approximately 1.5 MPa. Another study by Quick et al. (20) reported that the application of a silane coupling agent decreased the bond strength of ceramic brackets to a clinically unacceptable level. Han et al. (10) found that sandblasting can damage the delicate microcrystalline structure of the bracket base, leading to a decrease in shear bond strength. These differences are potentially attributed to variations in study methodologies, bonding systems, or bracket types.

The application of silane in this study did not cause a significant increase in the bond strength of sandblasted ceramic brackets, although the SBS value enhanced about 2.2 MPa after the silane addition. When making ceramic brackets with mechanical retention, a layer of glass is added to the bracket base to facilitate mechanical retention by creating a roughened surface. During sandblasting, aluminium oxide particles are projected onto the bracket base, removing any remaining bonded material and roughening the surface. This process can also cause erosion of the glass, leaving remnants of glass and bonding material on the bracket base. The silane coupling agent has reactive sites that bond with the glass traces on the ceramic surface, forming a siloxane bond. Additionally, the methacrylate group of the silane forms a covalent bond with the resin polymer. The presence of ethanol in the silane coupling agent formulation increases surface wettability and reduces surface tension, thus improving adhesion (10, 21).

The application of 9% hydrofluoric acid followed by a silane coupling agent is a commonly used method for bonding brackets to ceramic surfaces. The hydrofluoric acid dissolves the interstitial glass, creating micro-undercuts for better retention (6, 21). Additionally, the application of hydrofluoric acid generates hydroxyl groups on the ceramic surface, which promotes chemical bonding when using a silane coupling agent (15). Scanning electron microscopy (SEM) studies have shown that etching ceramics with hydrofluoric acid (HF) changes the surface topography. It creates micro and nanoscale pores of varying depths and widths, leading to increased interlocking of the composite material to the roughened surface. It also affects the wettability of the ceramic surface (15). In this study, we achieved a shear bond strength of 9.46 ± 3.43 MPa by using HF acid in combination with a silane coupling agent on the bracket base, which is considered clinically sufficient. However, the SBS value in the HF + silane group was significantly lower than in the new and sandblasted ceramic brackets. This may be attributed to the remaining adhesive material on the bracket base which prevents HF acid penetration on the ceramic surface. In previous studies, the use of HF has shown varying results. For example, Devjee et al. (22) found that HF application significantly reduced SBS due to the removal of the silica layer from the bracket base. Additionally, Chung et al. (9) reported a low SBS value of 1.22 MPa when HF acid was applied, leading to hesitation against its usage.

Er:YAG laser is a versatile laser that can be used for both hard and soft tissue treatments. Er:YAG laser can remove composite and roughen its surface. In this study, the brackets recycled by the Er:YAG laser had an SBS value of 9.71 ± 1.23 MPa, which was significantly lower than the new and sandblasted groups. However, the SBS surpassed the minimal threshold required for clinical applications and thus the Er:YAG laser treatment can be considered as a viable option for recycling ceramic brackets. Devjee et al. (22) concluded that using the Er:YAG laser for recycling ceramic brackets is the best method as it doesn't damage the bracket base like sandblasting (22). In contrast to the outcomes of this study, Yassaei et al. (23) reported no significant difference in SBS between Er:YAG laser-treated brackets and the control group. Ahrari et al. (15) achieved bond strengths of 14.3 MPa and 12 MPa using the Er,Cr:YSGG laser with 3.5 W and 4 W output power which was comparable to that of new brackets (16.2 MPa).

The amount of adhesive left on the tooth surface post-debonding is crucial for minimizing enamel damage. We found that methods resulting in higher bond strengths tended to leave less adhesive on the tooth. In this study, greater ARI scores were observed in hydrofluoric acid + silane and the Er:YAG laser groups as compared to the control, sandblasting, and sandblasting plus silane groups. This indicates that more adhesive was left on the teeth in groups with lower bond strength values. Although higher SBS values are desirable in the clinical setting, they may be associated with the risk of enamel damage during bracket removal. It is important to choose a recycling method that not only ensures adequate bond strength but also minimizes the risk of enamel damage during debonding.

Despite the promising results observed in vitro, it is crucial to consider how these findings translate to the clinical setting, where factors such as temperature changes, pH, saliva, and masticatory forces might influence debonding outcomes. The clinical performance of recycled brackets should be evaluated in future studies. Additionally, further studies could investigate the cost-effectiveness of each method and their impact on chair time.

Conclusions

The following conclusions can be drawn from the obtained results:

1- Treatment with sandblasting followed by silane application achieved the highest shear bond strength value (19.26 MPa), which was statistically comparable to new brackets (19.01 MPa) and sandblasting alone (16.98 MPa). Therefore, sandblasting either used with or without silane application is effective for recycling ceramic brackets.

2- Treatment with hydrofluoric acid + silane or Er:YAG laser resulted in lower bond strengths than new and sandblasted brackets, although SBS was still acceptable for clinical applications.

3- Regarding the adhesive remnant index (ARI), methods yielding higher bond strengths caused significantly less adhesive residue on the enamel surface.

Conflict of Interest

There are no conflicts of interest.

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