Original Article

Comparison of bracket debonding force between two conventional resin adhesives and a resin-reinforced glass ionomer cement: An in vitro and in vivo study

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Abstract: The purpose of this study was to compare the debonding force of orthodontic brackets bonded with two conventional resin adhesives (Resilience L3 and Light Bond) and a resin-reinforced glass ionomer cement (Fuji Ortho LC). For the in vitro part of the study, 80 extracted premolars were randomly divided into four groups. In groups A and B, brackets were bonded to unetched enamel using Fuji Ortho LC cement in wet and dry conditions, respectively. In groups C and D, brackets were bonded to etched enamel using Resilience L3 and Light Bond, respectively. Debonding force was determined using a servohydraulic testing machine at a crosshead speed of 1 mm/min. Data was analyzed using the ANOVA and Tukey-Kramer multiple comparison test at $p<0.05$. A significant difference was found in debonding force between unetched Fuji Ortho LC and the two conventional resins. There was no significant difference between the two conventional resins or between unetched resin-reinforced glass ionomer in the wet and dry conditions. For the in vivo part of the study, 30 patients were randomly assigned to one of the three bonding material groups. Bracket survival rates and distributions were obtained by following these patients for 1.2 years. Data was analyzed using the Kaplan-Meier product-limit estimates of survivorship function. Bond failure interface was determined using a modified adhesive remnant index (ARI). These results showed no significant difference between survival rates and distributions among the three bonding materials with respect to the type of malocclusion, type of orthodontic treatment, or location of bracket. There were significant differences between survival distributions of males and females in the unetched Fuji Ortho LC group and among type of teeth in the conventional resin groups. The predominant mode of bracket failure for the unetched Fuji Ortho LC cement was at the enamel-adhesive interface, and for conventional resins, the enamel-adhesive interface and the bracket-adhesive interface. These results suggest that resin-reinforced glass ionomer cement can withstand occlusal and orthodontic forces despite having a bond strength lower than that of conventional resin adhesives.

Key Words: Bond strength, Composite resins, Glass ionomer cement

In 1965, Newman[1] introduced the technique of combining acid-etching with composite resin for bonding orthodontic brackets. This procedure is technique-sensitive and may have undesirable effects, such as enamel loss during acid-etching[2] and enamel decalcification around the brackets.[3] Numerous modifications have been made, both to the type of resin as well as the acid-etching technique. Light-cured and fluoride-releasing resins are examples of such modifications.

Glass ionomer cement (GIC) was introduced into dentistry in 1972 by Wilson and Kent.[4] GIC adheres to enamel, dentin, and tin-plated gold or platinum surfaces.[5] It does not require acid-etching or tooth preparation other than cleansing with pumice, and it can be bonded to a moist enamel surface.[6,7] Another advantage of GIC is its ability to release fluoride. The new generation of GIC shows promise as an alternative bonding material to conventional orthodontic resins.[8,9] The new products are dual-

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or tri-cured hybrid materials containing both resin and glass ionomer components, and they differ considerably from the previous generation of glass ionomer materials.[10] However, it is still unclear whether, with current manufacturers' recommendations, the new generation of GIC has adequate bond strength to withstand occlusal and orthodontic forces.

Another important consideration for a good orthodontic adhesive is the bond-failure interface. Several studies have indicated that the majority of fractures occur at the bracket-resin interface.[11,12] Studies with GIC found that most of the failures occurred around the enamel-cement interface.[13] In 1984, Årtun and Bergland developed the adhesive remnant index (ARI) to assess bond failure.[14] Some investigators have used this clinical technique to rate the amount of orthodontic adhesive remaining on the enamel after bond failure.[15,16] The objectives of the present study were to determine (1) the in vitro bracket debonding force of the three adhesives: unetched Fuji Ortho LC in wet and dry conditions, Resilience L3, and Light Bond; (2) the in vivo orthodontic bracket survival rates of the three adhesives with respect to the patient' sex, type of malocclusion, type of treatment, location of brackets, and tooth type; and (3) the in vitro and in vivo bond failure interfaces of the three adhesives.

Materials and methods

Table 1 lists the properties of the three bonding materials used in this study: Fuji Ortho LC, a light-cured resin-reinforced GIC in powder and liquid form manufactured by GC America Inc, Chicago, Ill; Resilience L3, a light-activated orthodontic adhesive manufactured by Confi-Dental Corp, Louisville, Colo; and Light Bond, a fluoride releasing light-cured adhesive manufactured by Reliance Orthodontic Products, Inc, Itasca, Ill.

Table 1
Comparison of properties of the three bonding materials

Brand name	Fuji Ortho LC	Resilience L3	Light Bond
Manufacturer	GC America Inc	Confi-Dental Co	Reliance Orthodontic Inc
Description	Hybrid glass ionomer cement reinforced with composite	Composite resin adhesive	Composite resin adhesive
Preparation	Powder mixed into liquid	One paste and unfilled resin	One paste and unfilled resin
Curing method	Light-cured	Light-cured	Light-cured
Fluoride release	Yes	No	Yes
Enamel etching	No	Yes	Yes
Dry field	No	Yes	Yes

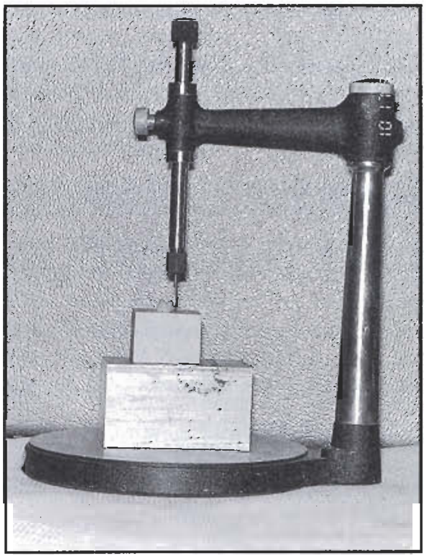

Figure 1
Dental surveyor used to orient brackets when teeth were mounted

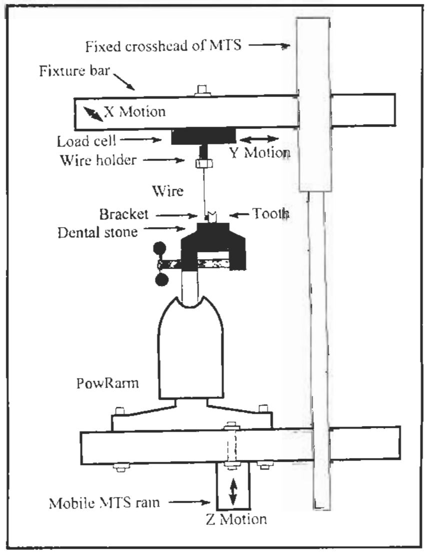

Figure 2
Servohydraulic testing machine (MTS) and fixture for measuring shear bond strength

In vitro bracket debonding force

Eighty extracted premolars were randomly divided into four groups: group A = Fuji Ortho LC in wet condition; group B = Fuji Ortho LC in dry condition; group C = Resilience L3; group D = Light Bond. A hole was drilled through each tooth 3 mm apical to the CEJ and a stainless steel wire inserted for additional retention when the teeth were mounted. The facial surfaces of all teeth were cleaned with a slurry of pumice and rinsed with water. The teeth assigned to Light Bond and Resilience L3 groups were etched with a 37% phosphoric acid solution for 30 seconds. The etchant was rinsed off with water for 20 seconds and the teeth were dried thoroughly. Stainless steel premolar brackets (GAC, Central Islip, New York), with a bracket base dimension of 2.91 x 3.96 mm, were bonded to the facial surface following the manufacturer's recommendations. All samples in groups A, C, and D were stored in saline until testing. Samples in group B (Fuji Ortho LC, dry con-

Table 2
Descriptive statistics for the *in vitro* shear bond strength test. All measurements in newtons

Group	Testing condition	N	Mean	Median	SD	Min.	Max.
Light Bond	Wet	13	134.335*	127.85	49.127	63.524	210
Resilience L3	Wet	17	124.031*	127.53	41.951	24.398	197.66
Unetched Fuji Ortho LC	Wet	14	64.050	64.753	27.932	22.875	103.91
Unetched Fuji Ortho LC	Dry	14	90.091	84.952	39.708	31.758	187.61

*$p<0.001$ when compared with unetched Fuji Ortho LC in wet or dry conditions

dition) were dried for 24 hours prior to testing. This was done to determine if desiccation of the reinforced glass ionomer cement was a factor in the bracket debonding force. Norevall[25] reported that patients with mouth breathing habits may have higher bracket failure rates. Each tooth was mounted vertically in dental stone with the crown exposed. A dental surveyor was used to orient the brackets while the teeth were being mounted so that the force could be applied parallel to the tooth surface (Figure 1). Bracket debonding force, in newtons, was determined using a servohydraulic testing machine (MTS) with a load rate of 1 mm/min (Figure 2). Data were analyzed using ANOVA and the Tukey-Kramer multiple comparison procedure with the level of significance set at 0.05.

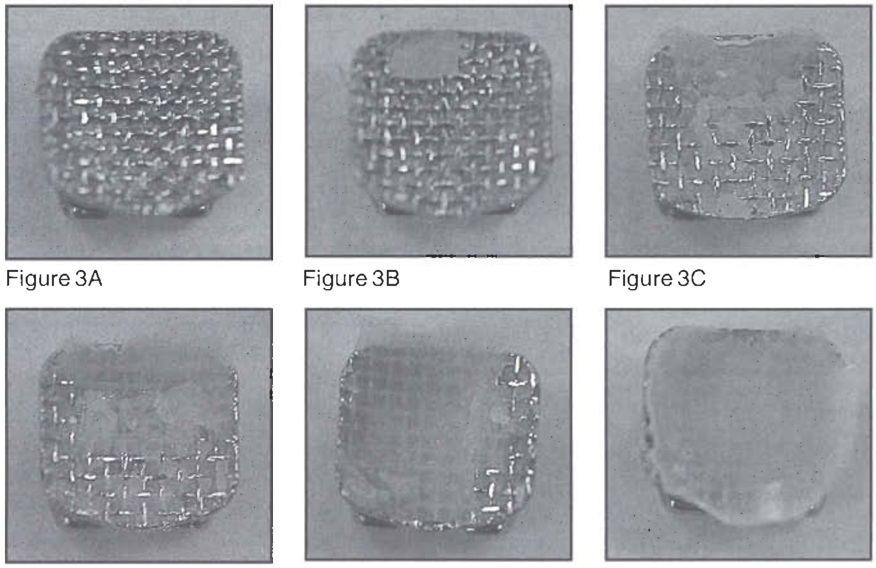

Figure 3A Figure 3B Figure 3C
Figure 3D Figure 3E Figure 3F

Figure 3A-F
Bracket bases with ARI scores of 0 through 5. (A) ARI=0, (B) ARI=1, (C) ARI=2, (D) ARI =3, (E) ARI=4, (F) ARI-5.

In vivo bracket survival distributions

Thirty patients who required comprehensive orthodontic treatment with full fixed appliances at the West Virginia University Department of Orthodontics were included in the in vivo study. Informed consent was obtained according to the protocol approved by the Institutional Review Board for the protection of human subjects. Patients were assigned randomly to one of the three orthodontic adhesives groups. A complete set of orthodontic records was taken and a treatment plan was established for each patient. The facial surfaces of all teeth were cleaned with pumice and rinsed with water. The teeth assigned to Light Bond and Resilience L3 groups were etched with a 37% phosphoric acid solution for 30 seconds. The etchant was rinsed off with water for 20 seconds and the teeth were dried thoroughly. Stainless steel brackets with 0.022 inch slots (GAC, Central Islip, New York) were bonded to the incisors, canines, and premolars following the manufacturer's instructions. Bracket failures in each group were recorded on the patients' charts. Bracket survival distributions for each of the three orthodontic adhesives were estimated using the Kaplan-Meier product-limit survival estimates with respect to sex, malocclusion, treatment type, location, and type of tooth. Significant differences among the three groups were determined using the Log-rank test with the level of significance set at 0.05.

Bond failure interface

Brackets used for the in vitro study and brackets that failed in the vivo study were examined under an optical microscope (American Optical Co, Buffalo, NY) at 10X magnification to determine the bond failure interface. Adhesive remnants were classified using a modified adhesive remnant index (ARI). The modified ARI was expanded from the original ARI scale[14] of 0 to 3 to a 0-to-5 scale, in order to more accurately depict the amount of adhesive left on the enamel after debonding (Figure 3). Score 0 = no adhesive left on

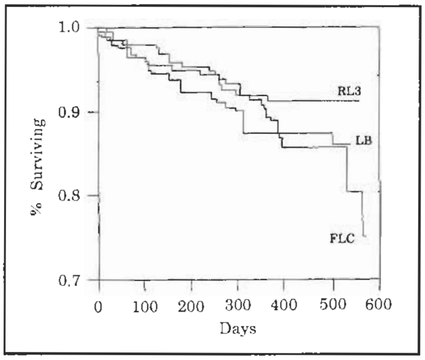

Figure 4
Survival distribution of the three orthodontic adhesives plotted against time

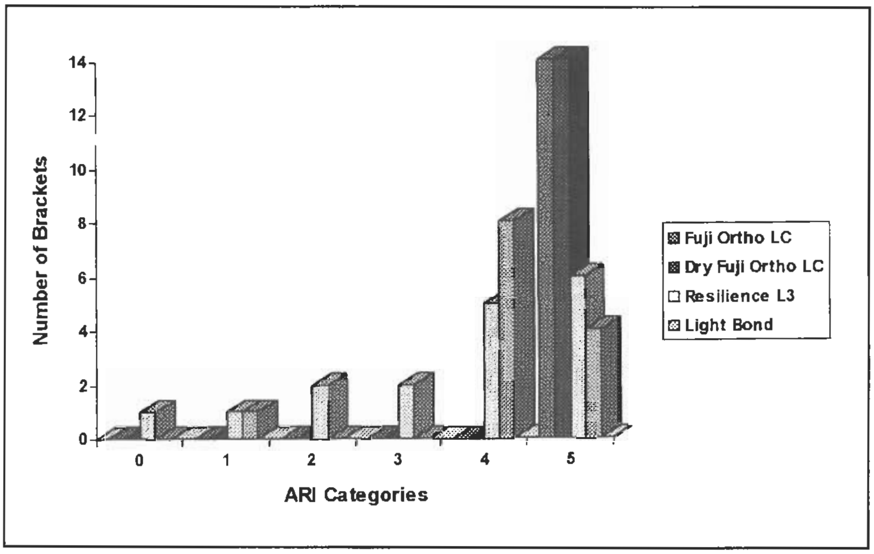

Figure 5
Distribution of ARI score for the in vitro brackets bonded with the three adhesives

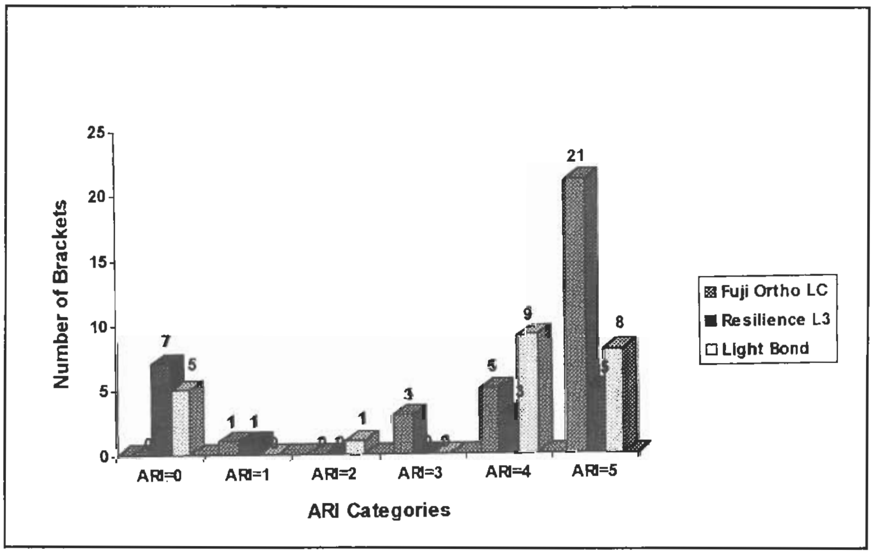

Figure 6
Distribution of ARI score for the in vivo brackets bond with the three adhesives

bracket; score 1 = less than 25% of adhesive left on bracket; score 2 = 25% of adhesive left on bracket; score 3 = 50% of adhesive left on bracket; score 4 = 75% of adhesive left on bracket; score 5 = 100% of adhesive left on bracket.

Results

In vitro bracket debonding force

Bracket debonding forces for the three orthodontic adhesives and testing conditions are shown in Table 2. ANOVA revealed significant differences in bracket debonding forces among the four tested groups ($p<0.001$). Significant differences were found between Light Bond (134.335 ± 49.127 N) and unetched Fuji Ortho LC in both wet (64.050 ± 27.932 N) and dry conditions (90.09 ± 39.708 N). Significant differences were also found between Resilience L3 (124.031 ± 41.951 N) and unetched Fuji Ortho LC in both wet and dry conditions. No significant difference was found between Light Bond and Resilience L3. No significant difference was found between unetched Fuji Ortho LC in wet and dry conditions.

In vivo bracket survival distribution

Thirty patients (13 males and 17 females) participated in the in vivo part of the study. The mean age at the time of bracket placement was 16.3 years (15.0 years for males and 17.3 years for females). The duration of the study was 1.2 years at the time of data collection. Figure 4 shows the estimated survival distribution of the three orthodontic adhesives plotted against time. No significant differences in bracket survival distribution were found among the three bonding adhesives. Table 3 shows the differences in bracket survival distribution among the bonding adhesives with respect to sex, type of malocclusion, type of treatment, location of brackets, and type of teeth. With respect to sex, no significant difference was found in the bracket survival distribution between males and females in the Light Bond and Resilience L3 groups. Significant sex differences ($p=0.033$) were found in the Fuji Ortho LC group. With respect to type of malocclusion, no significant difference was found in the bracket survival distribution between Class I and Class II Division 1 malocclusions in either the unetched Fuji Ortho LC, Light Bond, or Resilience L3 groups. With respect to the type of treatment, no significant difference was found in bracket survival distribution between the type of treatment (extraction vs. nonextraction) in the unetched Fuji Ortho LC and Light Bond groups, while a significant difference (p=0.03) was found in the Resilience L3 group. With respect to location of brackets, no significant difference in bracket survival distribution was found between maxillary and mandibular teeth in either the unetched Fuji Ortho LC, Light Bond, or Resilience L3 groups. With respect to the type of teeth, significant differences were found in the Light Bond (p=0.005) and Resilience L3 groups (p=0.03). No significant difference was found in the unetched Fuji Ortho LC group.

Table 3
Difference in bracket survival distribution among the bonding adhesives with respect to sex, type of malocclusion, type of treatment, location of brackets and type of teeth

Source	Material	DF	Probability
Sex (Male vs. Female)	Light Bond	1	0.9532
	Resilience L3	1	0.5495
	Unetched Fuji Ortho LC	1	0.0336*
Type of malocclusion (Class I vs. Class II div 1)	Light Bond	1	0.9093
	Resilience L3	1	0.2860
	Unetched Fuji Ortho LC	1	0.0715
Type of treatment (extraction vs. nonextraction)	Light Bond	1	0.6449
	Resilience L3	1	0.0339*
	Unetched Fuji Ortho LC	1	0.8311
Location of bracket (maxilla vs. mandible)	Light Bond	1	0.6599
	Resilience L3	1	0.2984
	Unetched Fuji Ortho LC	1	0.2444
Type of teeth (central incisors, lateral incisors, canines, first and second premolars)	Light Bond	4	0.0058*
	Resilience L3	4	0.0330*
	Unetched Fuji Ortho LC	4	0.6134

*p<0.05

Bracket failure interface

Figure 5 shows the distribution of ARI scores for the three adhesives tested in vitro. All the brackets bonded with unetched Fuji Ortho LC in either wet or dry conditions had an ARI score of 5. Most of the brackets bonded with Light Bond and Resilience L3 had an ARI score of 4 or 5. A few of the Resilience brackets had an ARI of 0, 1, 2, or 3. Only one of the Light Bond brackets had an ARI score of 1.

Figure 6 shows the distribution of ARI scores for the three tested adhesives using brackets that failed in the in vivo study. A majority of the brackets that were bonded with unetched Fuji Ortho LC had an ARI score of 5. A few of them had a score of 1, 3, or 4. Most brackets bonded with Resilience L3 and Light Bond had an ARI score of 0, 4, or 5.

Discussion

In vitro bracket debonding force

The bracket debonding force of Fuji Ortho LC tested in wet (64 ± 28 N) and dry conditions (90 ± 40 N) was found to be significantly lower than that of the conventional resins (134 ± 49 N for Light Bond and 124 ± 43 N for Resilience L3). These findings are in agreement with those reported by Messersmith et al.[17] and Cohen et al.[18] in 1998 and Chung et al.[19] in 1999. In these studies, the bond strength of unetched Fuji Ortho LC was found to be approximately half that of the Concise composite resin. Clinically, Tavas and Watts[20] recommended that an adhesive bracket debonding force greater than 58 newtons was suitable for clinical use. Unetched Fuji Ortho LC cement, with a bracket debonding force of 64 newtons, has the potential to resist forces during orthodontic treatment. The average force transmitted to a bracket during mastication has been reported to range between 40 and 120 newtons.[21,22] The bracket debonding force of unetched Fuji Ortho LC was in the lower part of that range. Recent studies showed that the bond strength of etched Fuji Ortho LC was comparable to that of conventional resins.[19] Therefore, when using this material, etching is recommended for optimal bond strength in areas of trauma or heavy occlusion.

Although there were no significant differences in bracket debonding force between unetched Fuji Ortho LC in wet and dry conditions, the bracket debonding force of the dry samples (90 N) was found to be slightly higher than that of the moist samples (64 N), perhaps because the dry samples were dehydrated after the critical time during polymerization. The critical time refers to the period from 15 minutes to several hours after the bonding procedure while the final setting of the material takes place. Powis,[23] in a 1982 in vitro study, reported on the sensitivity of GIC to dehydration during the setting period. If the samples are dehydrated during the critical time, bracket debonding force of glass ionomers may be decreased. In the present study, dehydration after the critical time had no effect on the bracket debonding force of the GIC.

In vivo bracket survival distribution

Bracket survival distributions for the type of bonding material, sex of the patient, type of malocclusion, type of orthodontic treatment, location, and type of tooth were determined using the Kaplan-Meier product-limit survival estimates from the time of bracket placement to final data collection. The survival distribution provides information about the performance of the bonding materials during the entire period of investigation.

Type of bonding materials: There were no statistically significant differences in bracket survival distributions among the three bonding materials. This is in agreement with the results of other studies, that the clinical performance of unetched Fuji Ortho LC is similar to that of the composite resins studied.[24]

Sex: There were no statistically significant differences in bracket survival distribution between males and females in the Light Bond and Resilience L3 groups. However, there was a statistically significant difference (p=0.03) in the Fuji Ortho LC group. This difference may be attributed to the assumption that males are less attentive to diet and care of the appliances. Also, males may have a higher incidence of trauma to the dentition due to greater participation in contact sports and rough play.

Type of malocclusion: There were no statistically significant differences in bracket survival distribution among the type of malocclusion in the three bonding material groups. However, there was a tendency for patients with Class II Division 1 malocclusion to exhibit higher rates of bracket failure. Norevall et al.[25] stated that this phenomenon might be due to a decrease in bond strength following dehydration of the GIC. This situation is more likely to occur in Class II Division 1 malocclusion with an increased overjet, incompetent lips, or mouth-breathing habit during the critical setting time of the material.

Type of treatment: There were no significant differences in bracket survival distributions between the two types of treatments, (extraction vs. nonextraction) in the three tested groups. Overall, it seems that bond strength of all three bonding materials, including unetched Fuji Ortho LC, is sufficient for extraction and nonextraction treatments.

Location: There were no significant differences in bracket survival distribution with respect to placement of brackets (maxilla vs. mandible) in the three tested groups. However, bracket failure rates were higher in the maxillary teeth in the unetched Fuji Ortho LC group. Wiltshire found increased bracket failures of composite resins in the mandible (especially premolars).[26] The reason for these differences may be the higher rate of moisture contamination in the mandible when using composite resins.[27,28]

Type of teeth: There were significant differences in bracket survival distribution with respect to the type of teeth in the Light Bond and Resilience L3 groups, while no significant differences were found in the unetched Fuji Ortho LC group. A high incidence of bracket failure in the posterior parts of the jaws can be explained by the sensitivity of the acid-etching technique to moisture contamination, which is more difficult to control in the posterior dentition.[29] Lower bracket failure percentages in premolars may be attributed to Fuji Ortho LC's dual-cured and moisture resistance properties.

Bracket failure interface

The predominant mode of failure for the Fuji Ortho LC cement was at the adhesive/enamel interface. Most of the adhesive material remained on the bracket bases in both the in vivo and in vitro experiments. The weak link in the bonding mechanism for glass ionomer appeared to be at the adhesive-enamel interface. The chemical bond of glass ionomer to metal seems to be stronger than the chemical bond of glass ionomer to enamel. The same results were found by McSherry,[22] who compared the in vitro shear bond strength of four bonding materials including glass ionomer. Also, Oen et al.[30] tested the bond strength of three types of glass ionomer cements and Concise to extracted premolars after 24 hours and at 4 months and found that failures occurred mainly at the glass ionomer-enamel interface.

The composite exhibited two different modes of failure. A majority of the brackets failed at the enamel-adhesive interface, while some failed at the bracket-adhesive interface. In addition, when examining the premolar brackets that failed at the enamel-adhesive interface, the failure was found to occur more frequently at the gingival half of the brackets. This may be due to the moisture sensitivity of the acid-etching technique involved in the composite resins.

Conclusion

The in vitro debonding force of brackets bonded with the resin-reinforced GIC is significantly lower than that of conventional resins. However, the in vivo data show that the new generation of glass ionomer cements, such as Fuji Ortho LC, may have adequate bond strength for use in orthodontic treatment, particularly in areas where moisture control is difficult to achieve.

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