Original Article

A Comparison of Shear Bond Strengths of Three Visible Light-Cured Orthodontic Adhesives

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Abstract: The purpose of this study was to evaluate the shear bond strength and the site of bond failure for 2 visible light-cured composites (Transbond XT and Enlight) and a resin-modified glass ionomer cement (RMGIC; Fuji Ortho LC). Seventy-five extracted human premolars were collected and randomly divided into 3 test groups. Brackets were bonded to the teeth in each test group with the respective adhesive according to the manufacturers' instructions. Each specimen was debonded using an Instron Universal Testing Machine at a crosshead speed of 0.1 mm/min. The mode of bond failure was observed by using light microscopy. The results of this study demonstrated that the light-cured composites had a higher shear bond strength than the RMGIC. The adhesive-remnant scores were similar for the composites with the mean values at about 2, which indicates that more than half of the adhesive remained on the tooth. The RMGIC had a mean score of 3, which was significantly different from the composites and indicated that all of the adhesive remained on the tooth with a distinct impression of the bracket. (*Angle Orthod* 2000; 70:352–356.)

Key Words: Visible light cure; Composites; Resin-modified glass ionomer; Shear bond strength

INTRODUCTION

Direct bonding of attachments revolutionized the placement of orthodontic appliances in the late 1970s and 1980s. The pioneering work of Buonocore, Bowen, Wilson, and Tavas made this valuable improvement in technique possible.[1–4] These researchers were instrumental in developing procedures and materials that have led to present-day standards in orthodontic adhesives. Acid etching, composite resins, glass ionomer cements (GICs), and visible light-curing adhesives have evolved from these early efforts.

Buonocore[1] advocated the use of phosphoric acid etching to improve the adhesion of acrylic resin filling materials to enamel as early as 1955. This procedure involves dissolution of the organic component of the enamel matrix, creating microporosities in the enamel surface. Etching increases the wettability of the surface and facilitates the penetration of the resin into the enamel. A mechanical bond is formed between the resin adhesive and the tooth.[5]

Bisphenol A glycidyl dimethacrylate, more commonly known as Bowen's resin or bis GMA, was patented in 1962 and is a diacrylate resin.[2] This resin is an acrylic-modified epoxy resin, combining the setting versatility of acrylic and the strength and dimensional stability of epoxy.[6] The eventual addition of filler particles to these resins to form composites greatly enhanced the strength of this material.

Wilson and Kent[3] introduced glass polyalkenoate, or GIC, to dentistry in 1972. GIC contains a powder similar to that of silicate cement and a polyacrylic liquid similar to that of polycarboxylate cement. It bonds chemically to enamel, cementum, dentin, nonprecious metals, and plastics.[7,8] The dry field necessary for composite bonding is not necessary for this type of cement.

Tavas and Watts[4] first described the use of visible light to cure composites used in orthodontic bonding in 1979. In 1983, Newman et al[9] investigated the depth of polymerization in teeth using a combination of 11 visible light-cured composite resins and 8 visible lights. He found large variations among the abilities of different light sources to polymerize the various light-cured composite resins. Read[10] described the use of a single paste, glass-filled resin that was catalyzed by visible light at a wavelength of 440–480 nm. The catalyst consisted of an alpha-diketone and an amine. The activator light was filtered to eliminate all but visible light, and this was transmitted by a quartz rod. Other single paste, light-cured, quartz-filled composite resins have been described that absorb blue light in the 420 to 450 nm range, which initiates polymerization.[11,12] Visible light-cured composites provide ease of use, extended working time, im-

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proved bracket placement, easier cleanup, and faster cure of the composite.

Early GICs consisted of glass powder, a concentrated solution of polyacrylic acid, or a glass powder blended with polyacrylic powder, which was mixed with diluted tartaric acid or water.[13] In response to the demand for improvement of the original product, Antonucci et al[14] introduced resin-modified glass ionomer cements (RMGICs) in 1988. Light-activated 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 glass ionomers. A small amount of resin in addition to a photoinitiator was added to conventional GIC.[15] The development of light-cured RMGIC has allowed the clinical orthodontist to take advantage of the positive features of conventional glass ionomers, combining them with the mechanical and physical properties of composites, controlled setting reaction, greater initial strength and hardness, and reduced sensitivity to moisture.

To date, a number of papers have been published comparing in vitro shear bond strengths of composite resin adhesive with either GIC or its resin-modified hybrid.[16–30] A universal problem in previous studies has been the lack of a standardized test procedure. This investigation was conducted according to a protocol suggested by Fowler et al[31] and by Fox et al.[32] The purpose of the investigation was to evaluate the shear bond strengths and the mode of bond failure of 2 light-cured composite resin adhesives and a light-cured RMGIC.

MATERIALS AND METHODS

Seventy-five human premolar teeth were collected over a 3-month period and placed in 10% formalin. Before the experiment, the teeth were debrided, washed in water in an ultrasonic cleaner to remove the formalin, examined for preexisting fractures and restorations, and stored in deionized distilled water. The bonding procedure was done over 3 sessions during a 2-day period, utilizing 25 teeth per session. Before bonding at each session, 25 teeth were randomly selected and polished with oil- and fluoride-free pumice and water by using a rubber prophy cup and a slow-speed handpiece. A twin bicuspid bracket coated with Optimesh XRT (Ormco Corp, Glendale, Calif) was bonded with each of the selected adhesives. The surface area of the 100-gauge mesh pad was calculated to be 16 mm^2 after measurement with a caliper (Mitutoyo, Japan). Each tooth was coded with the group assignment. The same operator did the bonding of the attachment to each tooth.

The teeth that were bonded with the 2 composite resin adhesives (Transbond XT, Unitek/3M, St Paul, Minn; Enlight, Ormco, Glendale, Calif) were prepared according to the following protocol: (1) the teeth were acid-etched for 30 seconds with 37% phosphoric acid gel (Dentonics Inc, Charlotte, NC), (2) rinsed 10 seconds with an air-water syringe to remove the etching gel and any remaining demineralized tooth particles, (3) dried 5 seconds with oil-free compressed air; (4) dried 5 seconds with warm air, (5) and coated with unfilled resin and light-cured for 10 seconds. (6) The adhesive-loaded bracket was placed in firm contact with the tooth and the flash removed, and (7) it was light-cured at 450 nm for 20 seconds on the mesial and 20 seconds on the distal. After bonding, the specimens were stored in deionized distilled water.

The teeth that were bonded with the resin-modified glass ionomer (Fuji Ortho LC, GC America, Alsip, Ill) were prepared according to steps 1–3 above and then lightly coated with deionized distilled water. The GIC was mixed in a Varimix III (LD Caulk Co, Chicago, Ill) for 7 seconds. The use of 1 capsule per tooth ensured a homogeneous mix and setting time for each tooth. Each loaded bracket was placed firmly in contact with the tooth, and the flash was removed. The adhesive was cured with a light (Ortholux XT, 3M/Unitek Co, St Paul, Minn) for 20 seconds on the mesial and distal. The curing light unit was calibrated before use to ensure a wavelength of 400–450 nm. After bonding, the specimens were stored in deionized distilled water.

Following the bonding procedure, the specimens were attached to a mounting jig and embedded with stone in numbered plastic rings 10 mm in diameter and 25 mm in length. The jig was used to align the occlusal portion of the bracket parallel with the bottom of the mold so the occlusal surface of the bracket would be perpendicular with the applied force during the shear test.[22] This ensured consistency for the point of application and direction of the debonding force for all specimens. The specimens were again stored in deionized distilled water until the shear bond test was performed.

Twenty-five specimens were used to test each of the adhesives. The debonding took place in an occlusal-gingival direction using an Instron Universal Tester (Instron Corp, Canton, Mass) at a crosshead speed of 0.1 mm/min.

During the shear bond test, 10 of the specimens failed because of fractured enamel surfaces. Six of these failures were Transbond XT, 2 were Enlight, and 2 were Fuji Ortho LC. Because these enamel fractures were believed to have resulted from either preexisting fractures that were not detectable in the enamel surface or an artifact due to the experimental design, additional teeth were added to the study. Six more Transbond XT specimens were fabricated and the test performed again. One of these specimens was damaged before testing and could not be included. Twenty-three Enlight and Fuji Ortho LC specimens and 24 Transbond specimens were used to conduct the experiment.

The force to debond the brackets was reported in megapascals (MPa). The debonding strength data were analyzed for normality and homogeneity of variances. One-way analysis of variance and Scheffé's multiple comparison

TABLE 1. Shear Bond Strengths (MPa)

	n	Mean ± Standard Deviation	Range
Transbond XT	24	7.9 ± 2.1[a]	2.5–11.7
Enlight	23	6.8 ± 2.1[a]	3.3–7.1
Fuji Ortho LC	23	5.3 ± 1.2	4.5–13.0

[a] No significant difference at $P = .05$.

TABLE 2. Adhesive Remnant Index

	n	Mean ± Standard Deviation	Range
Transbond XT	24	1.7 ± 1.1[a]	0–3
Enlight	23	2.1 ± 0.9[a]	1–3
Fuji Ortho LC	23	3.0 ± 0.2	2–3

[a] No significnat difference at $P = .05$.

tests were performed to identify statistical differences at the .05 significance level.

The debonded specimens were examined at 50× magnification with an optical microscope (Stereomicroscope SR, Zeiss, Oberkochen, Germany) to evaluate the mode of failure. The specimens were coded, and the examiner had no knowledge of which material was being evaluated at the time of observation. The surfaces of the enamel and the bracket backings were observed to determine the amount of adherent cement as a percentage of the total bonded area. Percentages of cement remaining on these interfaces as judged by the evaluator were recorded, and averages were determined.

Using the percentages of adherent cement on the enamel surface, Adhesive Remnant Index (ARI) scores[33] were assigned to each specimen. A score of 0 indicates that no adhesive was left on the tooth in the bonding area, 1 indicates that less than half of the adhesive was left on the tooth, 2 indicates that more than half was left on the tooth, and 3 indicates that all adhesive was still on the tooth, with a distinct impression of the bracket mesh. The ARI data were analyzed with the Kruskal-Wallis and Mann-Whitney *U* nonparametric statistical tests at the .05 significance level.

The examination of the bracket backings revealed that all or nearly all recessed areas between the mesh wires were filled with cement. Therefore, for the bracket interfaces, the percentage of cement covering the surface of the mesh was recorded. The failure mode analysis reported whether the failure was adhesive or cohesive. The adhesive failure occurred at either the adhesive-bracket interface or the adhesive-enamel interface, and the cohesive failure occurred within the adhesive material itself.

RESULTS

The shear bond strength results are listed in Table 1. The statistically significant comparisons are noted. The data satisfied the normality of distribution and homogeneity of variances assumptions required for parametric statistical tests. The 1-way analysis of variance and Scheffé's multiple comparisons tests revealed that the Fuji Ortho LC mean was significantly lower than the Enlight and the Transbond XT means. Enlight and Transbond XT means were not found to be statistically different.

The ARI results (means, standard deviations, and ranges) are listed in Table 2. The means were statistically different among the 3 adhesives tested (Kruskal-Wallis, $\chi^2 = 20.31$, $P < .0001$). The mean score for Fuji Ortho LC was significantly different from those of the 2 composite materials, which were similar to each other.

An evaluation of the mode of failure revealed that the Enlight and Transbond XT specimens failed in a similar manner. When examining the bonding surfaces, both had a few cohesive failures, but most were adhesive and mixed failures at both the enamel and bracket interfaces. The Fuji specimens failed adhesively at the bracket interface almost exclusively. The frequency distributions of the failure locations are illustrated in Figure 1.

DISCUSSION

This investigation found no significant difference in shear bond strength between the 2 light-cured composite materials (Transbond XT and Enlight). However, there was a significant difference between the light-cured composites and the RMGIC (Fuji Ortho LC). It appears that the Fuji Ortho LC is approximately 70% as strong as Transbond XT and Enlight under the in vitro conditions in this study. These findings are in agreement with previous studies that report a lower shear bond strength for RMGIC than composites.[16,29] However, a recent study reported the shear bond strength for Fuji Ortho LC as not statistically different from Transbond XT.[26] Another study reported Fuji Ortho LC as not statistically different from composite adhesives, as long as the enamel is etched.[27] Fuji Ortho LC with unetched enamel yielded bond strength forces that were significantly lower compared to both composite adhesives and Fuji Ortho LC with etched enamel.[27] Similarly, another recent study reported that etching with Fuji Ortho LC was required to produce maximum bond strengths, with unetched specimens yielding significantly lower bond strength values.[28] Bond strengths of Fuji Ortho LC on etched enamel wetted with saliva before bonding[28] were very similar to those of the present study, which used etched enamel wetted with water. Although the bond strengths of the present study were in the range of similar published studies, the values for the composite materials were on the low end of the range. Variations in results between studies may be due to differences in research protocol and the technique sensitivity of the materials. Further investigation in this area is warranted.

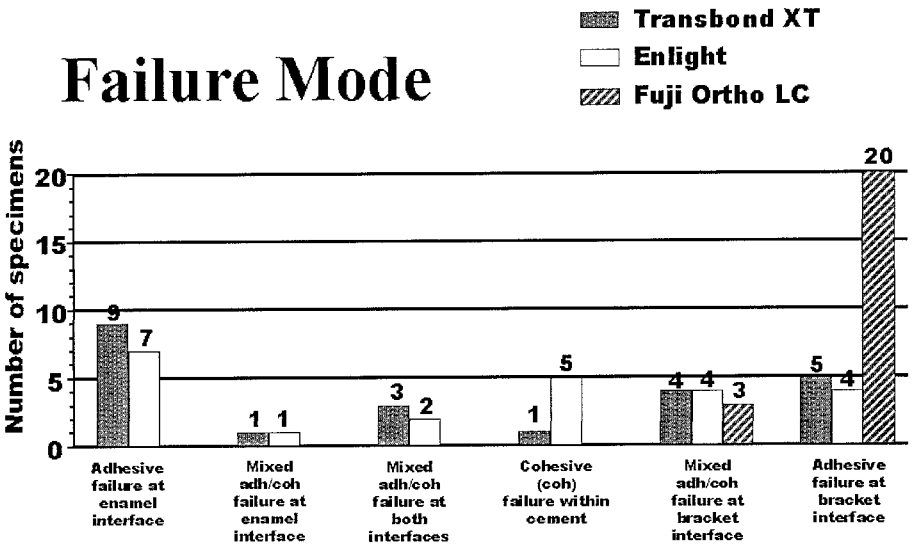

FIGURE 1. Frequency distribution of the location of bond failure.

The standard deviation of the shear bond strengths for the composites was essentially the same in this study. This could be due to the similarities in the procedures used and the composition of the material. The glass ionomer had a much lower standard deviation, possibly because it is less technique sensitive and has a natural adhesive tendency for tooth structure.

Ten specimens fractured through the enamel rather than at the bracket bonding site. These specimens were not included with the other data because the measured strength value was not of the adhesive bond strength. This relatively high number of enamel fractures might have been a result of undetectable preexisting fractures but could have been due to the placement of the teeth in formalin before debridement. A previous study[27] reported a similar problem and, as in the present study, the authors found it prudent not to include the values in the data pool.

ARI, developed by Årtun and Berglund,[33] has been used by investigators to help standardize the bond failure analysis. The ARI may oversimplify the very complex issues of bond failure analysis, but it does allow for statistical analysis and cross-study comparisons. Review of the literature reveals that although many investigators use an ARI system, they often modify the criteria,[27] the number system,[30] or both for their project. This makes cross-study comparison more difficult. For the present study, the ARI scores follow the original criteria established by Årtun and Berglund.[33]

In addition to the ARI scores, more descriptive observations were recorded and categorized. These data are helpful in characterizing the bond failure, since there are several interfaces in which fracture may occur. The weak link of the bond may be at the tooth surface (adhesive failure at enamel surface; no cement on tooth), at the bracket (adhesive failure at bracket material surface; cement on tooth, not on bracket), or within the adhesive cement (cohesive failure within the cement; cement on both tooth and bracket surfaces). Mixed failures are very common and can be characteristic of the stronger bond strength values. The failure-mode analysis of this study verified the differences and similarities between the composites and GIC shown by the shear bond strength data. The mixed cohesive and adhesive bond failures of the composites showed that composites bond well both to enamel and metal, and the glass ionomer bond failures showed a very strong bond to enamel and less bond strength to metal.

According to the results of several studies,[12,17,24,26,34] orthodontic forces that are generated during treatment can vary between 5 and 20 MPa. This wide range of values is more than likely due to the large variations in experimental design and procedures.[17] Bonds are subjected to stresses that are torsion, tensile, or shear or a combination of all of these, and it is difficult to precisely measure and quantify these forces.[35] Establishing the threshold for shear bond strength in vivo would be a valuable piece of information. However, because of the aforementioned obstacles, this may never be a reality. Therefore, individual clinicians must make the decision regarding the type of adhesive to use on the basis of their own clinical judgment and available research. Even though the results of this investigation, as well as many previous ones, show that composite resin adhesives are clearly stronger, recent evidence indicates that the latest generation of light-cured RMGICs may fit within the parameters of clinical shear bond strength requirements.[26,29]

CONCLUSIONS

In conclusion, it is evident from the investigation that if bond strength is the primary consideration for choosing an

adhesive, then composite resin should be utilized. More study is warranted in this area because there have been conflicting reports in the literature. Analysis of the mode of bond failure is helpful to characterize the adhesive bond and to determine at which interface the weak link may be found.

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