European Journal of Orthodontics 33 (2011) 180–184
doi:10.1093/ejo/cjq056
Advance Access Publication 30 August 2010

Bond strength of orthodontic light-cured resin-modified glass ionomer cement

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SUMMARY The purpose of this study was to compare the bond strengths and debonded interfaces achieved with light-cured resin-modified glass ionomer cement (RMGIC) and conventional light-cured composite resin. In addition, the effects of acid etching and water contamination were examined.

One hundred human premolars were randomly divided into five equal groups. The mini Dyna-lock upper premolar bracket was selected for testing. The first four groups were treated with light-cured RMGIC with or without 15 per cent phosphoric acid-etching treatment and with or without water contamination preceding bracket bonding. The control samples were treated with the conventional light-cured Transbond composite resin under acid etching and without water contamination. Subsequently, the brackets were debonded by tensile force using an Instron machine. The modified adhesive remnant index (ARI) scores were assigned to the bracket base of the debonded interfaces using a scanning electron microscope. The bond strength and modified ARI scores were determined and analysed statistically by one-way analysis of variance and chi-square test.

Under all four conditions, the bond strength of the light-cure RMGIC was equal to or higher than that of the conventional composite resin. The highest bond strength was achieved when using RMGIC with acid etching but without water contamination. The modified ARI scores were 2 for Fuji Ortho LC and 3 for Transbond. No enamel detachment was found in any group. Fifteen per cent phosphoric acid etching without moistening the enamel of Fuji Ortho LC provided the more favourable bond strength. Enamel surfaces, with or without water contamination and with or without acid etching, had the same or a greater bond strength than Transbond.

Introduction

Composite resin is by orthodontists because it allows easy manipulation for precise bracket placement (Newman, 1965), which reduces the amount of time spent when banding (Bishara *et al.*, 1998). However, the disadvantage of using composite resin is plaque accumulation (Øgaard *et al.*, 1988), which can lead to demineralization of the enamel surrounding resin-bonded brackets (Mizrahi, 1983; Øgaard, 1989). In addition, in order to achieve adequate bond strength, the enamel surface must undergo acid etching and drying before bracket bonding (Bishara *et al.*, 1998). In practice, full-mouth bonding can be time consuming.

Glass ionomer cements (GICs) were invented to resolve these problems (Pettemerides *et al.*, 2001; Pascotto *et al.*, 2004). The cement consists of a basic glass and an acidic polymer and sets when an acid-based reaction occurs (McLean *et al.*, 1994; Mount, 1994). On application, the resin releases fluoride ions that prevent enamel demineralization during orthodontic treatment (Newman *et al.*, 2001; Pettemerides *et al.*, 2001; Pascotto *et al.*, 2004). Furthermore, with GIC, the enamel does not require acid etching or drying before bonding (Cook, 1990). However, previous studies have shown that GIC has a weak bond strength when the teeth have been etched with phosphoric acid or conditioned with polyacrylic acid (Wiltshire, 1994).

In an attempt to increase fluoride release and to improve bond strength, resin-modified glass ionomer cements (RMGIC) were developed (Rix *et al.*, 2001). They also utilize the auto set mechanism of acid–base reaction between glass ionomer and polyacid-modified composite resin, behaving similarly to conventional composite resins (Silverman *et al.*, 1995; Sfondrini *et al.*, 2001).

Dual- and light-cured RMGICs are widely used by orthodontists. However, depending on the material used and pre-treatment of the teeth before bonding, the achieved bond strengths can vary (Newman *et al.*, 2001; Sfondrini *et al.*, 2001; Valente *et al.*, 2002; Cacciafesta *et al.*, 2003; Summers *et al.*, 2004; Chitnis *et al.*, 2006). These studies not only used different bonding materials and treated the enamel surface under different conditions prior to bonding and various debonding conditions but they also did not focus on whether different treatment conditioning of the enamel surfaces influences the bond strength of RMGICs on human teeth.

Before the introduction of RMGIC, most previous studies followed the manufacturer's recommendation and used 10 per cent polyacrlic acid for surface treatment before bonding. Polyacrylic acid was reported to contain functional groups potentially capable of hydrogen bonding to the tooth surface (Powis *et al.*, 1982). On the other hand, with conventional composite resin, 37 per cent phosphoric acid was popular for surface treatment before bonding, which created microporosities on the enamel surface. After resin curing, the formation of resin tags will extend into these microporosities and form a mechanical bond to the enamel surface (Retief, 1978). However, because RMGIC contains the properties of resin, its bond strength with the use of phosphoric acid for surface pre-treatment is of concern.

The purpose of this study was to compare the bond strengths and debonded interfaces achieved with a conventional light-cured composite resin and a light-cured RMGIC with the same acid-etching procedure. The effects of acid etching and water contamination were also investigated.

Materials and methods

Two light-cured adhesives were used in this study: Fuji Ortho LC (a light-cured RMGIC; GC International Corp., Itabashiku, Tokyo, Japan) and Transbond (conventional light-cured composite resin; 3M Unitek, St Paul, Minnesota, USA)

One hundred premolars extracted for orthodontic purposes from 9- to 16-year-old patients were used in the study with the consent of the patients. After extraction, the teeth were washed and immersed in normal saline for no more than 3 months before testing. The criteria of tooth selection were (1) grossly perfect crowns, with no defects and (2) no pre-treatment with chemical agents, such as hydrogen peroxide or formalin. The samples were randomly divided into five groups of 20 teeth.

In group 1 (G1), the buccal surfaces of the crowns were polished with a pumice powder (Prophypol fine particle; Moyco Industries Inc., Philadelphia, Pennsylvania, USA). A 15 per cent phosphoric acid solution (Wang *et al.*, 1994) was then used to etch the buccal enamel surfaces for 15 seconds (Wang and Lu, 1991). On a mixing pad, Fuji Ortho LC was added to one scoop of powder and was divided into two equal parts. One half was mixed for 10 seconds and then the second half was mixed for a further 10 seconds, as recommended by the manufacturer. The mixture was placed on the bracket base (Mini Dyna-lock 118-503; 3M/Unitek), the bracket was positioned on the enamel with a placement scaler, and then excess cement was removed with a dental probe. The specimens were cured using a halogen lamp (Translux CL, 15/33140; Kulzer Corp., Wehrheim/TS, Germany) for which the long axis (8 mm in lamp tip diameter) was perpendicular to the bracket surface (3.1 × 3.4 mm base area) and cured for 40 seconds (Wang and Meng, 1992). In Group 2 (G2), the enamel surfaces were etched with 15 per cent phosphoric acid solution for 15 seconds. The teeth were then sprayed with water for 10 seconds and dried with an air spray. Subsequently, a cotton roll moistened with distilled water was used to smear the enamel surface before bonding. Groups 3 (G3) and 4 (G4) were similarly prepared, except G3 was neither acid etched nor contaminated with water prior to bonding. Group 4 was also not acid etched but was contaminated with distilled water prior to bonding. The enamel in Group 5 (G5) was etched for 15 seconds with 15 per cent phosphoric acid, dried, and the brackets bonded with Transbond composite resin (Table 1).

The specimens were incubated in a 37°C in a water bath for 24 hours. The tensile bond strength was measured with an Instron machine (Instron, AGS-1000kGW; Shimadzu Corp., Chiroda-Ku, Tokyo, Japan) at a crosshead speed of 2 mm/minute (Wang and Meng, 1992). The debonded interfaces in each group were examined with a scanning electron microscope (Hitachi S-2400; Hitachi Corp., Chiyoda-Ku, Tokyo, Japan) under 15 KV at ×20 magnification The amount of adhesives remaining on the bracket base was calculated with the soft imaging system software (Soft imaging system 2000; Soft Imaging System Corp., Lakewood, Colorado, USA) and scored using the modified adhesive remnant index (ARI; Årtun and Bergland, 1984). The mean and standard deviation of bond strength were assessed and analysed by one-way analysis of variance (ANOVA). The modified ARI was calculated by chi-square test to determine statistically significant differences (Grafen and Hails, 2002).

Results

The bond strength of each group is shown in Table 1. One-way ANOVA showed that the *F* value was 6.06, indicating

Table 1 Treatment conditions of the enamel surface, bonding material, and strength.

Group	Acid etching	H_2O contamination	Cement	Bond strength (MPa)
G1	+	−	Fuji Ortho LC	17.3 ± 2.73
G2	+	+	Fuji Ortho LC	13.2 ± 5.95
G3	−	−	Fuji Ortho LC	14.4 ± 5.93
G4	−	+	Fuji Ortho LC	11.3 ± 4.35
G5	+	−	Transbond	11.6 ± 1.74

G1: acid etching without water contamination; G2: acid etching and water contamination; G3: no acid etching or water contamination; G4: no acid etching but using water contamination; and G5: acid etching without water contamination.

statistically a significant difference ($P < 0.01$). Using Scheffe's test where α value was set as 0.05, the bond strength of G1 was statistically greater than that of G4 and G5. However, there were no statistical differences among G1, G2, and G3 or between G4 and G5.

The modified ARI scores of the debonded interfaces of the bracket base are shown in Table 2. The chi-square test showed that there were significant differences among the five groups ($P < 0.001$). Overall, 62 per cent of the samples were assigned a modified ARI score of 2, 20 per cent a score of 3, and 16 per cent a score of 1. None of the debonded interfaces were scored as 0. In addition, no enamel detachment was seen on any of the samples.

Discussion

The bond strength of G1 was statistically greater than that of G4 and G5. There were no statistically significant differences among G1, G2, and G3 or between G4 and G5. This indicates that the Fuji Ortho LC achieved an equal or higher bond strength than Transbond, regardless of whether the enamel surface was contaminated with water or acid etched. The bond strength of Fuji Ortho LC was greater or equal to Transbond.

RMGIC have two setting systems, including polymerization of composite resin and an acid–base reaction (Silverman *et al.*, 1995, Sfondrini *et al.*, 2001). RMGIC consists of 4–6 per cent polymerizable resin and the setting reaction involves three stages (Silverman *et al.*, 1995). The first stage is light irradiation to initiate free radical polymerization of the composite resin/hydroxyethyl-methacrylate matrix, which may offer dimensional stability and an early setting strength. The next stage in setting is the acid–base reaction of the GIC in the polymer matrix. The third reaction is self-cure of the resin monomers. These setting mechanisms may need more time to complete. Hence, 40 seconds of light exposure may have caused an increase in the bond strength of the RMGIC in the present study. The bond strength of Transbond with 40 seconds of light exposure was greater than 20 seconds of light exposure with the long axis of the lamp tip perpendicular to the bracket surface (Wang and Meng, 1992).

Table 2 Modified adhesive remnant index (ARI) scores assigned to the bracket base of the debonded interfaces.

	No	ARI score				Enamel detachment	X^2	P
		0	1	2	3			
G1	20	0	1	19	0	0	43.75	0.001
G2	20	0	7	13	0	0		
G3	20	0	0	15	5	0		
G4	20	0	1	14	5	0		
G5	20	0	7	3	10	0		

G1: acid etching without water contamination; G2: acid etching and water contamination; G3: no acid etching or water contamination; G4: no acid etching but water contamination; and G5: acid etching without water contamination.
ARI scores: 0, no composite remaining; 1, less than half of the composite remaining; 2, more than half of the composite remaining; and 3, all composite remaining.

The bond strength of G1 and G2 with acid etching was greater than that of G3 and G4 without etching. Etching for 15 seconds with 15 per cent phosphoric acid may improve micro-retention and increase bond strength. Valente *et al.* (2002) investigated how different acid etch preparations and concentrations affect the tensile bond strength of a RMGIC (Fuji Ortho LC) for bonding orthodontic attachments. They found no significant difference in tensile bond strength when 10 or 37 per cent phosphoric acid or 10 per cent polyacrylic acid was used to etch the tooth surface before bonding.

There was no difference in bond strength with etching times of 15, 30, 60, and 90 seconds. However, enamel detachment was found when the etching time exceeded 30 seconds (Wang and Lu, 1991) or the concentration of phosphoric acid solution exceeded 30 per cent (Wang *et al.*, 1994).

The bond strengths of G1 and G3 were greater than those of G2 and G4, indicating that water contamination prior to bonding reduced bond strength in the RMGIC groups.

Chitnis *et al.* (2006) compared the *in vitro* shear bond strength of four adhesives: a standard resin-based composite, a RMGIC, a giomer, and a polyacid-modified composite resin. They found no statistical difference in bond strength between the resin-based composite and the RMGIC when the enamel surface of the resin-based composite was etched with 37 per cent phosphoric acid and the RMGIC with 10 per cent polyacrylic acid; both had a significantly higher mean bond strength than the polyacid-modified composite resin or the giomer at 1 hour and 7 days.

Newman *et al.* (2001) indicated that, under moist conditions, Fuji Ortho LC provided adequate bond strength when compared with conventional light-cured no-mix composite resin adhesives but was weaker than that of mixing types of composite resin. Fuji Ortho LC produced higher bond strength when the enamel surfaces were etched with 10 per cent polyacrylic acid prior to bonding. This was consistent with the present results except the current study did not test the mixing type of the composite resin.

Sfondrini *et al.* (2001) observed no significant difference in shear bond strength (SBS) between a conventional composite resin and RMGIC if the enamel surface was acid etched prior to bonding; however, under non-etched conditions, the SBS achieved with the RMGIC was statistically lower than that of the conventional composite resin. In that study, bovine permanent mandibular incisors were used.

The *in vitro* SBS and *in vivo* survival rate between a conventional resin and a RMGIC were compared by Summers *et al.* (2004). For the resin group, 37 per cent phosphoric acid was used to pre-treat the enamel surface for

40 seconds, rinsed with water for 10 seconds, and then air dried before bonding. For the RMGIC group, the samples were conditioned with 10 per cent polyacrylic acid for 20 seconds, rinsed with water for 10 seconds, and then wiped with a moist cotton roll to remove excess water. Subsequently, Light Bond and Fuji Ortho LC were applied to the enamel surfaces and light cured for 40 seconds with an Ortholux XT visible light-curing unit. The results showed that the bond strength of Fuji Ortho LC after 30 minutes and 24 hours was significantly lower than that of Light Bond. This was contrary to the findings of the present study.

When assessing the failure site of debonded interfaces, most studies (Grubisa *et al.*, 2004; Trites *et al.*, 2004; Cehreli *et al.*, 2005) used the ARI. However, this index is largely subjective and it is difficult to discriminate between tooth and resin on the debonded intersurface (Årtun and Bergland, 1984). ARI scores are also significantly different under ×10 and ×20 magnification (Montasser and Drummond, 2009).

According to ARI analysis, the debonded interfaces of the RMGIC surfaces were mainly scored 2 (50–90 per cent of adhesive remaining on bracket base) while in approximately 76 per cent of the sample, the debonded surfaces of the Transbond composite resin group were scored 3 (more than 90 per cent of adhesive remaining on bracket base) for 50 per cent of the sample. These results indicate that more resin remained on the bracket base when using RMGIC and Transbond composite resin for bonding. The reasons may be (1) Light-curing of the composite resin was satisfactory (40 seconds), the debonded interface within the resin itself was low, (2) Etching for 15 seconds with 15 per cent phosphoric acid was sufficient (Wang and Lu, 1991; Wang *et al.*, 1994), and (3) The one piece casting of the mini Dyna-lock bracket had a knife edge design for retention of the base, which may have affected penetration of the resin and the escape of air during bonding (Wang *et al.*, 2004).

Conclusions

1. RMGIC is capable of achieving the same or greater bond strength as Transbond, even if the enamel has not been acid etched or is not contaminated with water prior to bonding.
2. Etching with 15 per cent phosphoric acid for 15 seconds and without moisture contamination of the RMGIC resulted in optimal bond strength.
3. The ARI scores for the adhesive remaining on the bracket surface were 2 for Fuji Ortho LC and 3 for Transbond.
4. No enamel detachment was found on the debonded interface in any group.

Funding

This study was partially supported by a grant from the Chi Mei Medical Center, Tainan, Taiwan (CMFHR 9139).

Acknowledgement

Special thanks to Ms Hui-Min Chen at the Department of Anatomy and Electron Microscopy Center, College of Medicine, Taipei Medical University for her technical assistance.

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