**A COMPARISON OF THE SHEAR BOND STRENGTHS OF
TWO GLASS IONOMER CEMENTS**

by

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ABSTRACT

The objective of this study was to determine the in vitro shear bond strength (MPa) and location of bond failure using two light-cured glass ionomer resin systems. These systems, Fuji Ortho LC (GC Orthodontics) and Ultra Band Lok (Reliance) were compared to a light-cured composite resin. Maxillary premolar brackets (n=200) were bonded to the facial surface of human premolar teeth. The two glass ionomer resin systems were each evaluated by two protocols, one according to the manufacturers' direction plus a variation of their respective technique. The five distinct groups (n=40) were stored in 37°C distilled water for 30 days and subjected to thermocycling prior to shear bond strength testing.

The findings indicated that large variations existed between the bond strengths of the materials tested. The laboratory shear bond strength of the Reliance Ultra Band Lok, whether tested in a dry or moist field, was similar to the composite control with all being significantly ($p<0.01$) higher than both Fuji Ortho LC groups. However, the Fuji Ortho LC with enamel conditioner demonstrated a clinically acceptable mean MPa value. The Adhesive Remnant Index (ARI) values ranged from 0.53 to 1.62. The Fuji Ortho LC without enamel conditioning recorded the lowest mean ARI score and the lowest mean MPa score.

Although both products are glass ionomer resin systems, their individual chemistries vary which may influence their bond strengths. Clinically, it may be suggested that glass ionomers used in a dry field may be beneficial for orthodontic bonding and glass ionomer resin systems used in a moist environment need an enamel conditioner.

Keywords: Glass Ionomer Cements, Orthodontic Bonding, Shear Bond Strength

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INTRODUCTION

A significant change in orthodontics over the last twenty years has been the replacement of cemented bands by bonded orthodontic brackets. The development of the acid etch technique¹ has led to the bonding of orthodontic brackets with composite resins², which improves esthetics, greatly reduces chairside time and makes oral hygiene easier for the patient. Although technique sensitive, the development of composite resins has enabled the placement of orthodontic brackets with bond strengths that resist masticatory forces. The literature³⁻⁷ has reported that the bond strength values for adhesion vary somewhat, however values greater than 5 Megapascals are suggested to be adequate for bonding.

Etching of the enamel prior to bonding provides a strong mechanical bond of the composite resin to the enamel rods.⁷ However, previous studies⁸⁻¹² have shown that this increase in shear bond strength may come at the expense of the outer layer of enamel. Localized enamel fractures created during debonding procedures have been attributed to the micromechanical retention produced from acid etching treatment.¹⁰⁻¹³ Although Zachrisson et al¹³ found that a sample of orthodontically treated teeth had a significantly higher ($p < 0.05$) prevalence of enamel cracks than did a nontreated sample, he suggested that careful debonding does not result in a significant increase of enamel cracks.

In the absence of good oral hygiene and fluoride treatments, demineralization can occur rapidly around bracket margins.¹⁴ Gorelick et al¹⁵ studied the incidence of decalcification following fixed orthodontic treatment and found a significant increase after debanding. The control group of fifty children showed 24 of the cases to have

demineralization on one or more of the teeth. Of the control's 1006 teeth examined, 3.6% showed decalcification. This was compared to 49.6% of a sample of 121 randomly selected patients who after debonding had a white spot lesion on at least one tooth and of the total of 2211 teeth examined, 11% showed decalcification.

Unlike resin-filled composites, glass ionomer cements (GICs) adhere to unetched enamel by physiochemical means and do not remove the fluoride-rich outer layer. This adherence is based on molecular interactions between the calcium ions in the enamel and the carboxyl groups of the GIC.^{16,48} Glass ionomer cements also have the benefit of being a long-term, low-concentration fluoride-releasing agent.¹⁷ Hallgren et al¹⁷ tested the fluoride concentration in plaque adjacent to orthodontic appliances that were retained with GIC and composite cement. After 3 days, the plaque taken from around the GIC bonded brackets showed fluoride concentrations that were 44 times higher than that taken around composite bonded brackets. Although the fluoride concentration decreased significantly from 3 days to 6 months, an 11-fold difference was still present between the two cements at 6 months. Hallgren et al,¹⁸ in a similar study, compared the L(+)-lactic acid production in plaque around brackets bonded with both GIC and composite resin. The plaque around brackets bonded with the GIC showed significantly ($p < 0.05$) less acid production. Fluoride releasing GICs create a "zone of inhibition" on the enamel surrounding the bracket.¹⁷ GICs have also shown a less effected enamel surface after debonding.¹⁹

A drawback between composite resins and conventional GICs is that GICs show consistently lower bond strengths.²⁰⁻²³ Fajen et al²² compared three conventional GIC's to a composite control, and found low bond strengths ranging from 0.84 to 3.91 MPa for the

GICs compared to 11.27MPa for the composite resin. Wiltshire²³ reported mean bond strengths of the unetched and etched samples of GIC of 4.4 and 5.5 MPa, respectively, compared to 26 MPa for the composite control. Clinical comparisons of the conventional GICs also show them to be inferior in bond strength to composite resins.^{24,25} In a 12 month trial, Miquel et al²⁴ reported bond failure rates of 51% and 8% for GIC and composite resin groups, respectively. Miller et al²⁵ in a three year clinical trial also found that brackets bonded with GIC were more likely to fail ($p<0.022$).

New generation, resin reinforced, light-cured glass ionomer cements have been reported to be successful in bonding orthodontic brackets.^{26,27} These new resins are of two types: resin incorporated into the glass filler and methylmethacrylate incorporated into the polyacrylic acid. Fricker²⁶ bonded 10 cases (120 teeth), half of each malocclusion with a composite resin and the other half with a resin-modified light-activated GIC. After 12 months the GIC group had 2 debonds as compared to one debond for the composite group. Silverman et al²⁷ bonded 150 cases also using a new generation GIC and claimed a 96.8% success rate in which many second molars were included.

The in-vitro studies to date have shown that resin reinforced GICs retain brackets significantly better than conventional GICs.²⁸⁻³¹ Ewoldsen et al³¹ tested the effects of various methods of enamel conditioning on bond strengths using a resin reinforced GIC and compared them to a composite control. Four of the five GIC subgroups (no conditioning, 10% polyacrylic acid, 37% phosphoric acid, and PA-HEMA copolymer primer) were not statistically significant from one another. Only the human saliva contaminated group was significantly weaker ($p<0.05$). The four non-significant GIC groups ranged in bond strengths

of 6.51 - 7.95 MPa. However, all of the GIC groups were significantly less ($p < 0.05$) in bond strength when compared to the composite resin (10.39 MPa). If the resin-reinforced GICs exhibit bond strengths suitable for the bonding of orthodontic brackets, then their advantages over composite resins make them the product of choice. The two cements selected for this study are Fuji Ortho LC[^] and Ultra Band Lok^{*}. The Fuji cement is a resin-reinforced, water based, dual cure cement which the manufacturer claims can be used without the need of acid-conditioning. Light-curing activates free radical polymerization of HEMA and two other monomers, to form a poly-HEMA matrix, thus, immediately setting the material. The Ultra Band Lok is a photoinitiated, resin base cement which uses a 3 second non-phosphoric acid conditioner to create a larger surface area to bond to the enamel. The conditioner is followed by the placement of a photoinitiated BIS GMA hydrophilic sealant.

The purpose of this study is to compare the shear bond strengths of the two light-cured glass ionomer cements to a composite control. In addition, the clinical value will further be assessed by determining the location of bond failure after debonding.

[^]GC Orthodontics, Aslip, IL

^{*}Reliance Orthodontic Products, Inc., Itasca, IL

MATERIALS AND METHODS

Bonding of brackets to premolars:

Two hundred extracted human premolar teeth were divided into five groups of forty. Fuji Ortho LC and Ultra Band Lok were tested using the manufacturers' recommendation plus a technique variation and compared to the control composite, Transbond XT[#]. Each bicuspid bracket[~] was bonded using an Ortholux XT[#] standard curing light at a curing distance of 1mm or less. The curing light was calibrated every 10 minutes to ensure a proper wavelength of above 400nm. The five groups (n=40) were bonded as follows:

Ultra Band Lok, GIC (No Moisture) (Fig 1)

Each tooth was rinsed and dried after a pumice polish. With a brush, the tooth conditioner[°] was applied to the enamel. Three seconds later the conditioner was dried with air. A coat of the hydrophilic sealant[°] was painted on the conditioned tooth, allowed to sit for 10 seconds, lightly dried with air and then light cured for 10 seconds. The Ultra Band Lok paste was applied to the bracket base and positioned on the tooth. It was light cured for 20 seconds from the incisal edge of the bracket and 20 seconds from the gingival bracket edge.

[#]3M/Unitek Company, Minneapolis, MN

[~]"A" Company, Micromesh .022 Roth Rx., San Diego, CA

[°]Reliance Orthodontic Products, Inc., Itasca, IL.

Ultra Band Lok, GIC (Moistened)

Each tooth was rinsed and dried after a pumice polish. With a brush, the tooth conditioner was applied to the enamel. Three seconds later, the conditioner was dried with air. The surface was moistened with a water-soaked gauze. A coat of the hydrophilic sealant was painted on the conditioned tooth, allowed to sit for 10 seconds, lightly dried with air and then light cured for 10 seconds. The Ultra Band Lok paste was applied to the bracket base and positioned on the tooth. It was light cured for 20 seconds from the incisal edge of the bracket and 20 seconds from the gingival bracket edge.

Fuji Ortho LC, GIC (No Conditioner) (Fig 2)

Each tooth was left moist after a pumice polish and thorough water lavage. The bracket was then placed on the enamel surface with the GIC adhesive and light cured for 20 seconds from the incisal edge and 20 seconds from the gingival bracket edge.

Fuji Ortho LC, GIC (With Conditioner)

Each tooth was rinsed and dried after a pumice polish. A 10% polyacrylic acid was placed on the tooth for 20 seconds. The tooth was left moist following a thorough water lavage. The bracket was then placed on the enamel surface with the GIC adhesive and light cured for 20 seconds from the incisal edge and 20 seconds from the gingival bracket edge.

Trandsbond XT (control) (Fig 3)

Following the manufacturer's directions, the brackets were bonded to the teeth. The enamel surface was rinsed and dried after a pumice polish, followed by a 60 second acid etch with 37% phosphoric acid^{^^} and then each tooth had a thorough water lavage. The bonding

^{^^}3M/Unitek Company, Minneapolis, MN

agent[™] was light cured for 10 seconds. The bracket was placed on the enamel surface with the Transbond composite adhesive and light-cured for 40 seconds.

Storage:

The teeth were allowed to bench set for 15 minutes before being placed into a 100% humidior for 24 hours. They were then transferred to an incubator of distilled water and stored for 30 days. Following water storage, the specimens were then further stressed by thermocycling which consisted of two thermally controlled streams of water maintained at 10°C and 55°C. Each cycle lasted for one minute (30 seconds at 10° and 30 seconds at 55°C). 1500 cycles were completed over a period of 24 hours. (Fig 4)

Debonding:

Each specimen was placed in a custom acrylic block which approximated the height of normal bone. There was special emphasis on securing the block in a vice in a position that would place the facial surface of each premolar parallel to the plunger of the testing machine. (Fig 5) This allowed the plunger to be perpendicular to the bracket. Each premolar bracket had a segment of a 21 X 25 stainless steel wire ligatured in the bracket slot to prevent the debonding machine from deforming the bracket during debonding. The brackets were debonded using a shear load on an Instron Universal Testing machine.^{**} A 50 kg load cell was applied on each bracket at a cross-head speed of 0.5mm/min. The kilogram value was divided by the bracket base size (13.564mm²) to give a reading in kg/mm². Kg/mm² was then

^{**}Instron Corp., Canton, MA

converted to megapascals (MPa) by multiplying by 9.81.

Bond failure was assessed by examination of the bracket bases and the debonded enamel surfaces using a 10X illuminated magnifying lens. The debonded surfaces were evaluated using the Adhesive Remnant Index (ARI)⁴⁷ which quantifies the amount of adhesive remaining on the bonded surface following debonding. A score of 0 indicates no adhesive was left on the enamel, 1 indicates less than half of the adhesive remained on the enamel, 2 indicates more than half of the adhesive remained on the enamel, and 3 indicates all of the adhesive was left on the enamel. Debonds that resulted in enamel fracture were eliminated from the ARI evaluation.

Statistical Analysis:

To determine the statistical significance in shear bond strengths between the five groups, the mean MPa values were analyzed using one-way ANOVA. Tukey's Test at a 5% level of significance was used to determine specific pairwise group differences. The significance of the difference between the five groups of ARI data were analyzed using the Kruskal-Wallis one-way ANOVA and multiple comparisons.

RESULTS

The distribution of the MPa data from all five groups showed high intersample variation. Subsequently the non-symmetrical data was normalized by using a square-root transformation ($x^1 = x^{0.5}$), and statistical analysis was performed using these transformed values. The mean and median Megapascals, standard deviations and the range of shear bond strengths for the five groups are listed in Table 1 and displayed graphically in Figure 6. At least two of the means were statistically different among the five bonding systems (one-way ANOVA, $F_{4,193}=32.85$, $p = 0.0001$). The bond strengths of the two Ultra Band Lok groups were not significantly different from the Transbond control group (Table 2). The Ultra Band Lok group in which the manufacturer's recommendations were followed, showed a higher mean bond strength than the Transbond control, with scores of 11.36 and 11.23, respectively. These three groups showed mean shear bond strengths that were significantly higher than those of the Fuji Ortho LC groups ($p<0.01$). The Fuji Ortho LC without enamel conditioning, produced a significantly lower mean bond strength than the other four groups ($p<0.001$). Only the Fuji Ortho LC without conditioner did not achieve a clinically acceptable bond strength of above 5 MPa.

The mean ARI scores, standard deviations and range for the five groups are listed in Table 3 and displayed graphically in Figure 7. The means were statistically different among the five bonding systems tested (Kruskal-Wallis one-way ANOVA, $\chi^2_4 = 55.90$, $p<0.0001$). The Ultra Band Lok group in which the manufacturer's recommendations were followed (group 1) and the Fuji Ortho LC with enamel conditioning (group 4) showed the highest

mean scores of 1.62 and 1.44, respectively, indicating that they were approaching the level where bond failure occurs at the bracket/adhesive interface. The difference between these two groups were statistically different from groups 2, 3, and 5 ($p < 0.05$) (Table 4). Fuji Ortho LC without conditioner (group 3) recorded a mean score of 0.53 indicating a bond failure at the enamel/adhesive interface. This group was not statistically different from the next two higher scores (groups 2 and 5).

DISCUSSION

The replacement of banding with bonding has reduced the use of separators, conserved arch perimeter, facilitated oral hygiene and esthetics, and eliminated the need for band-space closure during the retention stage of treatment.²² However, acid etching impacts upon the outer enamel layer²⁻¹² and may potentially create decalcification.^{14,15,32}

A viable alternative to the traditional acid etch technique, provided bond strength is adequate, is the use of resin reinforced glass ionomer cements. These cements can chemically adhere to both enamel and metal,³³ and they release fluoride and subsequently may help prevent demineralization.¹⁷ The fluoride content of enamel adjacent to brackets bonded with glass ionomer cements is increased.³⁴ However, the fluoride uptake may be variable with resin reinforced GICs. Also, GICs have been shown to debond through dessication from air drying potentially making debonding easier³⁵ and have shown a less affected enamel surface after debonding.¹⁹

The present study showed that the Ultra Band Lok GIC groups were not significantly different in shear bond strength from the Transbond control group, and these three groups were significantly stronger ($p < 0.01$) when compared to the two Fuji Ortho LC groups. However, the Fuji Ortho LC with conditioner displayed clinically acceptable bond strength values. The two glass ionomer cements have different chemical make-ups which may contribute to their differences in shear bond strength. The Fuji Ortho LC is a resin reinforced water based GIC whereas the Ultra Band Lok GIC is a composite filled with glass ionomer powder (also known as compomer).³⁶ The Fuji Ortho LC consists of fluoroalumino-silicate

glass, and a liquid that contains polyacrylic acid, a water soluble monomer (hydroxyethylmethacrylate), an activator, and water as the base of the cement. The resin, in which HEMA is the major constituent, makes up approximately 11.25% of the mixed product.³⁷ The Ultra Band Lok GIC, being a glass filled composite with 33% resin, introduces some controversy in whether it should be classified as a GIC or composite resin and its chemistry may help to explain why the bond strength was similar to the Transbond composite control. The superior adhesion and physical properties in Ultra Band Lok are attributed to the acidic difunctional monomer and the increased percentage of resin.³⁶ The resin content strengthens GICs by making them more flexible unlike the brittleness seen in conventional non-resin filled GICs. The resin content also makes GICs much less susceptible to dehydration and less soluble in intra-oral fluids with a stronger bond both cohesively and adhesively.³⁷

The Ultra Band Lok group that simulated moisture contamination was not significantly weaker in bond strength than was the Ultra Band Lok group in which the manufacturer's recommendations were followed. The mean shear bond strength of the former was 10.03 MPa and 11.36 MPa for the latter, which may be attributed to the hydrophilic sealant which is a combination of an unfilled resin sealant and Reliances Enhance™ Adhesion Booster.³⁶ No other studies using this material for bonding brackets were found in the literature making comparisons difficult. However, the data suggests that Ultra Band Lok with its higher resin content behaved in a manner similar to a composite.

The mean shear bond strengths of the Fuji Ortho LC were significantly less ($p < 0.001$) than the composite control which is in agreement with other studies.^{28,29,31,38-41} Acid

conditioning of the enamel prior to bonding produced significantly stronger bond strengths ($p < 0.001$) for the Fuji Ortho LC which concurs with Jaochakarasiri et al³⁸ who tested three resin-modified GICs to see the effect of acid etching. The authors³⁸ reported a significant ($p < 0.001$) increase in bond strength with acid etching and suggested it was required to achieve adequate bond strengths. Shin and Lee⁴² also found that their sample of resin modified GIC had significantly higher bond strengths to enamel, when a 10% polyacrylic or a 37% phosphoric acid solution was used, as compared with a slurry of pumice only. When testing a resin reinforced GIC, Ewoldsen et al³¹ found no significant differences in shear bond strengths between non-conditioned and conditioned enamel. In fact, the mean bond strengths for the non-conditioned sample was higher at 6.97 MPa as compared to the group in which a 37% phosphoric acid was used (6.51 MPa). The authors³¹ attributed this to the GIC's ability to chemically bond to the enamel surface and therefore the need for enamel conditioning is eliminated. Carter and McCabe⁴⁰ reported enamel conditioning to increase bond strengths, but not significantly, for their sample of resin modified glass ionomer cements. The Fuji Ortho LC with conditioner had a significantly ($p < 0.001$) stronger shear bond strength than the unconditioned Fuji group lending strength to the claim^{38,40,42} that acid conditioning of enamel prior to bonding produces stronger bond strengths. Obviously, the use of an enamel conditioner to promote a stronger bond will alter the outer layer of enamel more than if a GIC is used without conditioning.

Millett and McCabe⁴³ report that in vitro glass ionomer cements studies typically have large standard deviations in bond strengths values which may create concern over the reliability of both the test system and the bond strength achieved. The data suggests that the

manipulation of glass ionomer cements is currently technique sensitive in providing optimal bond strengths.

Fox et al⁴⁴ suggested that the ideal location for an adequate bond to fail is at the enamel/adhesive interface for this would make bonding and subsequent debonding much easier. In the present study, the non-conditioned Fuji Ortho LC group had a mean ARI score of 0.53 which suggests that little to no adhesive was left on the enamel causing the bond failure at the enamel/adhesive interface. The regular Ultra Band Lok group and the conditioned Fuji Ortho LC group showed the highest ARI scores, 1.62 and 1.44 respectively. These groups were more likely to have the bond failure between the bracket/adhesive interface. The composite control group and the moistened Ultra Band Lok group had mean ARI scores of 0.84. The composite control value differed from other studies.^{31,41,42} Scott et al⁴¹ and Shin and Lee⁴² found their composite control groups to debond mainly at the bracket/adhesive interface whereas the resin modified GIC groups were more likely to debond at the enamel/adhesive interface. Shin and Lee⁴² reported light-cured GIC bonded to enamel treated with 10% polyacrylic acid showed less residual materials on the enamel surface than composite resin bonded to enamel etched with 38% phosphoric acid. Similar to the current study, Nollie et al⁴⁵ determined the fracture site for their composite control group to be principally at the enamel/adhesive interface. The authors⁴⁵ suggest that the increased bond stress placed on the tooth by the 30 day water storage and the thermocycling may have influenced the fracture site.

Matasa⁴⁶ claimed that the strongest bond with orthodontic adhesive is achieved when the failure is cohesive which means that the adhesive remains on both the enamel and bracket

in almost equal proportions after debonding. On the ARI scale, this type of bond failure would compute to a mean score between 1 and 2. The regular Ultra Band Lok had an ARI score within this range and also produced the highest mean MPa score which supports the author's⁴⁶ claim. As well, the Fuji Ortho LC without enamel conditioning prior to bonding showed both an adhesive type of bond failure (0.53) and a low bond strength. In contrast, the remaining data did not support Metasa's⁴⁶ claim. The conditioned Fuji Ortho LC group had a cohesive bond failure, yet this group's shear bond strength was significantly ($p < 0.001$) weaker than the Transbond control and moistened Ultra Band Lok which had adhesive bond failures (0.84).

There appears to be a lack of standardization in in-vitro bonding protocols making inter-study evaluation and comparison difficult.^{43,45} The limitations for interpreting and comparing results from other studies comes mainly from three areas: (a) the environmental stressing of material, (b) sample size, and (c) bond strength units. Stress testing by thermocycling has been shown to reduce bond strength. Supak and Burgess²⁹ found thermocycling to decrease the bond strengths of their sample of GICs by nearly 50%. In the present study, the sample was thermocycled on the premise that by exposing the specimens to a simulated environmental stress this would allow a more accurate comparison to a clinical situation.⁴³ Fox et al⁴⁵ stated that at least 20 and preferably 30 specimens should be used per test and bond strengths reported in megapascals.^{43,45}

The suggested advantages that the resin modified GICs provide include: (a) the ability to be used in a moist environment without etching, (b) the provision of localized fluoride release, (c) the attribute of sufficient bond strength, and (d) the capacity for removal without

damage to the underlying enamel. From the current study, the Fuji Ortho LC did not provide an adequate bond strength without the use of an enamel conditioner prior to placement of the cement. This new generation of resin modified GICs show improved bond strength over the previous GICs. In the current study there may be some controversy as to whether two GICs were compared. Although Ultra Band Lok is considered a glass ionomer cement, its chemical makeup suggests that it is a composite filled with glass ionomer powder or compomer. At the present time, a system where only a chemical bond of adhesive to enamel is used does not provide a bond strength sufficient to keep orthodontic brackets from debonding from posterior teeth. However, the present study suggests that the addition of a mechanical bond through enamel conditioning to the chemical bond may provide a clinically acceptable bond strength.

SUMMARY AND CONCLUSIONS

A total of 200 human premolar teeth were used to bond orthodontic brackets using two glass ionomer cements and a composite control. The findings were as follows:

- 1. Ultra Band Lok, when used concurrently with its 3 second conditioner and hydrophilic sealant, achieved an in vitro shear bond strength similar to the composite control.**
- 2. The Fuji Ortho LC glass ionomer system should be used concurrently with 10% polyacrylic acid to enhance its bond strength to a clinically acceptable level.**
- 3. The Fuji Ortho LC without enamel conditioning prior to bonding showed inadequate bond strength.**
- 4. The nonconditioned Fuji Ortho LC, the moisture contaminated Ultra Band Lok, and the Transbond control had mean ARI values of less than one indicating fracture site principally at the enamel/adhesive interface.**
- 5. The regular Ultra Band Lok and the conditioned Fuji Ortho LC had mean ARI values of 1.62 and 1.44 respectively indicating fracture sites principally within the adhesive.**

Table 1 **Shear Bond Strengths (MPa)**

	Group 1	Group 2	Group 3	Group 4	Group 5
	Ultra Band Lok (regular)	Ultra Band Lok (moistened)	Fuji Ortho LC (no conditioner)	Fuji Ortho LC (with conditioner)	Transbond (control)
Mean	11.36	10.03	3.21	7.68	11.23
Median	10.85	9.67	2.71	6.42	10.58
SD	5.13	3.93	2.22	5.15	4.66
Range	4.52 - 27.48	1.08 - 22.42	0.36 - 8.32	0.54 - 22.60	2.71 - 23.14
N	40	40	38	40	40

Table 2 Mean Difference (MPa) and Statistical Significance as Determined by Multiple Comparison

N= 40	Group 1		Group 2		Group 3		Group 4		Group 5	
	Bonding System	Ultra Band Lok (regular)	Ultra Band Lok (moistened)	Fuji Ortho LC (no conditioner)	Fuji Ortho LC (conditioner)	Transbond (control)				
		difference of means	P <	difference of means	P <	difference of means	P <	difference of means	P <	
	Ultra Band Lok (regular)	---	---	+1.33	.200	+8.15	+3.68	+0.13	.884	
	Ultra Band Lok (moistened)	-1.33	.200	---	---	+6.82	+2.35	-1.20	.264	
	Fuji Ortho LC no conditioner	-8.15	.000*	-6.82	---	---	-4.47	-8.02	.000*	
	Fuji Ortho LC (conditioner)	-3.68	.000*	-2.35	+4.47	---	---	-3.55	.001*	
	Transbond (control)	-0.13	.884	+1.20	+8.02	+3.55	---	---	---	

* = statistical significance at $p < 0.05$

Table 3

ARI Scores

	Group 1	Group 2	Group 3	Group 4	Group 5
	Ultra Band Lok (regular)	Ultra Band Lok (moistened)	Fuji Ortho LC (no conditioner)	Fuji Ortho LC (conditioner)	Transbond (control)
Mean	1.62	0.84	0.53	1.44	0.84
SD	0.54	0.59	0.76	0.77	0.50
Range	1 - 3	0 - 3	0 - 2	0 - 3	0 - 3
N	39	38	38	36	37

- 0 = no adhesive remaining on enamel surface
 1 = less than half of the adhesive remaining on enamel surface
 2 = more than half of the adhesive remaining on enamel surface
 3 = all adhesive left on enamel surface

Table 4 Multiple Comparison Z-values and Statistical Significance

N=40	Group 1		Group 2		Group 3		Group 4		Group 5		
	Ultra Band Lok (regular)	Ultra Band Lok (moistened)	Fuji Ortho LC (no conditioner)	Fuji Ortho LC (conditioner)	Transbond (control)	Z-value	P <	Z-value	P <	Z-value	P <
Ultra Band Lok (regular)	---	4.00	5.66	1.08	4.01	---	0.05	---	0.05	---	0.05
Ultra Band Lok (moistened)	4.00	---	1.64	-2.85	0.03	---	0.05	---	0.05	---	0.05
Fuji Ortho LC no conditioner	5.66	1.64	---	-4.47	-1.60	---	0.05	---	0.05	---	0.05
Fuji Ortho LC (conditioner)	1.08	-2.85	-4.47	---	2.88	---	0.05	---	0.05	---	0.05
Transbond (control)	4.01	0.03	-1.60	2.88	---	---	0.05	---	0.05	---	0.05

NS = not statistically significant

Figure 1
Ultra Band Lok glass ionomer cement

Figure 2
Fuji Ortho LC glass ionomer cement

Figure 3
Transbond orthodontic bonding material

Figure 4
A sample placed in the Thermocycle unit

Figure 5

Premolar tooth with bonded bracket in an acrylic block secured in vice

Note: the plunger of Instron machine is
perpendicular to bracket

Figure 6

Figure 7

**Appendix 1 Shear Bond Strengths (kg, MPa) and Adhesive Remnant Index (ARI) Scores
for all Specimens (EF = enamel fracture)**

Tooth	Band Lok (regular)			Band Lok (wet)			Fuji - no conditioner			Fuji with conditioner			Transbond control		
	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI
1	15.25	11.03	2	15.25	11.03	1	7.25	5.24	0	18.75	13.56	1	6.75	4.88	1
2	10.75	7.78	1	18.25	13.2	EF	2.75	1.99	0	7.00	5.06	1	26.5	19.17	1
3	16.75	12.11	1	22.75	16.45	1	2.75	1.99	0	1.75	1.26	1	19.25	13.92	1
4	9.75	7.05	2	13.0	9.40	1	11.25	8.14	1	23.5	17.0	EF	22.5	16.27	1
5	12.5	9.04	2	19.75	14.28	0	10.5	7.59	1	4.50	3.26	1	14.75	10.67	1
6	9.75	7.05	1	11.0	7.96	0	4.75	3.44	0	4.50	3.26	2	21.25	15.37	2
7	19.5	14.1	2	6.75	4.88	1	11.25	8.14	2	0.75	0.54	0	24.5	17.72	1
8	13.75	9.95	1	18.25	13.2	2	1.75	1.27	2	9.00	6.51	1	14.0	10.13	1
9	6.75	4.88	2	19.25	13.92	0	11.5	8.32	2	6.25	4.52	3	14.5	10.49	EF
10	8.75	6.33	2	9.75	7.05	1	3.75	2.71	0	21.75	15.73	EF	13.75	9.95	1
11	6.25	4.52	3	13.25	9.58	1	2.75	1.99	0	10.0	7.23	3	22.5	16.27	1
12	13.5	9.76	2	15.75	11.39	0	1.00	0.72	0	31.25	22.6	EF	22.0	15.91	0
13	14.75	10.67	2	12.25	8.86	1	3.00	2.17	0	8.50	6.15	3	11.0	7.96	2
14	17.75	12.84	2	12.5	9.04	1	3.75	2.71	1	11.25	8.14	1	20.75	15.01	0
15	7.5	5.42	2	22.75	16.45	1	5.25	3.80	0	18.75	13.56	2	16.5	11.93	1

Appendix 1 cont'd

Tooth	Band Lok (regular)			Band Lok (wet)			Fuji - no conditioner			Fuji with conditioner			Transbond (control)		
	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI
16	15.5	11.21	2	16.5	11.93	0	4.25	3.07	1	12.0	8.68	2	13.00	9.40	0
17	12.5	9.04	2	31.0	22.42	0	1.25	0.90	0	5.25	3.80	2	14.50	10.49	1
18	8.75	6.33	2	16.75	12.11	1	2.75	1.99	0	6.25	4.52	1	32.00	23.14	1
19	10.0	7.23	2	6.50	4.70	0	7.25	5.24	1	17.25	12.48	2	15.75	11.39	1
20	12.75	9.22	1	8.50	6.15	1	1.25	0.90	0	9.75	7.05	1	17.75	12.84	EF
21	17.75	12.84	2	17.0	12.30	0	2.75	1.99	2	17.0	12.30	0	11.25	8.14	1
22	26.25	18.98	EF	16.0	11.57	1	4.50	3.26	0	4.25	3.07	1	16.50	11.93	1
23	13.75	9.95	2	12.75	9.22	1	0.75	0.54	0	12.5	9.04	1	19.50	14.10	1
24	14.75	10.67	1	11.75	8.50	1	5.50	3.98	0	27.25	19.71	EF	10.50	7.59	1
25	9.75	7.05	2	14.0	10.13	0	0.50	0.36	0	8.75	6.33	1	3.75	2.71	0
26	36.25	26.22	1	10.5	7.59	1	2.25	1.63	0	8.0	5.79	2	11.50	8.32	1
27	8.0	5.79	1	10.75	7.76	1	2.5	1.81	0	14.25	10.31	1	23.75	17.18	1
28	16.0	11.57	2	9.25	6.69	1	6.25	4.52	0	9.0	6.51	2	13.75	9.95	EF
29	17.5	12.66	1	9.0	6.51	1	4.75	3.44	0	6.25	4.52	2	17.50	12.66	1
30	27.25	19.71	1	17.5	12.66	2	6.5	4.70	1	2.5	1.81	2	6.75	4.88	1
31	11.25	8.17	2	16.25	11.75	1	0.75	0.54	0	5.25	3.80	2	6.00	4.34	0
32	17.0	12.3	2	13.5	9.76	1	0.75	0.54	0	16.0	11.57	1	24.00	17.36	1

Appendix 1 con't

Tooth	Band Lok (regular)			Band Lok (wet)			Fuji - no conditioner			Fuji with conditioner			Transbond (control)		
	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI	kg	MPa	ARI
33	22.00	15.91	1	13.25	9.58	1	6.50	4.70	1	4.25	3.07	2	9.50	6.87	1
34	18.25	13.20	2	11.50	8.32	2	4.50	3.26	2	5.75	4.16	1	8.50	6.15	1
35	16.75	12.11	1	14.75	10.67	1	2.75	1.99	0	10.50	7.59	1	8.00	5.79	1
36	25.75	18.62	1	18.75	13.56	1	3.00	2.17	0	3.00	2.17	2	15.75	11.39	1
37	16.25	11.75	2	13.50	9.76	2	7.25	5.24	2	5.00	3.62	1	14.00	10.13	0
38	17.25	12.48	1	3.50	2.53	EF	7.00	5.06	1	10.75	7.78	0	19.50	14.10	0
39	15.75	11.39	1	1.50	1.09	0	***	***	***	18.00	13.02	2	4.50	3.26	0
40	38.00	27.48	1	9.75	7.05	1	***	***	***	8.75	6.33	1	13.00	9.40	1

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