Original Article

Bond Strength of Orthodontic Brackets Using Different Light and Self-Curing Cements

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Abstract: The purpose of the study was to evaluate the shear bond strength of stainless steel orthodontic brackets directly bonded to extracted human premolar teeth. Fifty teeth were randomly divided into five groups: (1) System One (chemically cured composite resin), (2) Light Bond (light-cured composite resin), (3) Vivaglass Cem (self-curing glass ionomer cement), (4) Fuji Ortho LC (light-cured glass ionomer cement) used after 37% orthophosphoric acid–etching of enamel (5) Fuji Ortho LC without orthophosphoric acid–etching. The brackets were placed on the buccal and lingual surfaces of each tooth, and the specimens were stored in distilled water (24 hours) at 37°C and thermocycled. Teeth were mounted on acrylic block frames, and brackets were debonded using an Instron machine. Shear bond strength values at fracture (Nw) were recorded. ANOVA and Student-Newman-Keuls multiple comparison tests were performed ($P < .05$). Bonding failure site was recorded by stereomicroscope and analyzed by Chi-square test, selected specimens of each group were observed by scanning electron microscope. System One attained the highest bond strength. Light Bond and Fuji Ortho LC, when using an acid-etching technique, obtained bond strengths that were within the range of estimated bond strength values for successful clinical bonding. Fuji Ortho LC and Vivaglass Cem left an almost clean enamel surface after debracketing. (*Angle Orthod* 2003;73: 56–63.)

Key Words: Composite resins; Dental cements; Bonding; Brackets

INTRODUCTION

The acid-etching technique for bonding composite resins to enamel surfaces is extensively used for direct attachment of orthodontic appliances.[1] This fact facilitates resin penetration into the tissue and provides the mechanism by which the resin bulk is retained in the enamel, mediating the attachment of the bracket.

But acid-etching technique produces some undesirable effects: the risk of decalcification of the enamel surface, enamel fractures created during debonding, resin residue that cannot be easily removed because of enamel porosity, enamel loss caused by burs or disks when the composite residue is removed,[2] and finally, allergic reaction to the acrylic resin.[3] Ideally, in orthodontics, an adequate bond, which fails at the enamel-composite interface, would be desirable because debonding and subsequent polishing would become much easier.

Various bonding agents were developed after the introduction of the acid-etch technique. The first and most popular bonding resins were chemical-curing (CC) bonding systems. A major drawback of the autocured adhesive systems is the inability of the practitioner to manipulate the setting time of the composite resin.[4]

The use of light-cured (LC) materials in vitro for orthodontic bonding was first described in 1979.[5] In the direct bonding technique, the material is cured under metal-based brackets by direct illumination from different sides and by transillumination because the tooth structure transmits visible light. A rapid polymerization occurs when visible light is applied, producing a ''command set'' that is of great advantage; such setting ''on demand'' results in a nearly unlimited working time, allowing more accurate bracket placement.[6]

Fluoride-releasing adhesives for bracket bonding inhibit caries lesion development during fixed orthodontic treatment.[7] Glass ionomer cements (GICs) have been considered as alternative adhesives in direct orthodontic bracket bonding. The use of these cements for direct bonding of orthodontic brackets has been proposed because of their ability to adhere to base metal alloys.[8] The advantages of GICs

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have been well documented. One major characteristic would be their fluoride release capacity over a period of months,[9] acting as a reservoir for fluoride ions[10] and reducing the potential risk of enamel decalcification.[6] But their weak bond strength has been the main obstruction to wider acceptance of these cements.[11] Moreover, they have a prolonged setting reaction and a late gain in strength. Also, they are initially sensitive to moisture contamination and later to dehydration.[12] The adhesion of GICs to base metals and enamel has not yet been fully clarified, but it could be physicochemical. Searching for improved physical characteristics has lead to the development of resin-modified glass ionomer cements (RMGICs) that are hybrid materials of traditional GICs with a small addition of LC resin. They should have the advantages of both materials, such as adhesion to tooth structure, fluoride release, rapid hardening by visible light, and enhanced mechanical and physical properties.[13] Recently, they have been tested in vitro for their use in orthodontics resulting in different recommendations on their application.[14]

The aim of this study was to evaluate the shear bond strength to enamel of self- and light-cured glass ionomer and composite resin materials used for direct orthodontic bonding, to identify the site of bond failure, and to examine enamel surface after debonding.

MATERIAL AND METHODS

A total of 50 human extracted premolars were stored in a 0.5 chloramine T solution at 4°C for a maximum of six months after extraction. The buccal and lingual surfaces of each crown were cleaned with fluoride-free pumice in a rubber cup, sprayed with water, and dried with a compressed oil-free stream for about 15 seconds. All teeth were divided at random into five groups of 10 specimens each.

One hundred stainless steel orthodontic brackets (Roth prescription minitaurus, nominal surface area 5.22 mm^2) (R.M.O. Inc, Denver, Colo) were directly bonded with four different cements: a CC composite resin System One (Ormco Corp, Glendora, Calif), a LC composite resin Light Bond (Reliance Orthodontic Products, Itasca, Ill), a self-curing GIC Vivaglass Cem (Vivadent Ets., Schaan, Lichtenstein), and a RMGIC Fuji Ortho LC (GC America Inc, Chicago, Ill). Two groups were made with the last material; half of the samples received an etching procedure with 37% orthophosphoric acid (Vivadent Ets., Schaan, Lichtenstein) for 15 seconds, washing and drying for 30 seconds, and the rest of them were not etched. Materials were handled according to manufacturers' instructions. Bonding procedures were carried out by the same operator, using a standard technique. To avoid deficiencies around the bracket margins, an excess of material was used, and this was extruded around the entire periphery of the base on seating; excess material was gently removed with a probe, before polymerization. Enamel was kept dried before bonding. LC materials were exposed to light source (Optilux 400, Demetron Research Corp, Danbury, Conn) at the bracket's gingival and incisal margins for 20 seconds and then exposed to a further 20 seconds of transillumination with visible light through the palatal side of the tooth. The light was tested for light output (>600 mW/cm^2) before each use with a Demetron radiometer (model 100, Demetron Research Corp). After an initial polymerization of 15 minutes at room temperature and high humidity environment, specimens were stored in distilled water for 24 hours at 37°C to allow hardening of the adhesives.

Samples were then thermocycled 500 times (from 5°C to 55°C, with a dwell time of 30 seconds). Teeth were mounted on acrylic block frames, and brackets were debonded using a Universal testing machine (Instron Corp, Canton, Mass) at a cross-head speed of 1 mm/min until fracture was noticed, being stressed in a inciso-gingival direction. Shear bond values (SBS) were recorded in Nw and converted to MPa (N/mm^2). Mean and standard deviations were calculated. The debonded surfaces were examined under a stereomicroscope (Olympus Optical Co, Hamburg, Germany) to evaluate the mode of failure. It was characterized as follows: type I—adhesive failure resin-enamel; type II—adhesive failure bracket-resin; type III—mixed failure. Selected surfaces of each group were also examined under scanning electron microscope (SEM) (ZEISS DSM 950, Germany) to observe enamel surface after debracketing. Specimens were desiccated for 48 hours (Sample Dry Keeper Samplatec Corp, Japan) and then mounted on aluminum stubs with carbon cement. They were then sputter-coated with gold by means of a sputter-coating Unit E500 (Polaron Equipment Ltd, Watfor, England) and observed under an SEM at an accelerating voltage of 20 kV and a working distance of 13–14 mm. Micrographs were taken at 20× and 200× magnifications.

Numerical data were subjected to analysis of variance (ANOVA) and the Student-Newman-Keuls multiple comparison tests. Analysis for types of failure was performed by a chi-square analysis. Statistical significance was set at .05. Data were analyzed with SPSS/PC+. v. 4.0. (SPSS, Chicago, Ill).

RESULTS

Means (N and MPa) and standard deviations are listed in Table 1. The independent variable type of cement significantly influenced SBS of brackets to enamel ($F = 30.19$; $P < .001$). The chemically cured resin composite (System One) showed the highest mean SBS value, followed by the rest of the groups in which enamel was acid etched (light-curing resin composite—Light Bond—and resin-modified glass ionomer—Fuji Ortho LC). The lowest SBS were attained in the groups in which the enamel was not etched (Fuji Ortho LC and Vivaglass Cem).

The sites of bond failure are also shown in Table 1. A

TABLE 1. Mean Bond Strength and Mode of Failure (Number of Specimens and Percentage of Specimens in Each Material Group) for the Tested Cements (n = 20)*

Material	Mean (SD) (N)	Mean (N/mm^2)	I. Adhesive resin-enamel	II. Adhesive resin-bracket	III. Mixed
System One	71.31 (30.3) a	13.71	2 (10%)	0 (0%)	18 (90%)
Light Bond	35.96 (27.3) b	6.91	0 (0%)	14 (70%)	6 (30%)
Fuji Ortho-Etched	34.42 (16.2) b	6.62	6 (30%)	0 (0%)	14 (70%)
Fuji Ortho-Nonetched	20.71 (9.5) c	3.98	15 (75%)	0 (0%)	5 (25%)
Vivaglass-Cem	5.59 (7.2) c	1.07	20 (100%)	0 (0%)	0 (0%)

* Means with the same letter are similar after multiple comparisons (P > .05). SD indicates standard deviations.

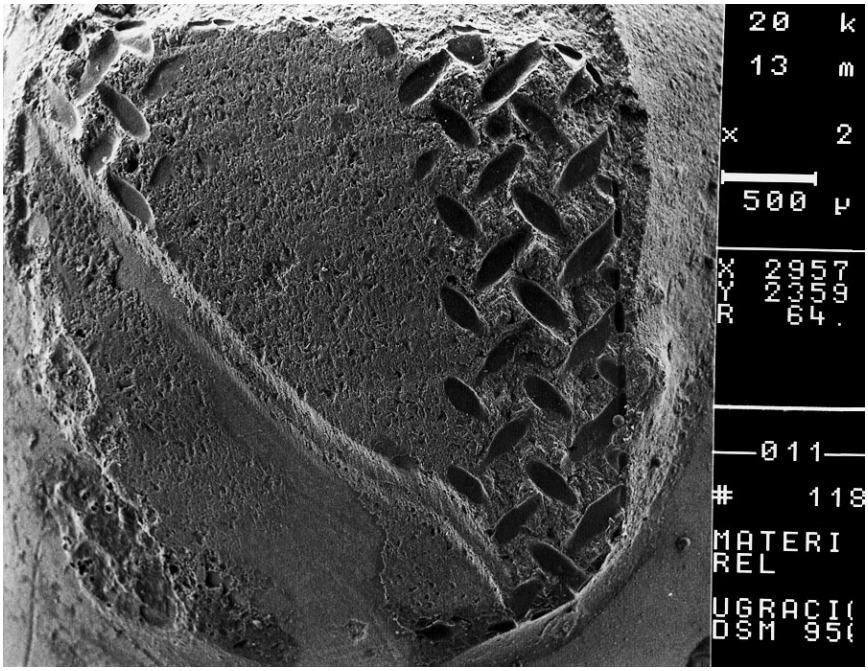

FIGURE 1. Specimen bonded with light-cured composite resin (Light Bond). A type III (mixed) failure can be observed. Almost the whole enamel surface is covered by composite resin (20× magnification).

significant difference in bonding failure sites was noted among the different materials (chi-square = 102.53, $P < .001$). The LC composite resin (Light Bond) showed the highest percentage of failures at the bracket-resin interface (70%) (Figure 1). For the CC composite resin (System One), most of the failures (90%) were mixed ones (Figure 2), and the same occurred with Fuji Ortho LC after acid etching (mixed failures: 70%) (Figure 3). When the acid-etching technique was not performed, almost all the failures appeared at the resin-enamel interface (75% in Fuji Ortho LC and 100% in Vivaglass Cem) (Figure 4).

Under SEM, enamel surfaces after debonding of the brackets appeared porous when an acid-etching process was performed on the surfaces (Figures 1 through 3), whereas enamels that were not etched presented smooth and almost clean surfaces (Figure 4). Fractures of enamel prisms (Figure 2) have only been observed when the chemically cured composite resin was used.

DISCUSSION

The CC composite resin (System One) attained higher bond strength when compared with the LC composite resin (Light Bond). Mean values obtained with both composite resins, generally, were in accordance with the bond strengths quoted in the literature when stainless steel brackets were tested.[3,15–18] Comparisons with previously reported results are difficult because there is a lack of consensus on the materials and methods (storage time before debonding, thermocycling, debonding device, bonding area, differences in the bracket mesh. . .) for orthodontic bond strength testing.[19] So, studies determining the bond strength are important mainly for their relative values and numerical comparisons are not always possible. The reduced SBS obtained in the LC composite resin, in accordance with previous reports,[13,20] may be because of an incomplete polymerization.[21] Degree of cure of CC composites is enhanced by

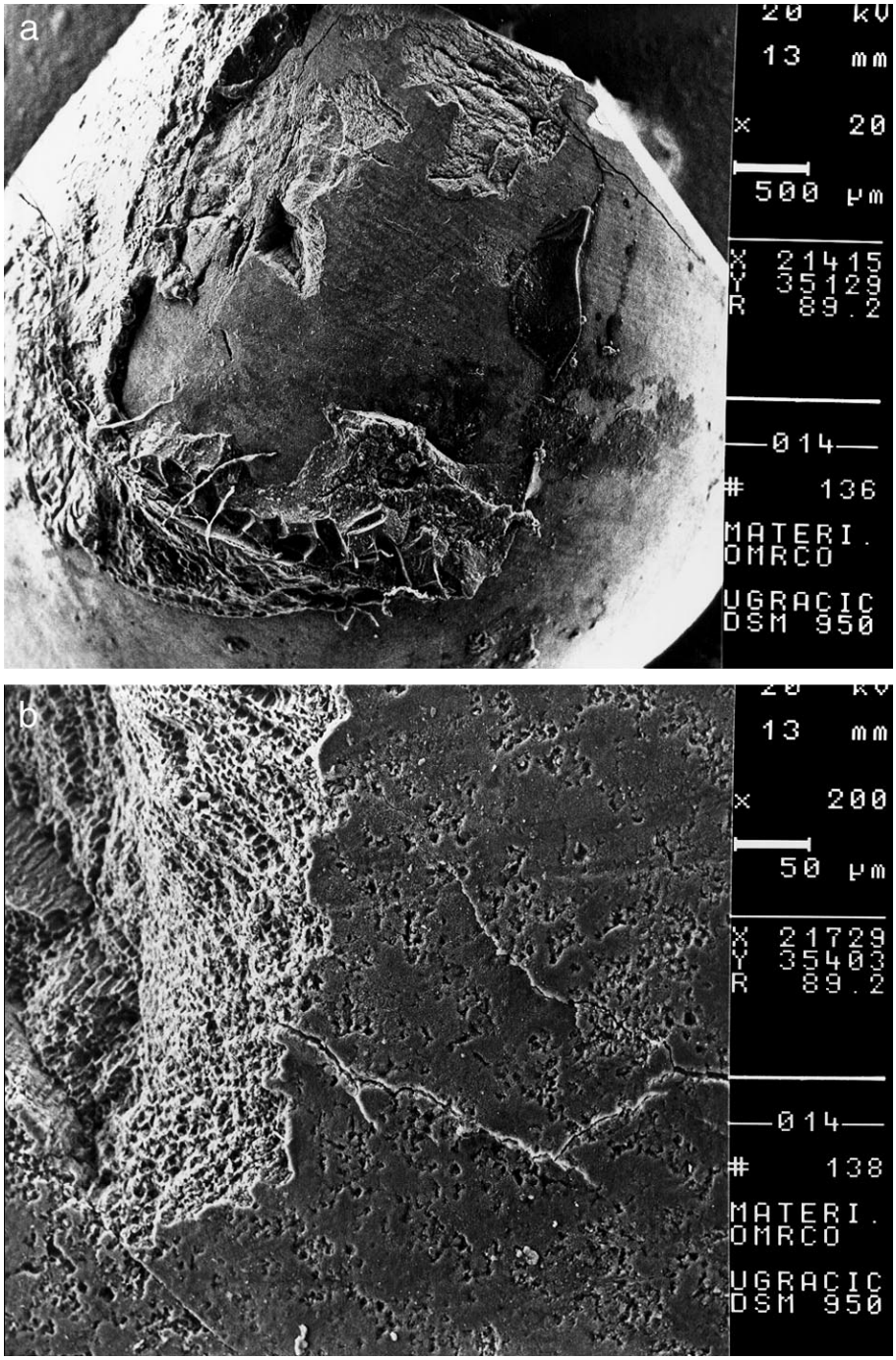

FIGURE 2. Specimen bonded with chemical-cured composite resin (System One). (a) A type III (mixed) failure may be observed. Cohesive failure of the enamel may also be observed (top-left) (20× magnification). (b) Higher magnification of the enamel morphology after debonding. Fractured enamel prisms and a porous enamel surfaces are shown (200× magnification).

thermocycling. The possibility that leakage of uncured bis-GMA from LC resin cements could occur, should be taken into account. Properly mixed and cured orthodontic adhesives may contain 14% of nonpolymerized material that could leak out[22] and uncured adhesive could predispose to the development of decalcification and caries around and underneath the brackets.[23]

Evan and Powers[24] also found that an increased layer thickness would result in lower bond strength; differences in film thickness may have also influenced differences between these composite resins.

It is not easy to evaluate the magnitudes of bond strengths that are required to continue active treatment without a bracket falling off under oral conditions,[17] but

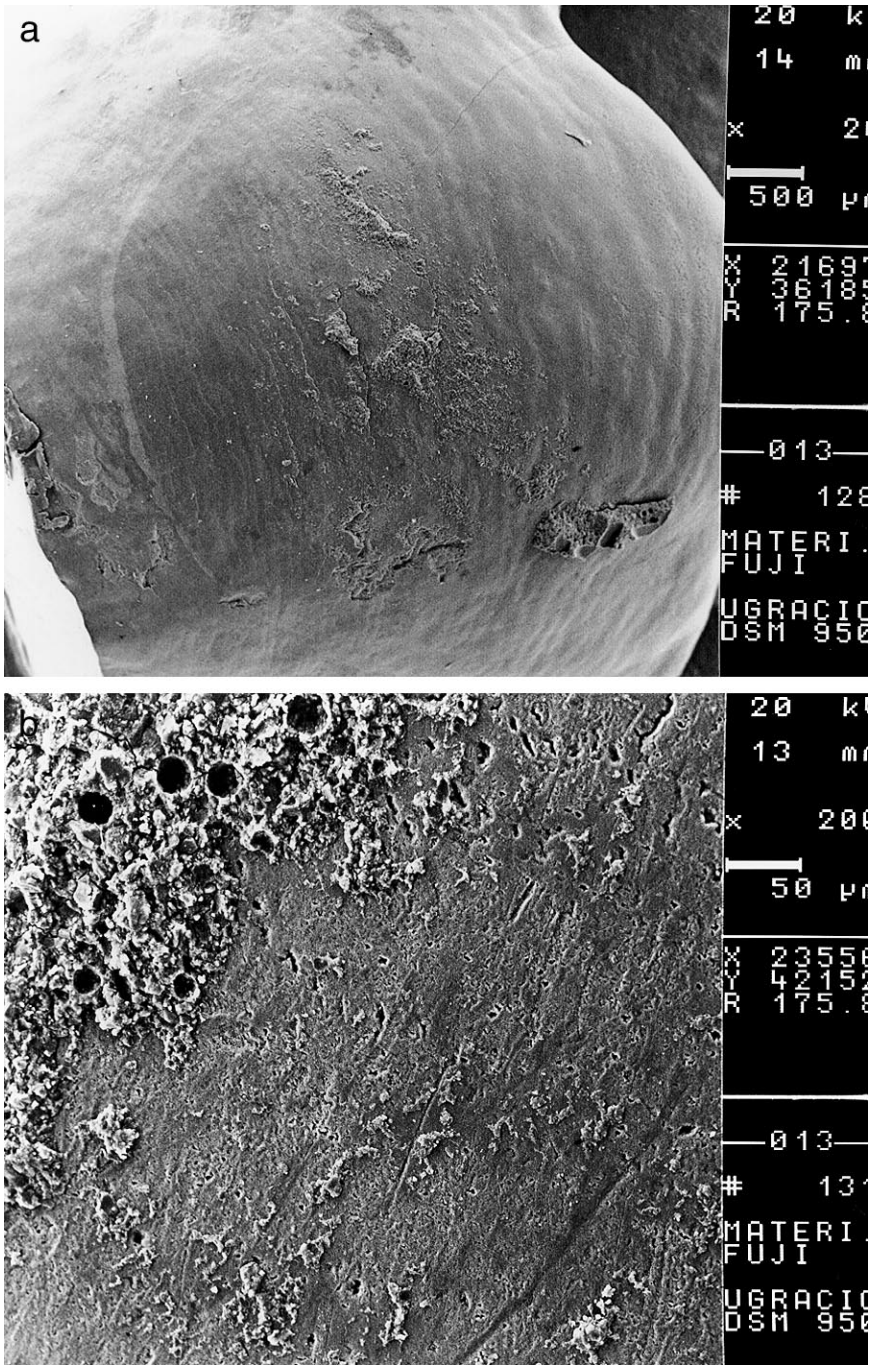

FIGURE 3. Specimen bonded with RMGIC (Fuji Ortho LC), after acid etching of the enamel surface. (a) A type III (mixed) failure may be observed. The enamel surface retained very little residual cement (20× magnification). (b) Porous enamel surface and residual cement (200× magnification).

some research articles[25,26] have stated that at least 6.5 to 10 N/mm^2 are necessary. So, the mean bond strength of the LC composite resin (Light Bond) is clinically acceptable.

The GIC (Vivaglass Cem) showed the lowest SBS, in accordance to previous in vitro studies.[6,9] It is a water-hardened formulation in which the polyacrylic acid is freeze-dried and mixed with the alumino-silicate powder. Apart from the lower strength because of their brittleness, GICs are sensitive initially to moisture contamination (specimens were stored in a high humidity environment), making the matrix chalky and porous, resulting in a loss of surface hardness, and later, they are sensitive to dehydration.[27] Mean SBS value obtained for Vivaglass Cem is below minimal recommended values for clinical purposes, so the cariostatic properties of the GICs, may not be the overriding reason for using these cements clinically.

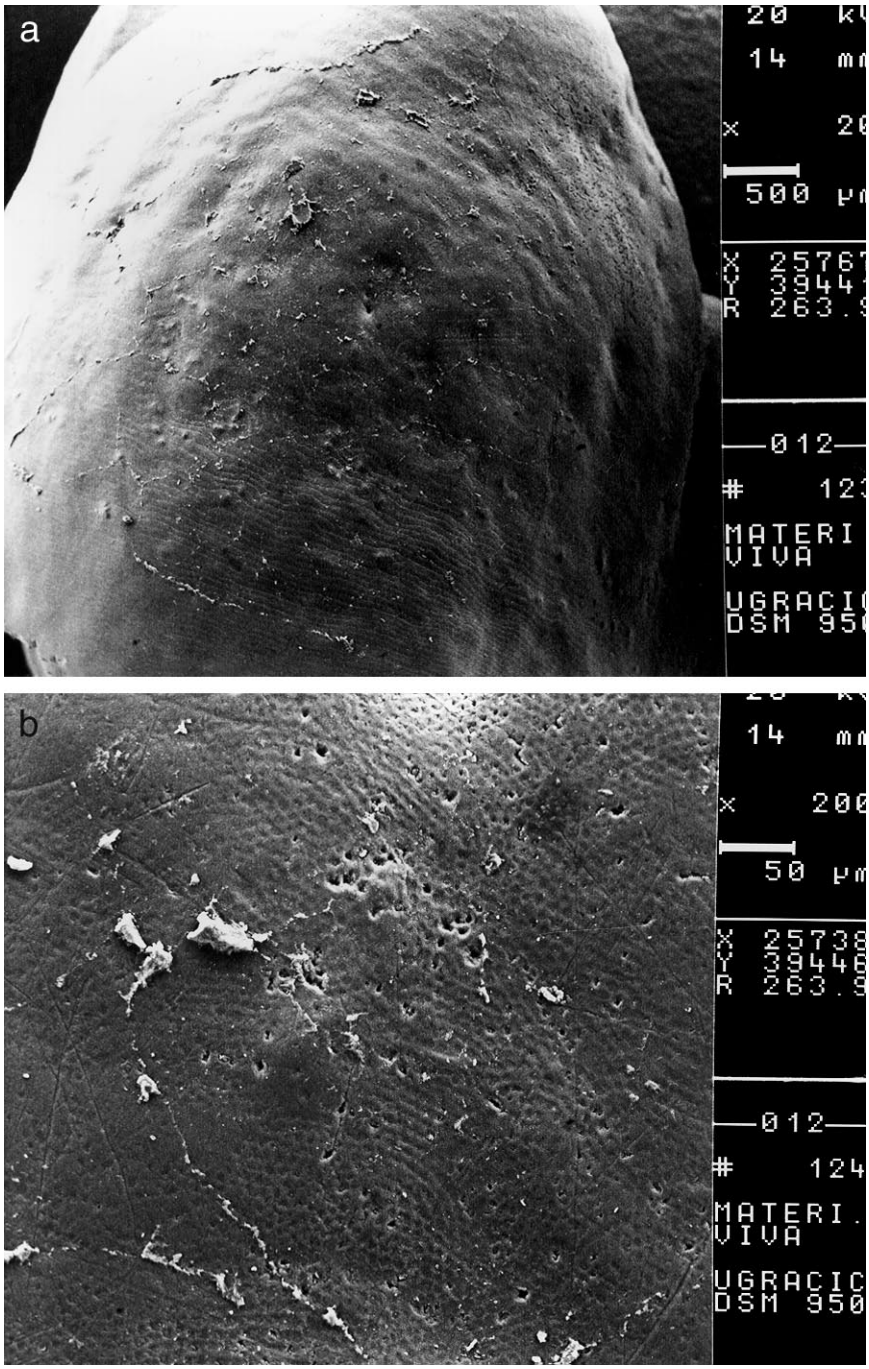

FIGURE 4. Specimen bonded with GIC (Vivaglass Cem). (a) A Type I (cement–enamel) failure (20× magnification). (b) Almost intact enamel surface is clearly evidenced (200× magnification).

The adhesive bond strength to enamel of RMGICs was greater than that obtained with conventional GICs. The small amount of resin present in the RMGICs may enhance the bonding properties of this kind of material to enamel.[14] The fast initial set of the RMGICs enables them to be less susceptible to dehydration.[28] Compton et al[29] reported that RMGICs with an initial set of 20 seconds may produce higher initial SBS, as well as decreased sensitivity to moisture contamination and desiccation, making their use as orthodontic bonding agents attractive. On the other hand, they also have the advantage of preventing decalcification caused by the fluoride ion release and of easier debonding and cleaning-up procedures[30] because GICs can adhere to nonetched enamel by physicochemical means, reducing the need for mechanical retention.[31]

Bonding of glass ionomers to enamel may be enhanced

by surface conditioning with 10% polyacrylic acid,[14] removing contaminants and debris. The acid promotes effective cleaning and wetting of the substrate surface.[32]

The bond strength of Fuji Ortho LC was highly increased by the orthophosphoric etching of the enamel surface. Mean SBS values of RMGICs after acid etching of the enamel surface were similar to those of LC composite resin. The preference for using the RMGICs is justified because debonding of brackets and clean up of composite resin residue may cause scratches and facets in the enamel that promote plaque and stain formation[2,33] damaging the esthetics of the teeth after the orthodontic treatment. Resin tags following orthophosphoric acid–etching generally penetrate the enamel surface to a depth of 80 μm sometimes reaching a depth of 100–170 μm,[34] and the complete removal of these resin tags cannot be effectively achieved.[35] SEM study of the enamel surface after debonding of brackets with either GICs, RMGICs, or composite resins always shows a porous enamel after acid etching (Figures 1 through 3) and an almost intact enamel surface when RMGICs or GICs were used as bonding adhesives and when no acid etching was performed (Figure 4). Other authors also show a less affected enamel when GIC is used instead of acrylic resins.[36]

Acid etching of enamel significantly increased bond strength of brackets to enamel, and mean shear bond strengths obtained for nonetched groups were under the minimum bond strength recommended for successful clinical bonding.[25,26,37]

The site of failure also provides useful information about the bonding process. Ideally, in orthodontics, an adequate bond that fails at the enamel-cement interface is desirable because debonding and subsequent polishing procedures would become much easier. When the acid-etching technique was used, almost none of the bonding failures were located at the resin-enamel interface (Figures 1 through 3), according to Jou et al[1] For Light Bond (LC composite resin) 70% of the failures were at the resin-bracket interface (Figure 1). This is, probably, because of incomplete polymerization of the resin[21] just below the metal base of the bracket. The inability of visible light to cure material behind the bracket mesh may be responsible, in part, for the site of failure. Polymerization of light-curing materials for orthodontic bonding, even with longer illumination times, does not result in the same degree of polymerization that is obtained by direct illumination.[37] Maijer et al[38] have also commented that air entrapment behind the mesh of a metal bracket may significantly affect polymerization, because of the role of oxygen inhibition of free radical polymerization, and may produce lower bond strength between the bracket mesh and the composite material. But this type of failure was only found with LC composite resin. Careful application of the material to the bracket base and/or the use of liquid-paste systems, may avoid air entrapment. This type of failure, at the resin-bracket interface, implies that all the resin should be cleaned up from the enamel surface.

Polymerization has been more effective and retention has also been greater with System One (CC composite resin); this could be the reason for the higher SBS and the greatest percentage of mixed failures (90%) found in this group (Figure 2a). When high shear bond strengths are obtained (CC composite resin), the process of debonding may exert some extra influence on the attained site of failure.[4] High shearing forces induce a fracture plane that would propagate through the union, at the resin-bracket area, increasing the number of resin-enamel and mixed failures. Some enamel prism fractures may also be observed (Figure 2a) in this group.

When using GICs or RMGICs, and specially when acid etching is not used, almost all the failures were at the cement-enamel interface (Figure 4), in accordance with previous reports.[1,9,39] No failure appeared at the bracket-cement interface, GICs bonds better to the metal base of the bracket than to enamel.[40] Unlike composite resins, GICs adhere to both metal and tooth surfaces by a chemical mechanism.[41] RMGIC group shows a lower number of cement-enamel failures than the GIC group (Figure 4) possibly because of the resin component existing in the RMGIC formulation that may confer a greater cohesive strength to the cement and may enhance adhesion to enamel,[14] specially when an acid-etching technique is used on enamel. The acid etching of the enamel when the RMGICs are used significantly increased the percentage of mixed failures (Figure 3), indicating an improvement of cement-enamel adhesion. It may be because of the existence of a higher surface energy (cleaner and rougher enamel) that improved microretention of the cement in the etched enamel.

In vitro, bracket bonding is performed under ideal conditions. In vivo, enamel surfaces are easily contaminated and sometimes, wetness is unavoidable. It should be taken into account, that in these cases, bond strengths of CC or LC composite resins will dramatically decrease, but RMGICs are able to stand and perform properly.[42]

CONCLUSION

Within the limitations of being an in vitro study, the clinical use of RMGICs for direct bonding of orthodontic brackets, after orthophosphoric acid–etching of enamel, is strongly encouraged. Obtained bond strengths are within the range of clinical use and are not different from those attained by LC composite resins. RMGICs are fluoride-releasing materials that are able to stand wet conditions, and enamel is less damaged after debracketing.

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