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Polymerization with a micro-xenon light of a resin-modified glass ionomer: a shear bond strength study 15 minutes after bonding

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SUMMARY The purpose of this study was to evaluate the initial shear bond strength (15 minutes after bonding) of a resin-modified glass ionomer (RMGIC, Fuji Ortho LC) cured with two different light-curing units: a conventional visible light (Ortholux XT) and a micro-xenon light (Aurys). Seventy-five freshly extracted bovine permanent mandibular incisors were randomly assigned to one of five groups; each group consisted of 15 specimens. Group A (Transbond XT) and group B (Fuji Ortho LC) were exposed to the visible light for 20 and 40 seconds, respectively, and used as controls. The remaining three groups (C, D, and E) were bonded with Fuji Ortho LC and cured with Aurys for 10, 5, and 2 seconds, respectively. All samples were tested in a shear mode on an Instron universal testing machine 15 minutes after bonding.

The shear bond strength of the control group bonded with Transbond XT was significantly higher ($P = 0.000$) than those of all the other groups tested. Regarding Fuji Ortho LC, no statistically significant differences were found between the bond strength of the control group cured with Ortholux XT, and those of the groups cured with Aurys for 2, 5, and 10 seconds. The present findings indicate that, compared with visible light-curing, the micro-xenon light enables the clinician to significantly reduce the curing time of RMGICs, without affecting their initial shear bond strengths.

Introduction

Bonding brackets with conventional composite resins involves a series of technique-sensitive steps and requires a completely dry field of operation throughout the bonding procedure. Although the acid etch technique of enamel has become a widely accepted dental procedure, many orthodontists remain concerned about decalcification, white spot lesions (Gorelick *et al.*, 1982; Øgaard *et al.*, 1988), and surface enamel loss (Brown and Way, 1978; Thompson and Way, 1981), often associated with such a technique.

In an attempt to minimize the incidence of decalcification around orthodontic appliances and increase tolerance to moisture contamination during bonding, glass ionomer cements (GICs) were introduced as alternatives to composite resins for bracket bonding. GICs have the ability to bond chemically to enamel, cementum, dentine, non-precious metals, and plastics (Kent *et al.*, 1973; Hotz *et al.*, 1977). The potential advantages of GICs are adhesion in a wet field, a non-etching technique, and the release of fluoride ions over long periods into adjacent enamel (Cook and Youngson, 1988). In addition, they have the capability of absorbing fluoride from sources such as fluoride toothpastes, thus acting as a rechargeable, slow-release fluoride device (Hatibovic-Kofman and Koch, 1991). The biggest disadvantage of GICs is their weak bond strength, as shown in several *in vivo* (Miguel *et al.*, 1995; Miller *et al.*, 1996; Norevall *et al.*, 1996) and *in vitro* (Fajen *et al.*, 1990; Wiltshire, 1994) studies.

In order to retain the positive characteristics of GICs, but also to improve bond strength, combinations of GICs and composite resins were developed as resin-modified glass ionomer cements (RMGICs). Light-cured RMGICs were formulated to overcome the problems of moisture sensitivity of composites and low early mechanical strength of glass ionomers, while maintaining the clinical advantages of conventional GICs. Several studies have reported less enamel demineralization under orthodontic bands and brackets retained with either conventional GICs (Rezk-Lega *et al.*, 1991; Marcusson *et al.*, 1997) or light-cured RMGICs (Vorhies *et al.*, 1998; Wilson and Donly, 2001).

The greatest advantage of light-cured adhesives is that they provide the orthodontist with ample time to accurately position the bracket on the enamel surface before polymerization. A disadvantage of the light-cured approach is the time it takes to expose each bonded bracket to the light. According to the manufacturer's guidelines, visible light-curing (VLC) units can cure orthodontic composite resins in 20 seconds (Transbond XT, 3M/Unitek, Monrovia, CA) and light-cured RMGICs in 40 seconds (Fuji Ortho LC, GC America Inc., Alsip, IL) per each bracket. This prolonged curing time is inconvenient for the patient, impractical with children, and uncomfortable for the clinician, particularly when bonding brackets with light-cured RMGICs. Therefore, various methods have been employed to enhance the polymerization of bonding agents, including the use of argon lasers (Lalani *et al.*, 2000; Talbot *et al.*, 2000) and xenon arc lights (Cacciafesta *et al.*, 2000; Silverman and Cohen, 2000).

Recently, Sfondrini *et al.* (2001) showed that, after a 24-hour period, Fuji Ortho LC and Transbond XT provided bond strengths adequate for clinical use when cured with a xenon arc light. These bond strengths were not statistically different from those achieved by curing both adhesives with a conventional VLC unit. However, the bond strengths of light-cured RMGICs and composite resins increased with time due to continued polymerization of the bonding agent under the bracket base (Chamda and Stein, 1996; Bishara *et al.*, 1999). As most orthodontists activate the appliances in the mouth from 10–15 minutes after bonding (Millett and Gordon, 1994), the initial bond strength of orthodontic adhesives is very important. Recently, Bishara *et al.* (2000) showed that RMGICs had a significantly lower shear bond strength 30 minutes after bonding than composite resins, when both adhesives were cured with a conventional visible light.

To date, however, the effect of high-intensity curing lights on the initial shear bond strength (15 minutes after bonding) of light-cured RMGICs has not been investigated. Accordingly, the purpose of this study was to compare the effects of a conventional and a micro-xenon light on the shear bond strength of a light-cured RMGIC 15 minutes after the direct bonding of stainless steel brackets. In addition, the amount of residual adhesive remaining on the tooth after debonding was measured.

Materials and methods

Seventy-five freshly extracted bovine permanent mandibular incisors were collected from a local slaughterhouse and stored in a solution of 0.1 per cent (weight/volume) thymol for 1 week. Previous studies have indicated that bovine enamel is similar in composition and physical properties to human enamel (Nakamichi *et al.*, 1983; Oesterle *et al.*, 1998) and it has been used for bond strength testing in several comparative studies (Nakamichi *et al.*, 1983; O'Brien *et al.*, 1987; Barkmeier and Erickson, 1994; Süssenberger *et al.*, 1997; Cacciafesta *et al.*, 1998a,b; Oesterle *et al.*, 1998; Van Waveren Hogervorst *et al.*, 2000; Grandhi *et al.*, 2001; Sfondrini *et al.*, 2001).

The criteria for tooth selection included intact buccal and lingual enamel with no cracks caused by the pressure of the extraction forceps and no caries. The teeth were randomly assigned to one of five groups. Each group consisted of 15 specimens. The teeth were cleansed of soft tissue and then embedded in cold curing, fast setting acrylic (Leocryl, Leone, Sesto Fiorentino, Italy), and placed in metal rings. Each tooth was orientated so that its labial surface would be parallel to the force during the shear bond test. Before bonding, the facial surface of each incisor was wet-ground for 30 seconds on 600-grit silicone carbide paper using a rotating disc (DPU4, Struers, Copenhagen, Denmark), and then cleaned with a mixture of water and fluoride-free pumice using a rubber polishing cup for 10 seconds. The enamel surface was thoroughly rinsed with water to remove any pumice or debris, and dried with an oil-free air stream. Seventy-five maxillary central incisor brackets with 0.018-inch slot (Leone) were bonded by the same operator to all the teeth. The average surface area of the bracket base was determined to be 12.4 mm^2. Two orthodontic light-cured adhesive systems were evaluated: Fuji Ortho LC (GC America Inc.), which is a RMGIC, and Transbond XT (3M/Unitek), which is a conventional composite resin. Two groups (one for each type of adhesive) were exposed to a conventional visible light-curing unit (Ortholux XT, 3M Dental Products, St Paul, MO; light intensity: 550 mW/cm^2) and used as control groups. The remaining three groups were bonded with Fuji Ortho LC and were cured with a micro-xenon light (Aurys Degrè K, Schiltigheim, France; light intensity: 1650 mW/cm^2).

After initial prophylaxis, the bonding procedure for each adhesive system followed the manufacturers' guidelines. In the Transbond XT group, the enamel surfaces were etched with 37 per cent phosphoric acid gel for 30 seconds, followed by thorough washing and drying. After application of the primer on the tooth, the brackets were bonded near the centre of the facial surface of the tooth with sufficient pressure to express excess adhesive, which was removed from the margins of the bracket base with a scaler before polymerization. The curing protocol for the brackets bonded with Transbond XT was as follows:

Group A: light-curing for 20 seconds with the Ortholux XT, 10 seconds each from the mesial and the distal.

In the Fuji Ortho LC groups, teeth were conditioned with 10 per cent polyacrylic acid for 20 seconds, followed by thorough washing. The bonding surface of the tooth was wiped with a moistened cotton roll immediately before bonding. The refrigerated capsule that contained the adhesive was activated and triturated for 10 seconds. The bracket with the adhesive was placed on the tooth near the centre of the facial surface, with sufficient pressure to express excess adhesive, which was removed from the margins of the bracket base with a scaler before polymerization. The curing protocols for the brackets bonded with Fuji Ortho LC were as follows:

Group B: light-curing for 40 seconds with Ortholux XT, 10 seconds each from the mesial, distal, occlusal, and gingival.
Group C: light-curing for 10 seconds with Aurys, 5 seconds each from the mesial and the distal.
Group D: light-curing for 5 seconds with Aurys, 3 seconds from the mesial and 2 seconds from the distal.
Group E: light-curing for 2 seconds with Aurys, 1 second each from the mesial and the distal.

After bonding, all samples were stored in distilled water at room temperature for 15 minutes and subsequently tested in a shear mode on an Instron universal testing machine (Instron Corp., Canton, MA). For shear testing, the specimens were secured in the lower jaw of the machine, so that the bracket base of the sample paralleled the direction of the shear force. The specimens were stressed in an occlusogingival direction with a crosshead speed of 1 mm/min, according to previous studies (Jobalia *et al.*, 1997; Messersmith *et al.*, 1997; Oesterle *et al.*, 1998; Haydar *et al.*, 1999; Millett *et al.*, 1999; Shammaa *et al.*, 1999; Sfondrini *et al.*, 2001). The maximum load necessary to debond or initiate bracket fracture was recorded in Newtons and then converted into megapascals (MPa) as a ratio of Newtons to surface area of the bracket.

After bond failure, the bracket bases and the enamel surfaces were examined by the same operator under a light stereomicroscope at ×10 magnification and the amount of adhesive left on the enamel surface was scored for each tooth using the Adhesive Remnant Index (ARI;

Table 1 Descriptive statistics (in MPa) of shear bond strengths of the five groups tested.

	Mean ± SD (MPa)	Median (MPa)	Range (MPa)	Sample size (n)
Transbond XT				
Ortholux XT	17.0 ± 1.7	17.0	14.0–19.8	15
Fuji Ortho LC				
Ortholux XT	8.4 ± 1.5	8.4	5.9–11.1	15
Aurys 10 sec	7.3 ± 0.8	7.1	6.3–8.9	15
Aurys 5 sec	7.0 ± 0.9	7.2	5.9–9.1	15
Aurys 2 sec	7.1 ± 1.1	7.0	5.2–8.6	15

Oliver, 1988). The ARI scale has a range between 1 and 5: (1) all of the adhesive remaining on the enamel, along with the impression of the bracket base; (2) more than 90 per cent of the adhesive remaining; (3) more than 10 per cent, but less than 90 per cent of the adhesive remaining; (4) less than 10 per cent of the adhesive remaining; and (5) no adhesive remaining on the enamel surface. The ARI scores were used as a more complex means of defining the site of bond failure between the enamel, the adhesive, and the bracket base.

Descriptive statistics including the mean, standard deviation, median, minimum, and maximum values were calculated for each of the five groups tested. A two-way analysis of variance was used to determine whether significant differences existed among the various groups. If a significant difference was found, then the Scheffé's test was used to identify which of the groups was different.

The Chi-square (χ^2) test was used to determine significant differences in the ARI scores among the different groups. For the purpose of statistical analysis, ARI scores 1 and 2 were combined, and scores 4 and 5 were combined. The level of significance for all the tests was set at $P \leq 0.05$.

Results

The descriptive statistics of the shear bond strength for each group are shown in Table 1 and Figure 1. Shear forces are given in MPa. The results of the analysis of variance comparing the experimental groups revealed the presence of significant differences among the groups ($P = 0.000$). The shear bond strength of the

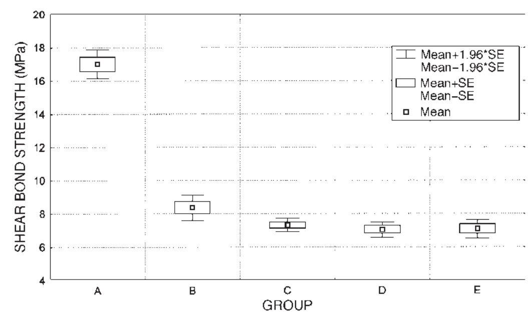

Figure 1 Mean shear bond strengths and standard deviations of each of the five groups tested (A = Transbond XT + Ortholux XT 20 seconds; B = Fuji Ortho LC + Ortholux XT 40 seconds; C = Fuji Ortho LC + Aurys 10 seconds; D = Fuji Ortho LC + Aurys 5 seconds; E = Fuji Ortho LC + Aurys 2 seconds).

control group bonded with Transbond XT and cured with Ortholux XT (17.0 ± 1.7 MPa) was significantly higher ($P = 0.000$) than those of all the other groups tested. When evaluating the shear bond strengths of the groups bonded with Fuji Ortho LC, no statistically significant differences were found between the control group cured with Ortholux XT (8.4 ± 1.5 MPa) and those cured with Aurys for 10, 5, and 2 seconds (7.3 ± 0.8, 7.0 ± 0.9, and 7.1 ± 1.1 MPa, respectively).

The ARI scores for the five groups tested are listed in Table 2 and Figure 2. The χ^2 test results ($\chi^2 = 66.6$; df = 10) indicated the presence of a significant difference between group A and the remaining groups ($P = 0.000$). Group A had a greater frequency of ARI score of 1 and 2 ($P = 0.000$). When examining the groups bonded with Fuji Ortho LC, no statistically significant differences in ARI scores were found between

Table 2 Frequency distribution of the Adhesive Remnant Index (ARI) scores of the five groups tested.

Groups tested	ARI scores			
	1–2	3	4–5	Sample size (*n*)
Transbond XT				
Ortholux XT	9 (60.0%)	2 (13.3%)	4 (26.7%)	15
Fuji Ortho LC				
Ortholux XT	0 (0.0%)	0 (0.0%)	15 (100.0%)	15
Aurys 10 sec	0 (0.0%)	0 (0.0%)	15 (100.0%)	15
Aurys 5 sec	0 (0.0%)	0 (0.0%)	15 (100.0%)	15
Aurys 2 sec	0 (0.0%)	0 (0.0%)	15 (100.0%)	15

$\chi^2 = 66.6$; df = 10; $P = 0.000$.

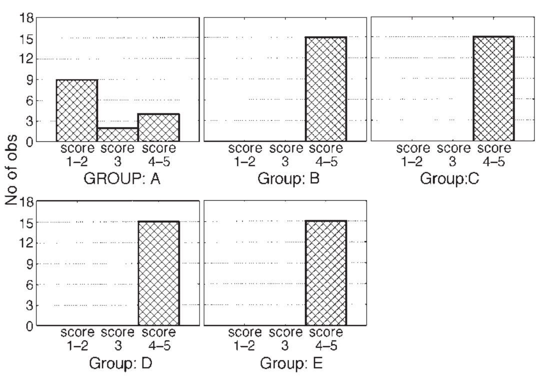

Figure 2 Comparison of ARI scores of each of the five groups tested (A = Transbond XT + Ortholux XT 20 seconds; B = Fuji Ortho LC + Ortholux XT 40 seconds; C = Fuji Ortho LC + Aurys 10 seconds; D = Fuji Ortho LC + Aurys 5 seconds; E = Fuji Ortho LC + Aurys 2 seconds).

the control group cured with Ortholux XT and those cured with Aurys ($P = 1.0$). The RMGIC had a greater frequency of ARI score of 4 and 5, regardless of the type of light source, which indicates that bond failure occurred more frequently at the enamel-adhesive interface.

Discussion

The present study shows that the initial shear bond strength (15 minutes after bonding) of Fuji Ortho LC cured with Aurys for 10, 5, and 2 seconds was not significantly different from that of the same adhesive cured with a conventional VLC unit. On the other hand, the composite resin cured with the conventional VLC unit produced significantly higher shear bond strengths than those of all the other groups tested.

The use of bovine teeth for bond strength testing in orthodontics is well documented, and bovine enamel has been reported to be a reliable substitute for human enamel in bonding studies. With a continual increase in dental health, more conservative dentistry, and limits on access to human materials, it is increasingly difficult to obtain non-carious, sound human teeth for bonding tests (Oesterle *et al.*, 1998). Previous studies have shown that bovine and human enamel are similar in their physical properties, composition, and bond strength (Nakamichi *et al.*, 1983; Oesterle *et al.*, 1998). Other advantages include the large, flat, labial surfaces, and availability of the teeth, which make them a useful alternative to human enamel. A disadvantage of using bovine teeth is the difference in bond strength compared with human enamel. It has been shown that slightly (Nakamichi *et al.*, 1983) or significantly lower (Barkmeier and Erickson, 1994; Oesterle *et al.*, 1998) bonding values than to human enamel can be anticipated. In this investigation, an attempt was made to standardize the enamel surface in order to obtain reproducible bonding specimens. It has been shown that the bovine permanent incisors have larger undulations on the labial surface than human incisors (Oesterle *et al.*, 1998). This has led some researchers to grind labial enamel to create a smoother surface (Nakamichi *et al.*, 1983; O'Brien *et al.*, 1987; Barkmeier and

Erickson, 1994; Cacciafesta *et al*., 1998a,b; Van Waveren Hogervorst *et al*., 2000; Grandhi *et al*., 2001). Accordingly, in the present study the enamel surfaces were wet-ground on 600-grit silicone carbide paper, as previous investigations have shown that this procedure does not affect the integrity of the enamel surface or the etching pattern of both human and bovine enamel (Nakamichi *et al*., 1983; Barkmeier and Erickson, 1994).

Stresses at the interface between the adhesive and the tooth are not uniform, and are highly dependent on the test geometry and loading configuration adopted. Shear stresses increase as the distance between the point of load application and the tooth surface is increased. Thus, experimentally measured differences in bond strength are not necessarily due to variation in the actual adhesive bond strength at the interface (Van Noort *et al*., 1989; Fox *et al*., 1994). Shear stresses can be applied by means of either a loop (Messersmith *et al*., 1997; Millett *et al*., 1999; Lalani *et al*., 2000) or a steel rod with a flattened end (Süssenberger *et al*., 1997; Bishara *et al*., 1998, 1999, 2000; Cacciafesta *et al*., 1998a,b; Talbot *et al*., 2000). In the present study, a steel rod with a flattened end was used because it is less flexible than a wire loop and was able to fill the entire bracket slot, so that the point of application was at the same distance from the bracket/adhesive interface in all cases.

Previous investigations comparing the bond strength of RMGICs with those of composite resins cured with conventional VLC units have shown conflicting results, both in the short-term and 24 hours after bonding (Jobalia *et al*., 1997; Messersmith *et al*., 1997; Süssenberger *et al*., 1997; Bishara *et al*., 1998, 1999; Cacciafesta *et al*., 1998b; Chung *et al*., 1999; Haydar *et al*., 1999; Meehan *et al*., 1999; Millett *et al*., 1999; Sfondrini *et al*., 2001). *In vitro* studies evaluating the initial bond strength of orthodontic adhesives are very clinically relevant, as most orthodontists insert the archwire into the brackets from 10–15 minutes after bonding (Millett and Gordon, 1994).

Bishara *et al*. (1999) compared the effect of time on the shear bond strength of Fuji Ortho LC and Transbond XT within 30 minutes, and at 24 hours after bonding, using a conventional VLC unit for curing both adhesives. They found that in the initial 30 minutes after bonding, the composite resin had a significantly greater shear bond strength than the RMGIC. These findings are confirmed by the present investigation in which the composite resin cured with the conventional VLC unit produced significantly higher shear bond strengths than those of all the other groups tested.

There are many factors that can explain why RMGICs have lower shear bond strengths when compared with composite resins: the type of enamel conditioner, acid concentration, length of etching time, composition of the adhesive, adhesion to tooth structure.

More recently, Bishara *et al*. (2000) showed that the initial low bond strength of RMGICs was significantly increased by increasing the conventional VLC time for an additional 5–10 seconds. However, all the bond strength values reported were below the limits suggested by Reynolds (1975), who found that a minimum bond strength of 6–8 MPa was adequate for most clinical orthodontic needs. It has been shown by Bishara *et al*. (1999, 2000) that in the initial 30 minutes after bonding, the bond strengths of both adhesives tested were below these optimal limits, and more so with the RMGIC than with the composite adhesive. These results are in contrast with those of the present study, in which the bond strengths of Fuji Ortho LC were within these limits, regardless of the type of light source. Even light-curing for only 2 seconds with Aurys produced clinically acceptable bond strengths 15 minutes after bonding. The variability of the above mentioned results can be attributed to differences in the type of light source, brackets, teeth, testing machine, and cross-head speed.

The reduced curing time achieved using the micro-xenon light represents a great advantage when bonding orthodontic brackets for both the patient and the orthodontist. Clinically, this means that all the brackets of an entire arch (10 teeth) bonded with a RMGIC can be cured with high-intensity light-curing for only 20 seconds, compared with the 400 seconds required with a VLC unit. Aurys is a micro-xenon light-curing unit, which permits a high-intensity photopolymerization of light-curing adhesives. Its light intensity is 1650 mW/cm^2, which is approximately three times greater than that of a conventional VLC unit. It has filters that narrow the spectrum of visible light to a band centred on the 470 nm wavelength for activation of the photo-initiator. A high energy, high pressure ionized gas in the presence of an electrical current is used to create a light source strong enough to increase the curing rate of light-cured RMGICs.

The findings of the present investigation confirm those of a recent study by Sfondrini *et al.* (2001), who reported that, after a 24-hour period, the shear bond strength of Fuji Ortho LC cured with a xenon arc light for 10, 5, and 2 seconds was not significantly different from that of the same adhesive cured with a conventional VLC unit.

Evaluation of the ARI scores indicated that there was a significantly higher frequency of bond failure at the bracket-adhesive interface with the composite resin group cured with the conventional light-curing unit. On the contrary, the remaining groups bonded with Fuji Ortho LC exhibited a significantly higher frequency of bond failure at the enamel-adhesive interface, regardless of the type of light source. Thus, in agreement with the findings of other authors (Jobalia *et al.*, 1997; Cacciafesta *et al.*, 1998a; Bishara *et al.*, 1999; Millett *et al.*, 1999; Sfondrini *et al.*, 2001) the RMGIC exhibited a stronger adhesion to stainless steel brackets than to enamel, allowing easy removal from enamel during debonding. This is clinically advantageous, because there is less adhesive to remove from the enamel surface after debonding.

Conclusions

After a 15-minute period:

1. Fuji Ortho LC provides bond strengths adequate for clinical use when cured with the micro-xenon light.
2. The shear bond strengths of Fuji Ortho LC cured with the micro-xenon light are not statistically different from those achieved with the conventional VLC unit.
3. The composite resin has a significantly higher shear bond strength when cured with the conventional VLC unit.
4. Light-curing for only 2 seconds with the micro-xenon light does not preclude clinically acceptable bond strengths of RMGICs.
5. Micro-xenon light sources can be recommended as an advantageous alternative for curing RMGICs, because they significantly reduce the time required for light-curing, without affecting their initial shear bond strengths.

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