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# An Analysis of Adhesion Promoters on Shear Bond Strength of Orthodontic Brackets to Teeth

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# AN ANALYSIS OF ADHESION PROMOTERS ON SHEAR BOND STRENGTH OF ORTHODONTIC BRACKETS TO TEETH

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ABSTRACT

AN ANALYSIS OF ADHESION PROMOTERS ON SHEAR BOND STRENGTH OF ORTHODONTIC BRACKETS TO TEETH

by

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Purpose: The aim of this study was to evaluate the shear bond strength of two adhesion promoters, Enhance $^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin, and their effects with two different adhesion systems (Light Bond $^{tm}$ and Transbond $^{tm}$ XT). To better understand their behavior upon failure, the amount of adhesive remnant remaining on the tooth surface was also observed.

Methods: One-hundred forty human premolars, which were extracted for reasons other than this study, were utilized and divided into seven groups of 20 teeth each. Groups A1 and B1 were bonded without adhesion promoters and with two different adhesive systems - Light Bond $^{tm}$ and Transbond $^{tm}$ XT. Groups A2 and B2 were bonded using Enhance $^{tm}$ LC. Groups A3 and B3 were bonded using Assure $^{R}$ Universal Bonding Resin. Group C, a third reference control, was bonded with Transbond$^{tm}$ Plus Self Etching Primer, not amendable with the adhesion promoter bonding protocol. A Universal Testing Machine was used to create bond failure and obtain the shear bond strength (SBS). After debonding, teeth and brackets were scored with a modified adhesive remnant index (ARI). Kruskal-Wallis with a Post-Hoc Bonferroni tests were completed on all SBS and ARI data.

Results: This study demonstrated that no significant differences were found in SBS of samples bonded with adhesion promoters, relative to their controls. Groups bonded with Assure $^{R}$ Universal Bonding Resin had significantly higher ARI scores than the control groups and groups bonded with Enhance$^{tm}$ LC. Shear bond Strengths achieved with the self-etching primer were comparable to conventional bond strengths with and without adhesion promoters. ARI scores for the self-etching primer resulted in more adhesive remnant than conventional bonding.

Conclusions: The application of adhesion promoters, Enhance$^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin, did not significantly increase SBS compared to non-adhesion promoter bonding with either adhesive system (Transbond $^{tm}$ XT and Light Bond$^{tm}$) upon normal enamel. The adhesion promoters did not demonstrate a material-specific predilection for one adhesive system over another. Since groups bonded with Assure $^{R}$ Universal Bonding Resin had significantly higher ARI scores than control groups and groups bonded with Enhance$^{tm}$ LC, more adhesive removal from the tooth will be required following debonding.

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# CHAPTER 1

# INTRODUCTION

The benefits of successful orthodontic treatment are well known today. While esthetics is a common motivator to seek orthodontic therapy, a harmonious smile often accompanies the achievement of good function, balance of hard and soft tissue relationships, and improved access to cleanse the teeth. The efficiency in obtaining these goals relates to how well the clinician can control tooth movement during treatment. Among the numerous types of appliances used, brackets are currently the most utilized and most recognizable feature of orthodontic treatment. When brackets lose their attachment to tooth structure during treatment, the clinician no longer has control over tooth movement, and reattachment of the bracket is often necessary. Such interruptions in the course of treatment often make obtaining treatment goals more difficult and less efficient.

While orthodontic bonding is generally successful, orthodontic bond failure occurs at 4.7-6.0% (O'Brien, Read, Sandison, & Roberts, 1989) for a variety of reasons such as poor operator technique, moisture contamination, and excessive masticatory forces. It has been suggested that values between 5.9 and 7.8 MPa of shear bond strength are sufficient for clinically effective bonding (Reynolds, 1975), being strong enough to control tooth movement in all three dimensions, but weak enough to fail safely during debonding. However, sometimes conventional bonding techniques are insufficient when bonding in uncontrolled humidity or on irregular enamel surfaces, such as deciduous teeth, hypocalcified enamel, and fluoridated enamel surfaces. Moreover, greater bond strengths may be preferred with noncompliant patients, when diet is unchanged to meet treatment needs, or when destructive chewing habits lead to bond failure.

Bond failure of a single bracket incurs a financial cost that is often difficult to measure. Sondhi (1999) estimates bond failure costs anywhere from $70 to $200 per instance accounting for all materials and procedures to rebond the bracket to the tooth. The orthodontic manufacturer industry is driven by the constant desire for more efficient treatment. Thus, the rationale for decreasing bond failure is continuous control of tooth movement, resulting in efficiency of treatment for both clinician and patient; as such, there have been many strategies to decrease bond failure rate including new adhesive materials, innovative bracket base designs, enamel etching procedures, and sandblasting techniques. A relatively new method to enhance the bond strength of orthodontic brackets is the use of adhesions promoters.

The term “adhesion promoter” was initially used to describe a surface-active co-monomer which attempts to create chemical adhesion of plastic to tooth structure (Ray, 1983). One of the first molecules of this kind was N-phenylglycine-glycidyl methacrylate (NPG-GMA) and some of the first dentin adhesives were created utilizing this molecule (Bowen, 1965); however, early commercial applications of products based on NPG-GMA had yielded poor clinical results (Swift, 1995). Significant improvements in dentin adhesion were made with the introduction of hydrophilic resins.

Based on these concepts, adhesion promoters have been introduced to orthodontics in the form of hydrophilic monomers to be applied to etched enamel. It is thought that bonding with hydrophilic monomers can facilitate the infiltration of resin into enamel at the level of the prisms, reducing interfacial porosity and improving bond strength and integrity (Hotta et al, 1992; Nakabayashi N, 1982). The current research regarding adhesion promoters is sparse, and what is available has yielded contradictory results. While the clinical effects of current adhesion promoters are still largely unknown, the desire for adhesion promotion still exists. Increased bond strengths, when indicated, could reduce bond failure rate.

As with any new product, adhesion promoters have their own limitations. It must be stressed that any product intending to increase orthodontic bond strength may have a higher likelihood of causing enamel fracture. The ideal hypothetical product would be one that increases bond strength while decreasing enamel fracture rate. However, considering the numerous factors that affect bond failure rate and the complexities of failure propagation in different failure modes, the exact relationship between orthodontic bond strength and enamel failure is ambiguous. Another limitation of adhesion promoters is that they are often applied as an extra step to the bonding process, a process which is already technique sensitive in the timing, application of materials, as well as isolation from moisture and other fluids of the oral cavity. The cost and risk to benefit ratio in a clinical setting is still unclear.

A conventional orthodontic adhesive system utilizing a total etch technique consists of application of a bonding agent, often an unfilled resin, to the etched enamel followed by a filled resin composite paste applied with a bracket. When adhesion promoters are used, they are typically applied to the etched enamel as the extra step before the adhesive system is utilized as normal. Enhance tm LC (Reliance Orthodontic Products, Inc., Itasca, Ill) is one such product. As described by the manufacturer, Enhance tm LC can improve bond strength to a variety of surfaces including alloy, porcelain, irregular enamel surfaces as well as normal enamel. However, only a handful of studies have shown conflicting evidence as to its efficacy when bonded to normal enamel. Recently, a product called Assure [R] Universal Bonding Resin (Reliance Orthodontic Products, Inc., Itasca, Ill) has been introduced to the orthodontic community. The manufacturer maintains that Assure [R] Universal Bonding Resin has the adhesion promotion capacity of Enhance [tm] LC, which improves bond strength to a variety of surfaces, but in addition, eliminates the need for the bonding agent. Thus, Assure [R] Universal Bonding Resin represents both the adhesion promoter and the bonding agent in one application, reducing adhesion promoted bonding by one step.

The scope of use for adhesion promoters has not been clearly delineated in the literature, largely because no consensus has been made as to their effects on bond strength. Once their effects have been well documented by in vitro studies, randomized controlled trials can demonstrate their clinical viability by way of in vivo investigation. With a better understanding of adhesion promoters and their impact on bond strength, the range of indications can be more clearly defined, and their use can better serve the orthodontic community.

## Purpose of the Study

To contribute to the greater understanding and role of adhesion promoters in orthodontics, this study evaluated the shear bond strength of Enhance [tm] LC and Assure [R] Universal Bonding Resin. While investigators have shown contradictory results with Enhance [tm] LC, Assure [R] Universal Bonding Resin has not been previously explored in the orthodontic literature. Higher bond strengths relative to their controls could validate adhesion promotion in a clinical setting when higher bond strengths may be indicated. In addition, the elimination of one step when bonding with Assure $^{R}$ Universal Bonding Resin may prove to increase efficiency and reduce the chance of contamination between steps when adhesion promoted bonding is desired. Testing these adhesion promoters with two different adhesive systems may indicate if any products demonstrate a predilection for specific products over others; this could also aid clinicians on which products show the most compatibility when using them in their practice. To better understand adhesion promoter properties upon failure, this study also investigated the location of failure, which relates to how much cleanup is required after debonding. The results of this in vitro study could help in the design of future in vivo studies and ultimately in developing a defined scope of use for adhesion promoters in orthodontics.

## Definition of Terms

Adhesive remnant – the remaining amount of adhesive left on a tooth or bracket following removal of a bracket.

Adhesion promoter - hydrophilic monomers proposed to facilitate the infiltration of resin into enamel at the level of the prisms, meant to improve bond strength

Bond failure – premature detachment of orthodontic bracket from tooth

Shear bond strength – the peak force required to cause detachment of the bracket from the tooth using a shear force divided by the contact area between the bracket and the tooth

Shear force – a force that causes a sliding displacement of one side of a specimen with respect to the opposite side.

## Research Questions

The overall research goal is as follows:

Comparison of the shear bond strengths between two adhesion promoters (Enhance $^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin) on teeth with metal brackets, using two types of adhesive systems - Transbond $^{tm}$ XT (3M Unitek, Monrovia, Calif.) and Light Bond$^{tm}$ (Reliance Orthodontic Products, Inc., Itasca, Ill)

The in vitro study attempted to address the following research questions.

1) Does Enhance$^{tm}$ LC increase bond strength compared to conventional bonding without an adhesion promoter?

Hypothesis:

Shear bond strengths using Enhance$^{tm}$ LC will be significantly higher than those achieved with conventional bonding without an adhesion promoter.

2) Does Assure $^{R}$ Universal Bonding Resin increase bond strength compared to conventional bonding without an adhesion promoter?

Hypothesis:

Shear bond strengths using Assure $^{R}$ Universal Bonding Resin will be significantly higher than those achieved with conventional bonding without an adhesion promoter.

3) How does shear bond strength using Enhance$^{tm}$ LC compare to bonding utilizing Assure $^{R}$ Universal Bonding Resin?

Hypothesis:

Shear bond strengths using Enhance$^{tm}$ LC will be similar to those achieved when bonding with Assure $^{R}$ Universal Bonding Resin.

4) Does Enhance$^{tm}$ LC or Assure $^{R}$ Universal Bonding Resin demonstrate a preference for one adhesive system over another – Transbond $^{tm}$ XT or Light Bond $^{tm}$?

Hypothesis:

Both Enhance$^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin will be adhesive specific to the Light Bond $^{tm}$ system and show higher bond strengths than with those using the Transbond $^{tm}$ XT adhesive system.

5) How does Enhance$^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin rate on the adhesive remnant index compared to non-adhesion promoter bonding?

Hypothesis:

Bonding with Enhance LC$^{tm}$ and Assure $^{R}$ Universal Bonding Resin will have similar ARI values with each other, with more adhesive remaining on the tooth surface compared to bonding without the use of an adhesion promoter

# CHAPTER 2

# REVIEW OF THE LITERATURE

Literature review of this topic comprised both US and Worldwide published literature via online databases. Search terms included the following: adhesion promoter, adhesion booster, bond failure, adhesive remnant. Searchable databases included: Pubmed, Science Direct, Medline, Scirus, Academic Search Premier, Web of Knowledge, and Cochrane Library. A search was also completed at the UNLV library to locate books related to these topics. The search terms were also placed into several internet search engines including Google search and Bing$^{tm}$ for further investigation. The literature search revealed 67 articles and 2 books related to adhesion promoters, orthodontic bond failure and adhesive remnant.

## Benefits of Orthodontic Bonding

Before the advent of bonding brackets to enamel, early orthodontic systems involved banding every tooth in the mouth. First, separators were placed to create spaces between teeth. Then, each individual band was fit and adapted to the contours of the tooth. Finally, the bands were cemented into place and excess cementing material was removed. With the proper fitting band and cement, three dimensional control of the surrounded tooth was possible via welded brackets through which a wire was ligated. What once were common practices are now regarded as the many tedious and unfortunate disadvantages of banding the entire mouth (Brantley & Eliades, 2001, p202):

- banding required extensive chair time;
- there was a more pronounced effect on periodontal health;
- there was a need for frequent screening for caries or decalcification of underlying tooth structure;
- additional arch space was required to accommodate the width of each band;
- separation of all teeth prior to band fitting was uncomfortable to patients.

Restorative dentistry had been utilizing the acid etch technique, as was first described by Michael Buonocore in 1955, to bond restorations to tooth structure. For the orthodontic profession, acid etching brought the prospect of adhering a bracket to the tooth surface, without the need for a surrounding band. Early reports indicated the first use of orthodontic bonding was done with epoxy resins as the adhesive (Brantley and Eliades, 2001, p202). In the few decades that followed Buonocore's acid etch introduction, advances in adhesive technology revolutionized orthodontics. The development of Bis-GMA composites in the mid 1960's aided the overwhelming conversion from bands to brackets. Shortly after, bonding brackets directly to teeth had effectively replaced banding every tooth in the mouth by the late 1970's (Brantley & Eliades, 2001, p144). The advantages of bonding over banding were as follows (Jenkins, 2005; Brantley & Eliades, 2001):

- improved esthetics;
- bonding required less chair time;
- there was greater access to maintain periodontal health;

- caries was more easily detectable;
- additional arch space was not required for separation for bands;
- ability to place an attachment on a partially erupted tooth, which was not possible with a band;
- less inventory, as a set of brackets could be used universally to fit any sized teeth, while different sizes of bands were needed to fit teeth individually

The initial hurdles of bonding were developing adhesives and attachments that could withstand the stresses of mastication, stresses exerted by archwires, allow for control in all three planes and maintain adhesion in a humid, oral environment subjected to rapid changes in temperature and pH (Newman, Snyder, & Wilson 1968). The adhesives and attachments should be able to remain in place for a reasonable treatment time, and at the conclusion of treatment, be removed with minimal effect on the underlying enamel surface. Improvements to adhesives, bracket bases, and bonding technique had answered most of these demands, including the ability to bond to irregular enamel and non-enamel surfaces. Bonding brackets to molar teeth, while generally successful, has not fully supplanted cementation of bands, due to their ability to withstand heavier masticatory and orthopedic forces (Jenkins, 2005). Regarding bonding brackets to teeth however, adhesion promoters are among the myriad of next generation products meant to further enhance bond strength. As bond failure is still a common problem, the potential benefits of such products could be reduced bond failure rate and increased efficiency of treatment.

## Disadvantages of Orthodontic Bonding

Even a breakthrough such as direct bonding did not arrive without its own shortcomings. Early on, one main problem was removing the adhesive remnant that remained on the enamel after treatment was completed. There were accounts of discoloration of the resin tags left in enamel over time as a result of absorption of oral fluids (Brantley & Eliades, 2001, p202). Obvious esthetic concerns had arisen from such discoloration. Advances in adhesive systems have since improved these properties.

Although rare, enamel fractures can occur during bond failure. Unsound enamel and improper debonding practices can increase the likelihood of enamel fracture. For example, one study found that when a twisting action is used to remove brackets, enamel fracture is more likely, causing a higher amount of stress on enamel (Knox, Jones, Hubsch , Middleton , & Kralj, 2000). With metal brackets, proper debonding involves distortion of the metal bracket base to minimize stress on the enamel. However, there have been higher incidents of enamel fractures associated with ceramic brackets (Jeiroudi, 1991), due to higher fracture toughness of ceramic over enamel (Scott, 1988). In addition, it is thought that ceramic brackets bonded to enamel have little ability to absorb stress when debonding (Swartz, 1988).

Bond failure is still a common problem. When this occurs, the tooth is no longer controlled by the system put in place by the clinician. The common solution following a bond failure is the necessity to rebond the bracket to resume control of the tooth. This requires additional chair time, materials, and can increase overall treatment time. Some clinicians revert to banding certain teeth that experience repeated bond failure. Bands on molar teeth are quite common place, due to their infrequent detachment, excellent control in all three dimensions, as well as their versatility with other orthodontic appliances. Bonded orthodontic attachments have not fully supplanted cementation of orthodontic bands, since bands can withstand higher force applications in conjunction with headgear, palatal expansion and Herbst appliances, as well as the ability to withstand heavy masticatory forces (Jenkins, 2005).

Disadvantages of adhesion promoters are not well known. While adhesion promoters are meant to increase bond strength, it is possible that adding an extra step to bonding allows another opportunity for isolation to be compromised; when a technique sensitive process is made more complex, the chances to repeat this process optimally becomes more difficult. In addition, compatibility issues with other products may actually inhibit the optimal bonding of an adhesion system. As with any product that attempts to increase bond strength, the risk of enamel fracture may increase. Since the benefits of adhesion promoters have not been well documented in literature, it is difficult to weigh the costs and risks of adhesion promoters against their potential benefits.

## Bond Failure

To understand the proposed purpose of adhesion promoters, it is important to examine the main problem being addressed – bond failure. Several clinical investigators have explored bond failure rates with chemically-cured adhesives. Gorelick (1977) found a 4% failure rate for upper incisors and 7% for lower premolars, inspecting 549 total brackets. A comparable study examined 705 brackets and discovered a 10% failure rate for incisors and 29% for molars (Zachrisson, 1977). As light-cured adhesives were introduced in the 80's, curing of the adhesive to achieve immediate bonding was made possible via transillumination through the tooth structure (Read, 1984).

With all the advances in adhesive dentistry and improvements in technique, bond failure is still a common occurrence. In a controlled clinical trial, overall failure rate for light-cured adhesive and chemical-cured adhesive has been shown at 4.7% and 6% respectively (O'Brien et al., 1989). Of all the debonded brackets, 82% failed in the first 6 months. In this study by O'Brien et al., (1989), the authors attribute the bond failures into three major categories; first, there can be deficiencies in the bond strength caused by contamination, air inclusion, or inadequate enamel etching. Second, patients initially receiving braces may inadvertently chew on food that has been restricted. Third, initial tooth positions, such as improper overbite, can subject heavy occlusal forces to the bonded appliances and result in bond failure as well.

The first major category of bond failures is a result of technique sensitivity. Several authors have demonstrated the effects of poor moisture control. Hormati, Fuller, & Denehy et al. (1980) has shown a 50% decrease in bond strength when moisture was present. Silverstone, Hicks and Featherstone et al. (1985) concluded that saliva deposits organic material into the etched enamel and interferes with the micromechanical retention. In addition to saliva, moisture can come from blood, crevicular fluid, inadequate drying after rinsing, and even the patient's breath. Research by Hobson, Ledvinka , and Meechan (2001) found that Transbond MIP (3M Unitek, Monrovia, Califor), a moisture insensitive paste, provided more than adequate bond strength for orthodontic bonding in the presence of moisture and blood. However, dry bonding still resulted in significantly higher bond strength than moist and blood-contaminated bonding at 15.69 MPa, 12.89 MPa, and 11.16 MPa respectively. The study by O'Brien et al. (1989) also demonstrated a higher failure rate for posterior teeth than anterior teeth at 11.8% and 2.6% respectively. These results are consistent with relatively more difficult moisture control in the posterior dentition.

Incomplete etching can result from failure of cleaning the tooth surface prior to etching, as well as inadequate duration of etching. A study by Johnston, Burden, Hussey, and Mitchell (1998) revealed that while a 15-second duration is adequate for anterior and premolar teeth, a 30 second duration is recommended for molar teeth, utilizing 37% phosphoric acid. Moreover, adhesive manufacturers recommend that if the recommended etching does not reveal a "frosty" appearance, additional etching be done. Identifying atypical enamel is important for when additional etching may be warranted.

Inadequate curing of the adhesive has also been shown to reduce bond strengths. Insufficient duration of curing, movement of the bracket during the curing process, and an increased distance from the bracket base to the light cure source can all result in a less than optimal bond. Cacciafesta, Sfondrini, Scribante, Boehme, and Jost-Brinkmann (2005) demonstrated that when using an LED curing light, bond strengths were significantly less at 3mm and 6mm from the bracket base compared to 0mm. When bonding to alloys, it has been shown that precuring of the bracket base may significantly increase bond strength, due to the inhibition of the transillumination effect of metal surfaces (Shon, Kim, Chung, & Jung, 2012). In addition, improper handling and loading of the adhesive into the bracket base can result in voids, contamination of the adhesive, lack of mechanical retention into the bracket mesh, and even premature curing of the adhesive material.

The second category of bond failure occurs when patients fail to follow the restricted diet as prescribed by the clinician. Orthodontists recommend that patients avoid hard and sticky foods that may cause damage to the intraoral appliances (Shirazi, Mobarhan, Nik, & Kerayechian, 2011). Masticatory forces generated by the musculature can be transmitted from the teeth, through the food, to the appliances. Such food can remove wires from the brackets, place permanent bends in wires, and also remove brackets. Patients who are not compliant with the diet modification will likely experience more bond failures. O'Brien et al. (1989) states that patients initially receiving braces undergo an experimental period of discovering what foods are comfortable for their tender teeth. As they attempt to chew harder and harder foods, the chances of bracket failures increase.

The third category of bond failures relates to the bracket position in the mouth relative to other tissues during function. Higher masticatory forces are experienced in the posterior dentition, where teeth are closer to the fulcrum (Okeson, 2008, p 105). This is consistent with posterior teeth having higher bond failure rates than anterior teeth as mentioned previously (Gorelick, 1977; Zachrisson, 1977; O'Brien et al., 1989). Linklater and Gordon (2003) found that in vivo, mandibular and posterior teeth had significantly greater bond failures than maxillary and anterior teeth. When teeth in one arch have excessive vertical overlap with teeth in the opposing arch, masticatory forces from teeth can transmit forces through direct contact with the braces. This type of unwanted tooth-appliance contact can be mitigated with modifying bracket positions, using bite openers, and delaying of bonding until relationships between teeth are more favorable for bonding.

The variables that affect bond failure can have a cumulative effect. A bracket bonded in the posterior dentition with incomplete etching and poor moisture isolation is more likely to fail when hard foods are chewed on. Troubleshooting the exact reason for bond failure in a clinical situation is difficult. Since clinical bond failure occurs in an uncontrolled environment, one can only speculate whether a slight increase in shear bond strength would have prevented a premature debonding. While clinicians attempt to minimize operator error and stress compliance with diet modification, orthodontists continue their search for products that could optimize efficiency and reduce bond failure rate. Adhesion promoters are among such products that attempt to answer this call.

## Location of Bond Failure

Adhesive failures are those that occur between two materials, while cohesive failures are those that occur within one material. Orthodontic adhesive failures can occur between enamel and adhesive, as well as between adhesive and bracket. Cohesive failures can occur within the adhesive, within the tooth, and within the bracket itself. Cohesive failures can often reflect high adhesion strengths, since the adhesion between two separate objects would be so strong that failure within the material occurs. Often, failures are a combination of adhesive and cohesive failure (Powers & Messersmith, 2001), failing partially between enamel and adhesive, between adhesive and bracket, and cohesively within the adhesive connecting the other two adhesive failures. This mixture of failure patterns has been demonstrated clinically (Vicente, Toledano, Bravo, Romero, Higuera, & Osorio, 2010).

Artun and Bergland (1984) have used an adhesive remnant index (ARI) to evaluate the amount of adhesive left on the tooth after debonding. A tooth is scored on a four point scale as follows: score of 0 = no adhesive left on the tooth; score of 1 = less than half of the adhesive left on the tooth; score of 2 = more than half of the adhesive left on the tooth; and score of 3 = all adhesive left on the tooth with a distinct impression of the bracket mesh. This is generally accomplished by observing the amount of adhesive left on the bracket following debonding, and subtracting it from 100%. Over the years, this scale, as well as modified versions of the original ARI, has been used to evaluate the amount of adhesive left on the tooth, and draw conclusions of the locations of orthodontic bond failures.

There has been debate whether or not ARI scores reflect a difference in bond strength (Montasser & Drummond, 2009). While some studies demonstrated a correlation or a parallel between shear bond strength and ARI (Parish et al., 2011; Mirzakouchaki, Kimyai, Hydari, Shahrbaf, & Mirzakouchaki-Boroujeni, 2012), others have shown the contrary, suggesting the amount of adhesive remaining following debonding is not related to shear bond strength, but is instead governed by numerous factors, including bracket base design and adhesive properties (O'Brien, Watts, & Read, 1988).

Caution must be taken when interpreting ARI results, as the location of failure only gives an indication of the total failure propagation, not initiation. When the failure initiates, localized flexure may occur in other areas of the attachment and in turn concentrate stresses in a way that was different prior to failure initiation. Conclusions on the "weakest link" can only be inferred from area majority of failures, but conclusive initiation of the failure cannot be clearly determined. Caution must also be taken when comparing SBS with ARI scores. For example, comparable shear bond strengths can be achieved in two different samples even if the failures take place in separate locations. This is further complicated when failures demonstrate a mixture of adhesive failures between interfaces, connected by cohesive failures within the adhesive. A failure pattern that results with most of the adhesive remaining on the tooth can be interpreted as protection of the enamel from the stresses of debonding, with the disadvantage of having more adhesive to remove mechanically after removing the bracket (Bishara, Ostby, Laffoon, & Warren, 2008). This can potentially reduce enamel fracture rate. On the other hand, reduced adhesive on the enamel following debonding will require less cleanup, and the risk of damaging the enamel by mechanical resin removal and polishing is reduced (Sinha, Nanda, Duncanson, & Hosier, 1995). One study found that the greatest enamel surface loss occurred during the cleanup process with a rotary instrument, compared to the other stages of bonding and debonding, such as etching and debonding (Hosein, Sherriff & Ireland, 2004). Thus, there has not been a consensus on whether more or less adhesive remaining is preferred or most beneficial.

## The True Cost of Bond Failure

When bond failures occur, the consequences are usually detrimental to the progress of treatment and the overall efficiency of the office. Placing a numerical value on the true cost is challenging, as there are many variables affected by bond failure. As the true cost is difficult to measure, Sondhi (1999) estimated that it is $70 to $200 per bond failure. Cook (2010), an orthodontic clinical consultant, estimated that each failure is likely to cost more than $200. According to these estimates, an office that bonds 30 new cases a month, at a 5% bond failure rate and $200 per failure, will lose $8,400 every month.

Sondhi argues that the actual cost of the bracket is relatively insignificant; lost clinic time and lost treatment time are the major concerns. In the best case scenario, when there is no loss of tooth movement, the cost is approximately $70-80 dollars when considering all systems, materials and time needed to reappoint, including office time, sterilization, untying, rebonding, and retying. This cost increases to $150 to $200 when there is relapse of tooth movement, since additional appointments may be necessary to get treatment back on track. If the clinician must revert to a lighter arch wire, the cost incurred by longer treatment times is even more enhanced, as the progress of other teeth is halted. How many systems are affected will differ from one instance to the next. Since no bond failure situation is exactly the same, determining costs remains a very rough estimate.

While lost chair time and lost treatment time are major financial matters, altered patient perception and its sequelae can also negatively affect one's office reputation. Rapport with patients can be affected by the extended length of treatment time, extra appointments to rebond, loss of confidence in the clinician, and the frustration and stress a patient experiences at the time of bond failure. Cook (2010) mentions that bond failures can lead to elevated stress in the clinic, which can additionally affect office efficiency and patient perception. It is important to note that intangibles such as altered patient rapport and elevated stress are difficult to track and even more difficult to measure. This further obscures the true cost of bond failure.

If clinicians can utilize products such as adhesion promoters to reduce bond failure rate, the benefits could potentially reduce the large financial burden spent managing clinical bond failure. The prospect of losing less clinic and chair time to bond failure is real, but whether the products and techniques exist to make bond failure a rarity has yet to be seen. Less treatment interruption means more efficient and comfortable treatment for both clinician and patient. Any potential stress, frustration, or loss of rapport could be reduced.

## Adhesion Promoters in the Literature

Utilizing an adhesion promoter based on Bowen's formula, an early study found that the highest bond strengths were achieved when Megabond tm (Kuraray Medical, Tokyo, Japan) was applied to the tooth surface, in combination with applying it to the sandblasted metal mesh surfaces (Newman GV, Newman RA, Sun, Ha, & Ozsoylu, 1995). Lower bond strengths were demonstrated when either the adhesion promoter or sandblasting component were removed in other test groups. Adhesion promoted bond strengths, with sandblasting, represented a 48% increase compared to the control group that received no Megabond tm and no sandblasting. Another study found that application of Enhance tm adhesion booster (Reliance, Inc., Itasca, Ill) to the bracket base failed to improve bond strength (Egan, Alexander, & Cartwright, 1996). This result may be misleading, as the manufacturer's recommendation is for Enhance tm to be applied to the tooth surface, instead of the bracket base.

One study demonstrated that neither All-bond 2R (Bisco, Schaumburg, Ill) nor Enhance tm LC significantly increased bond strength of new brackets (Chung, Fadem, Levitt, & Mante, 2000); however, this study did find that All-bond 2$^{R}$ significantly increased the bond strength of sandblasted rebonded brackets, while Enhance $^{tm}$ LC did not.

Vicente, Bravo, Romero, Ortiz, and Canteras (2004) demonstrated that while Enhance $^{tm}$ LC did not significantly improve bonding for new brackets, its greatest bond strengths showed a material specificity preference for the Light Bond$^{tm}$ adhesive system (Reliance, Itasca, Ill.) over the Transbond$^{tm}$-XT adhesive system (3M Unitek, Monrovia, Calif.). Fox (2004) demonstrated comparable results in a similar study. Vicente et al. (2005) found that Orthosolo$^{tm}$ (Ormco, Orange, Calif.) significantly increased bond strength while All-bond 2$^{R}$ did not. Both of these adhesion promoters were tested with Transbond$^{tm}$-XT adhesive system. Later, Vicente et al. (2006) tested three adhesion promoters, Orthosolo$^{tm}$, All-bond 2$^{R}$ and Enhance $^{tm}$ LC, utilizing both Light Bond$^{tm}$ and Transbond$^{tm}$XT adhesive systems, and none of the promoters significantly increased bond strength.

One of the first in-vivo studies looking at adhesion promoters demonstrated that Enhance $^{tm}$ LC appeared to have a reduction in bond failure rate (Goel & Patil, 2005). Utilizing a split mouth design, this study group observed 150 brackets over a 90 day period and used the Light Bond$^{tm}$ adhesive system. While reporting that only two failures occurred in the Enhance $^{tm}$ LC group versus eleven in the control, the study lacked any reports of statistical analysis.

More recently, one study demonstrated that three adhesion promoters significantly increased bond strength of new brackets over control groups (Vijayakumar, Venkateswaren, & Krishnaswamy, 2010). Using the Light Bond$^{tm}$ adhesive system, Orthosolo[tm] group had the highest bond strengths, followed by All-bond 2[R], and Enhance [tm] LC. This study also showed that Orthosolo[tm] improved bond strength to rebonded brackets while All-bond 2[R] and Enhance [tm] LC did not. Hoogan et al. (2011) did not find significant differences between adhesion promoter groups and control groups, yet Enhance [tm] LC paired with Light Bond[tm] had the highest bond strengths while Enhance [tm] LC with Transbond[tm]XT had the lowest bond strengths.

Another focal point of adhesion promoters has been their effect on fluorosed enamel. There was a reported significant increase in adhesion-promoted bond strength for fluorosed enamel using Enhance [tm] LC (Adanir, Turkkahraman, & Gungor, 2009). An in vivo study, using a split mouth design, demonstrated that bond failure rate over 9 months with Scotchbond[tm] Multipurpose Plus Primer(3M Unitek, Monrovia, Calif.) were comparable to those aided with micromechanical abrasion on fluorosed enamel (Noble, Karaiskos, & Wiltshire, 2008). This study concluded that when adhesion promoters were used on fluorosed enamel, micromechanical abrasion was no longer necessary to achieve clinically viable bond strengths.

# CHAPTER 3

# METHODOLOGY

**Teeth:**

One hundred forty freshly extracted human premolars were collected from the greater Las Vegas, NV area over the course of one year. These teeth were extracted for reasons other than the purposes of this study. Both upper and lower premolars with intact buccal enamel were included in this investigation and were initially collected in a solution containing Acclean Chlorhexidine Gluconate 0.12%, (Henry Schein, Melville, NY) and distilled water (1:10 solution). The teeth were then sterilized in 10% formalin for 14 days. Afterwards, the teeth were stored in distilled water, which was changed periodically, every 2 weeks, until bonding was conducted.

**Groups:**

The teeth were randomly divided into 7 groups of 20 teeth each. **A Groups** were all bonded with the Light Bond$^{tm}$ adhesive system, while **B Groups** were bonded with the Transbond$^{tm}$ XT adhesive system. Groups A1 and B1 acted as controls and were bonded without an adhesion promoter. Groups A2 and B2 were bonded with Enhance $^{tm}$ LC, while Groups A3 and B3 were bonded with Assure $^{R}$ Universal Bonding Resin. **Group C** was treated as a third reference control, using a self etch primer, which was not amenable for use with an adhesion promoter. This group was bonded with Transbond$^{tm}$ Plus Self Etching Primer (3M Unitek, Monrovia, Calif.) and the Transbond-XT$^{tm}$ adhesive paste.

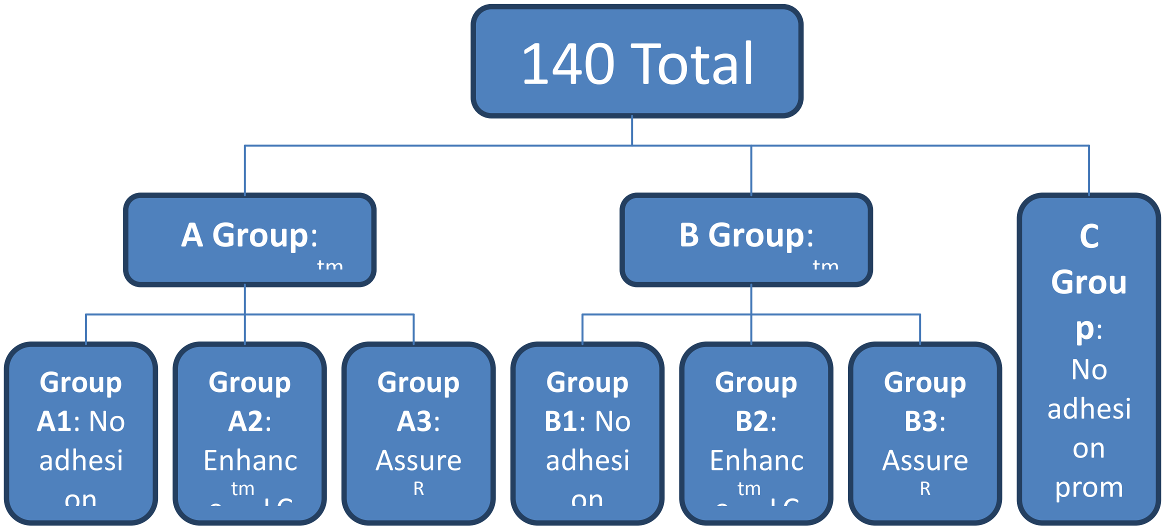


Figure 3.1- Flow Chart of Group Division and Teeth Distribution


Fig 3.2- Photo of Adhesion Systems: Light Bond$^{tm}$, Transbond$^{tm}$ XT, and Transbond Plus Self Etch Primer (from left to right)

Table 3.1-Table of Product Chemical Compositions

| Product | Ingredient | % |
|---|---|---|
| Light Bond™ | Resin bond: | % Conc. |
| | Bisphenol A Diglycidylmethacrylate | 20-30 |
| | Urethane Dimethacrylate | 20-40 |
| | Triethyleneglycol Dimethacrylate | 20-40 |
| | Paste: | |
| | Silica-crystalline, Silica, fused | 60-99 |
| | Bisphenol A Diglycidylmethacrylate | 3-7 |
| | Amorphous Silica | 7-13 |
| Transbond™ XT | Primer: | % by Wt. |
| | Bisphenol A Diglycidyl Ether Dimethacrylate | 45-55 |
| | Triethylene Glycol Dimethacrylate | 45-55 |
| | 4-(Dimethylamino)-Benzeneethanol | <0.5 |
| | DL-Camphorquinone | <0.3 |
| | Hydroquinone | <0.03 |
| | Paste: | |
| | Silane Treated Quartz | 70-80 |
| | Bisphenol A Diglycidyl Ether Dimethacrylate | 10-20 |
| | Bisphenol A Bis(2-hydroxyethyl ether) Dimethacrylate | 5-10 |
| | Silane Treated Silica | <2 |
| | Diphenyliodonium Hexafluorophosphate | <0.2 |
| Enhance ™ LC | Adhesion promoter: | % Conc. |
| | Ethanol | 40-60 |
| | Hydroxyethyl-Methacrylate | 10-30 |
| | Tetrahydrofurfuryl Cyclohexene Dimethacrylate | 10-30 |
| Assure ® Universal Bonding Resin | Adhesion promoter: | % Conc. |
| | Biphenyl Dimethacrylate | >10 |
| | Hydroxyethyl Methacrylate | >10 |
| | Acetone | >40 |
| Transbond™ Plus Self Etching Primer | Self-etching primer: | % by Wt |
| | 2-Propenoic Acid, 2-Methyl-Phosphinicobis (Oxy-2,1-Ethandiyl)Ester | 25-40 |
| | Water | 15-25 |
| | Mono HEMA Phosphate | 10-25 |
| | Tris[2-(Methacryloyloxy)Ethyl]Phosphate | 1-10 |
| | DL-Camphorquinone | <3 |
| | N,N-Dimethylbenzocaine | <3 |
| | Dipotassium Hexafluorotitanate | <3 |

Fig 3.3- Photo of Adhesion Promoters: Enhance$^{tm}$LC (left) and Assure$^{R}$ Universal Bonding Resin (right)

**Bonding:**

For all 7 groups, buccal surfaces of teeth were polished with a rubber polishing cup and pumice. In the A and B groups, buccal surfaces were etched with 40% phosphoric acid gel (Henry Schein, Melville, NY) for 15 seconds and then rinsed with water for 20 seconds as recommended by the etchant manufacturer. Etching for the C Group was done with a self-etching primer. For groups A1, B1, A3 and B3 the enamel surfaces were completely dried with air. For groups A2, B2, and C the enamel surfaces were air dried leaving the surface slightly moist. All bonding was conducted with use of Micro Front-Mounted-Lens Loupes (SurgiTel$^{R}$, Ann Arbor, MI) with 3.5x magnification to ensure uniform bracket placement, complete excess resin removal, and uniform light curing distance. All brackets utilized were identical, twin, metal, premolar brackets (American Orthodontics, Sheboygan, WI) with .018 slot, zero tip, and -7 degree torque.

All brackets had a universal premolar base with an 80 gauge mesh and a measured area of .0163 inches$^2$.

**Group A1: Light Bond**[tm] - A layer of Light Bond[tm] sealant resin was applied to the etched enamel with a brush. Light Bond[tm] paste was applied to the base of the bracket, and positioned against the tooth with firm pressure. Excess adhesive material was removed from around base of bracket with a scaler. An Ortholux Luminous Curing Light (3M Unitek, Monrovia, Calif.) was positioned as close to the bracket as possible without touching it. The bracket was light-cured three seconds on the mesial and distal side of the bracket as per recommendation of the manufacturer of this high-intensity LED light. The curing light intensity listed by the manufacturer is1600 mW/cm$^2$ with an 8 mm light guide.

**Group A2: Light Bond**[tm]**/ Enhance** [tm] **LC**. Three coats of Enhance [tm] LC were applied to the etched and slightly moist enamel with a brush. Then the surface was lightly air-dried after the last coat leaving a shiny appearance. Light Bond[tm] sealant resin and paste were applied and light-cured as in Group A1.

**Group A3: Light Bond**[tm]**/Assure** [R] **Universal Bonding Resin**. Two coats of Assure [R] Universal Bonding Resin were applied to the etched enamel with a brush. The surface was lightly dried with air to evaporate solvent. The bracket with Light Bond[tm] adhesive paste was positioned on tooth with firm pressure. Excess adhesive material was removed from around base of bracket and was light-cured as described in Group A1.

**Group B1: Transbond**[tm]**XT**. A thin layer of Transbond[tm]XT primer was applied to the etched enamel with a brush. Transbond[tm]XT paste was applied to base of bracket, and was positioned on tooth with firm pressure. Excess adhesive material was removed and the bracket was light-cured as described in Group A1.

**Group B2: Transbond$^{tm}$XT/Enhance$^{tm}$ LC**. Enhance$^{tm}$ LC was applied to etched enamel as in Group A2. Then, Transbond$^{tm}$XT primer and paste were applied as described in Group B1.

**Group B3: Transbond$^{tm}$XT/ Assure $^{R}$ Universal Bonding Resin**. Assure $^{R}$ Universal Bonding Resin was applied to the etched enamel as in Group A3. Bracket with Transbond$^{tm}$XT paste was positioned on tooth with firm pressure. Excess adhesive material was removed from around base and light-cured as described in Group A1.

**Group C: Transbond$^{tm}$ Plus Self Etching Primer**. Transbond$^{tm}$XT Plus Self Etching Primer was rubbed into the unetched enamel surface with some light pressure for 3 seconds. The surface was then lightly air thinned. Bracket with Transbond$^{tm}$XT paste was positioned on tooth with firm pressure. Excess adhesive material was removed from around base and light-cured as described in Group A1.

All bracketed teeth were stored in distilled water at room temperature for approximately 12-14 hours until teeth could be mounted.

**Mounting:**

The teeth were ultimately set in place utilizing type III gypsum (Henry Schien, Inc, Melville, NY) in a copper coupling cylinder (W.W. Grainger, Inc, Lake County, Ill) approximately 49mm long, 31mm wide with an internal diameter of 29mm. A mounting jig was fabricated to hold the bracketed tooth in place while the gypsum had time to harden in the copper cylinder. The mounting jig featured a .018 in. x .018 in. stainless steel wire suspended above circular slots for the copper cylinders to fit snugly in place. The gypsum was loaded into the cylinders, and teeth were tied onto the stainless steel wire with steel ties, centered by a mark that bisected the diameter of each cylinder. This ensured that every bracket of each tooth was mounted in the same 3-dimensional space and orientation relative to the copper tube.

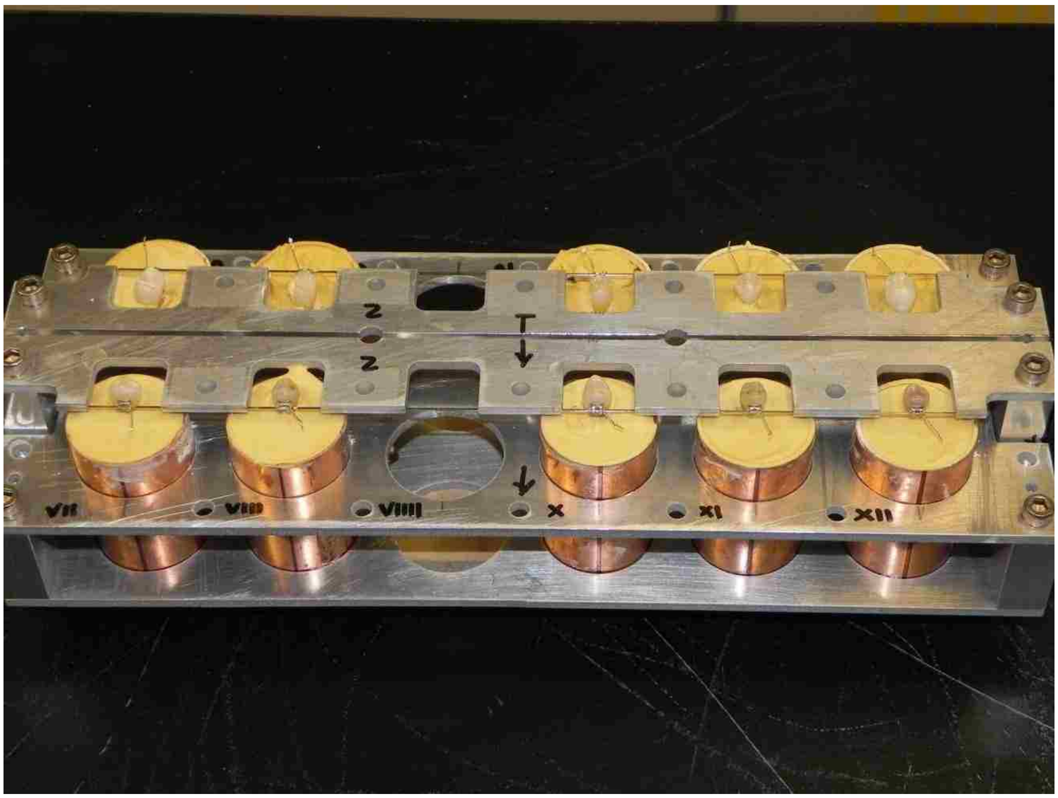


Fig 3.4- Photo of Mounting Jig

Fig 3.5- Photo of Tooth held in place by Mounting Jig: Tooth secured to wire with steel ligature, held in place by mounting jig

The level of stone approximated the cemento-enamel junction, and any additional stone was added or removed to maintain consistency from tooth to tooth. Moist paper towels were draped over all the teeth to keep them from drying out while the gypsum was setting. After gypsum was hardened to touch, the teeth were placed in a distilled water bath (Sheldon Manufacturing, Cornelius, OR) at 37 degrees Celsius for 1 week.

Fig 3.6- Photo of Samples placed into Water Bath: 37 degrees Celsius

## Collection of the Data

**Bond Strength Test:**

Shear bond strength (SBS) was measured with a Universal Testing Machine (United Calibration Corp. Huntington Beach, CA) with a 75 lb. load cell (Transducer Techniques, Temecula, CA) connected to a metal rod with one end shaped to a blade edge. The copper cylinders fit into a female component at the base of the testing machine, and held into place with a set screw. The sharp end of the rod was calibrated to reproduce its position between the base of the bracket and the wings for each sample. The cross-head speed was .01 in/min. The failure loads were measured in lbs, and then converted to lbs per square inch of the bracket base (.0163 inches$^2$). These values were then converted into Megapascals (MPa) using the conversion 1 Psi = 0.00689475729 MPa.

Fig 3.7- Photo of Debonding setup of Universal Testing Machine

**Adhesive Remnant Index:**

The surfaces of both the bracket and enamel were examined using a Stemi-SR microscope (Zeiss, West Germany) at 20x power to assess the amount of remaining adhesive. Two modified ARI scores were given (1 for the bracket and 1 for the enamel) for each sample and categorized with the following criteria:

0 = No adhesive left on the surface

1 = Less than or equal to 1/3 of the adhesive left on the surface

2 = More than 1/3 but less than or equal to 2/3 of the adhesive left on the surface

3 = More than 2/3 of the adhesive left on the surface

4 = All of the adhesive left on the surface

Enamel fractures were recorded and were scored as well.

To inspect the enamel surface of the tooth, a round stainless steel wire (.018 inch) was bent in the rectangular shape of the bracket base, using the internal window of the wire to approximate the total area of the bracket when held against the tooth. A scaler was used for tactile detection of the margins of the adhesive. The 2 ARI scores, one for the bracket and one for the tooth, were then added together. Scores that added up greater than 4 implied some significant cohesive failure within the cement had occurred, meaning that the total surface area of the adhesive remnants were more than the surface area of the bracket. If the score was less than 4, this implied a void under the bracket. Scores that added up to 4 implied that the total area of adhesive was equal to the total area of the bracket base; these would represent combinations of adhesive fractures between enamel, adhesive, and bracket, without voids and without a significant cohesive fracture element.

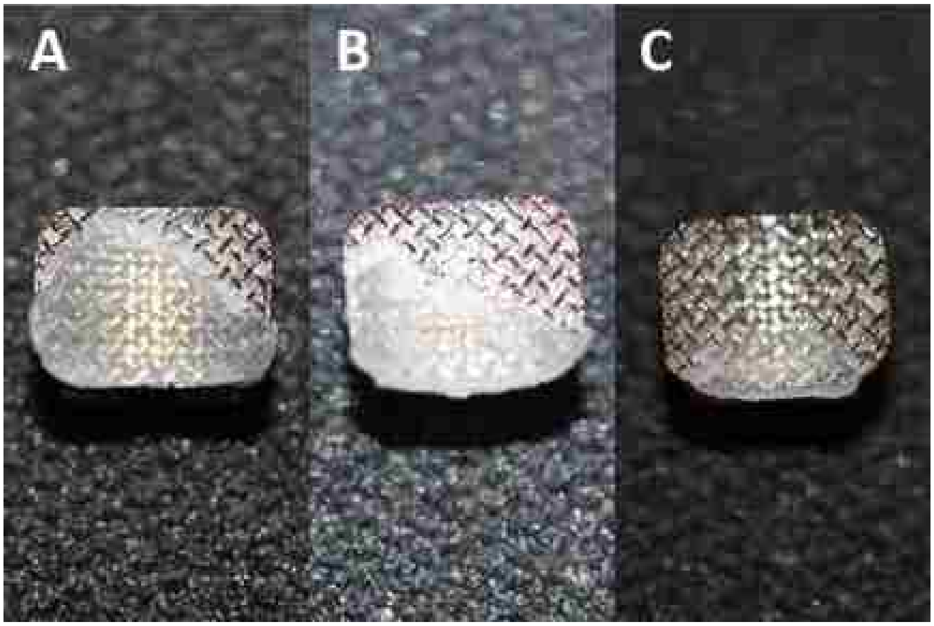


Fig 3.8- Photo of Examples of Debonded Brackets. ARI scores given for the brackets are 3, 2 and 1 for A, B and C respectively.

## Treatment of the Data

Descriptive statistics, such as the mean, median, standard deviation, standard error, minimum, and maximum values were determined for each group. The Leven variance homogeneity test was used to evaluate for normal distribution. The Kruskal-Wallis one-way analysis of variance was used to determine significant difference between groups with the SBS data at $p<0.05$ and the Bonferroni Post-hoc test determined which groups were significantly different for two independent samples. The ARI values were also analyzed using the Kruskal-Wallis test and Bonferonni Post-Hoc with a significant level of $p<0.05$. Both Pearson and Spearman correlations were run for SBS and ARI values as a whole at a significance of $p<0.05$. Lastly, the relationship for SBS and ARI for individual groups were analyzed with Pearson correlations at a $p<0.05$ significance level.

# CHAPTER 4

# RESULTS OF THE STUDY

Table 4.1- Table of Shear Bond Strengths (MPa) and Descriptive Statistics

| | A1 | A2 | A3 | B1 | B2 | B3 | C |
|---|---|---|---|---|---|---|---|
| 1 | 9.86 | 19.4 | 10.1 | 13.9 | 21.2 | 10.2 | 17.9 |
| 2 | 18.1 | 17 | 17.6 | 9.72 | 17.4 | 21.1 | 18.6 |
| 3 | 11.9 | 14 | 8.95 | 18.1 | 17 | 15.2 | 18.6 |
| 4 | 18.8 | 18.4 | 22.8 | 20 | 21.2 | 20.3 | 20.8 |
| 5 | 8.42 | 18.9 | 19.1 | 22 | 14.9 | 21.6 | 17.4 |
| 6 | 9.24 | 10.1 | 10.5 | 20.5 | 19.8 | 13.6 | 18.9 |
| 7 | 16 | 19.7 | 21.7 | 21.2 | 18 | 19.4 | 16.5 |
| 8 | 19.4 | 14.6 | 16.4 | 19.1 | 18.6 | 18.5 | 12.2 |
| 9 | 15.8 | 19.4 | 16.3 | 21.5 | 17.6 | 21.2 | 16.8 |
| 10 | 19.7 | 11.5 | 7.21 | 21.8 | 18.3 | 19.3 | 20.7 |
| 11 | 21.8 | 15.1 | 7.22 | 18.6 | 16.2 | 19.6 | 16.4 |
| 12 | 14.1 | 19.9 | 13.9 | 16.5 | 16.7 | 22.8 | 15 |
| 13 | 19.3 | 12.2 | 16.5 | 19.8 | 14.8 | 22.5 | 17.4 |
| 14 | 13.4 | 13.1 | 6.93 | 19.3 | 18.4 | 8.79 | 17.4 |
| 15 | 11.2 | 17.9 | 16.2 | 20.9 | 15.5 | 15.6 | 18.4 |
| 16 | 16.3 | 15.5 | 13.1 | 18.1 | 20.1 | 16.3 | 16.6 |
| 17 | 17.7 | 21.8 | 13.2 | 16.6 | 18.8 | 17.4 | 19.1 |
| 18 | 19.7 | 16.8 | 18.5 | 23.5 | 18 | 22 | 16.8 |
| 19 | 18.9 | 17.4 | 18.5 | 8.61 | 15.4 | 17.3 | 13.2 |
| 20 | 14.1 | 11 | 12.1 | 18.1 | 22.5 | 19 | 13.5 |
| **Avg** | **15.686** | **16.185** | **14.340** | **18.391** | **18.02** | **18.084** | **17.11** |
| Max | 21.8 | 21.8 | 22.8 | 23.5 | 22.5 | 22.8 | 20.8 |
| Min | 8.42 | 10.1 | 6.93 | 8.61 | 14.8 | 8.79 | 12.2 |
| Std Dev | 3.9726 | 3.3739 | 4.7909 | 3.8597 | 2.1634 | 3.8870 | 2.2810 |
| Std Error | 0.888 | 0.754 | 1.071 | 0.863 | 0.483 | 0.869 | 0.510 |

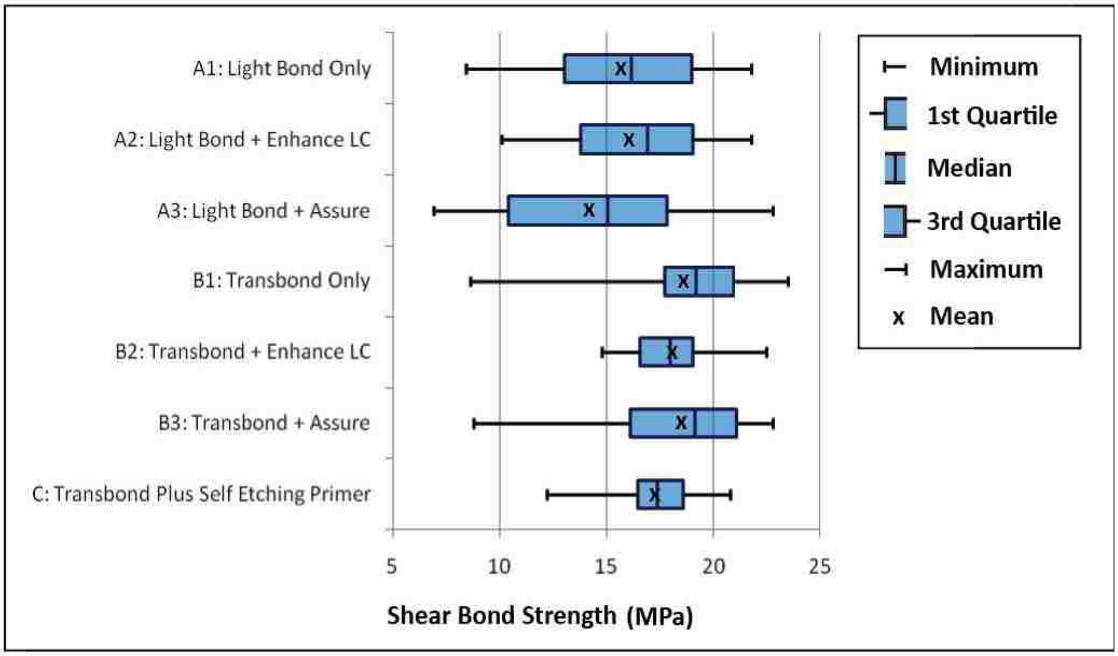


Figure 4.1- Distribution of Shear Bond Strength Data Graph

Table 4.2 - ARI scores of adhesive remaining on tooth

| | **ARI score** | | | | | **Mean** | **Median** | **Enamel Fractures** |
|---|---|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **3** | **4** | | | |
| **A1** | 2 | 12 | 3 | 3 | 0 | 1.35 | 1 | 3 |
| **A2** | 2 | 12 | 6 | 0 | 0 | 1.2 | 1 | 2 |
| **A3** | 0 | 4 | 1 | 15 | 0 | 2.55 | 3 | 4 |
| **B1** | 3 | 13 | 2 | 2 | 0 | 1.15 | 1 | 1 |
| **B2** | 1 | 5 | 8 | 6 | 0 | 1.95 | 2 | 0 |
| **B3** | 2 | 4 | 4 | 10 | 0 | 2.1 | 2.5 | 5 |
| **C** | 1 | 3 | 2 | 14 | 0 | 2.45 | 3 | 6 |
| **total** | **11** | **53** | **26** | **50** | **0** | _ | _ | **21** |

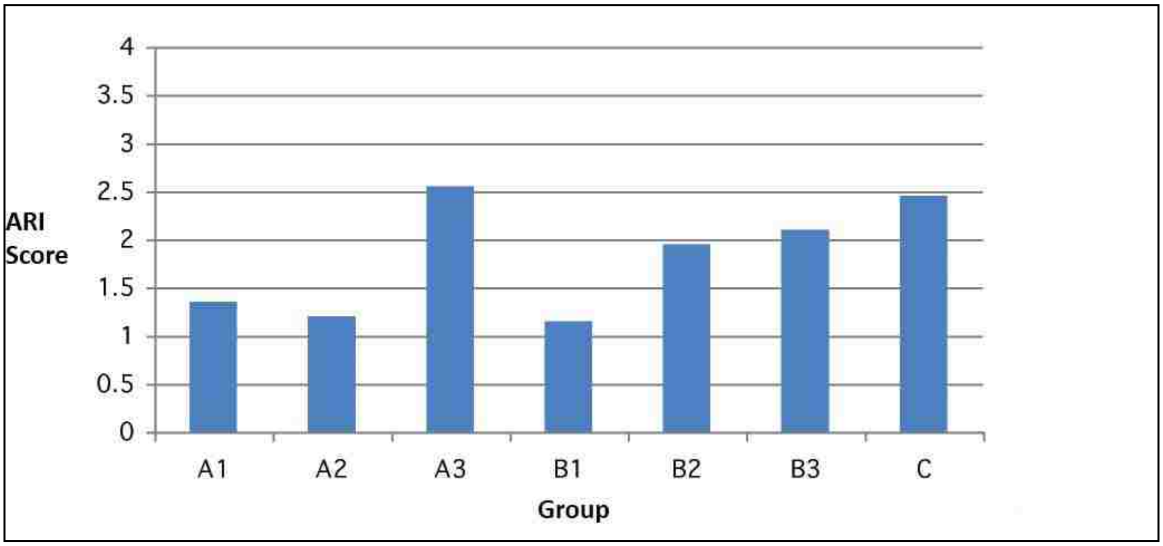


Fig 4.2 – Graph of Average ARI scores for Adhesive Remaining on Teeth

## Statistical Analysis of the Data

The Levene Statistic demonstrated that the obtained SBS data did not follow normal distribution ($p<.003$). The Kruskal-Wallis revealed significant difference between groups ($p<.003$), while the Bonferroni post hoc found significant differences via multiple comparisons between two independent samples. The SBS means for the controls, Groups A1 (Light Bond$^{tm}$) and B1 (Transbond$^{tm}$XT), were 15.7 and 18.4 MPa respectively. When Enhance$^{tm}$ LC was added to both adhesive systems, Groups A2 and B2 demonstrated bond strengths of 16.2 and 18.0 MPa respectively, neither showing a significant difference from controls. When Assure $^{R}$ Universal Bonding Resin was applied to both adhesive systems, Groups A3 and B3 demonstrated bond strengths of 14.3 and 18.1 MPa respectively and neither showing a significant difference from their respective controls. Groups B1, B2 and B3 were each significantly different from Group A3, at a significance of $p<.010$, $p<.031$ and $p<.026$ respectively. Group C, which served as an additional base reference, showed a mean shear bond strength of 17.1 MPa, which was not significantly different from any other group.

Adding both ARI scores for bracket and tooth revealed no composite score less than four, which meant no sample had a significant air void under the bracket. Only one sample in Group A1 had an added score greater than 4, which alluded to a large amount of fracture that was cohesive within the cement. The rest of the samples all added up to 4, which meant that failure took place mostly as adhesive fractures between enamel and adhesive, and or between adhesive and bracket.

With regard to ARI scores for adhesive remaining on teeth, the Kruskal-Wallis revealed significant difference between groups ($p<.000$). The A Groups demonstrated means of 1.35, 1.2, and 2.55 for Groups A1, A2, and A3 respectfully, while B groups displayed means of 1.15, 1.95 and 2.1 for Groups B1, B2, and B3 respectfully. The C group had a mean ARI score of 2.45. Group A1 was significantly different than Groups A3 and C ($p<.000$ and $p<.001$ respectfully). Group B1 was significantly different from Groups A3, B3 and C ($p<.000$, $p<.014$ and $p<.000$ respectfully). Group A2 was significantly different from Groups A3, B3 and C ($p<.000$, $p<.026$ and $p<.000$ respectfully). Group B2 was not significantly different from any other group.

As a whole, SBS and ARI values did not show a significant Pearson or Spearman correlation at $r=.116$ and $r=.127$ respectively at the 95% confidence interval. Analyzing correlations in individual groups revealed 2 of the 7 groups showing weak but significant correlations between SBS and ARI score for adhesive remaining on tooth. Group A2 demonstrated a negative correlation at $r = -0.536$ and Group A3 demonstrated a negative correlation at r = -0.494, both breaching the critical value of 0.444 at the 95% confidence interval.

There were a total of 21 enamel fractures with an enamel fracture rate of 15%. Groups A1, A2, and A3 had 3, 2 and 4 fractures respectively, while Groups B1, B2 and B3 had 1, 0 and 5 fractures respectively. Group C had the most enamel fractures at 6. Of the 21 enamel fractures, 16 of them were above their averages in their respective groups, and 5 were below. The average SBS of all fractured samples was 18.6 MPa with the lowest at 13.1 MPa and highest at 22.8 MPa.

## CHAPTER 5

## DISCUSSION, LIMITATIONS, CONCLUSIONS AND RECOMMENDATIONS

### Discussion of the Results

The application of Enhance$^{tm}$ LC with the Light Bond$^{tm}$ adhesive system (Group A2) did not appear to significantly enhance SBS. Even though Group A2 had a slight increase compared to the control, this difference was not significant. This was consistent with previous studies which found that bond strengths using Light Bond$^{tm}$ were higher, although not significant, when bonded with Enhance$^{tm}$ LC for new brackets (Chung et al., 2000; Vicente et al., 2006; Hoogan et al., 2011). This present study's results are contrary to those presented by Vijayakumar et al. (2010), in which Enhance$^{tm}$ LC significantly increased bond strengths bonded with Light Bond$^{tm}$ for new brackets over its control.

The results indicate that the application of Enhance$^{tm}$ LC with the Transbond$^{tm}$XT adhesive system (Group B2) did not enhance SBS, and in fact resulted in a slight decrease in mean SBS. This present study's findings are consistent with previous studies, finding no significant increase in SBS when Enhance$^{tm}$ LC is used with Transbond$^{tm}$XT (Vicente et al., 2004; Fox 2004; Vicente et al 2006). It should be noted that more consistent bond strengths were achieved with Group B2 than its control (B1), having a tighter grouping between the $1^{st}$ and $3^{rd}$ quartiles, as well as the highest minimum value of all groups, a lower maximum value than the control and the smallest standard deviation of all groups (2.16). Although the differences between A2 and B2 were not significant, Enhance$^{tm}$ LC did appear to behave differently between adhesive systems having a slight positive effect on one and a slight negative effect on the other as seen in another study (Hoogan et al., 2011). It may be concluded that Enhance[tm] LC may show a material specificity to Light Bond[tm] as was previously demonstrated (Fox, 2004; Vicente et al., 2006; Hoogan et al., 2011). Thus, whenever maximum bond strengths are desired when using the Light Bond[tm] adhesive system, application of Enhance[tm] LC may be indicated, even though the increase was not significant in several in vitro studies. The results also indicate that application of Enhance[tm] LC when using the Transbond[tm]XT adhesive system may not be needed for higher bond strengths, but may provide more consistent, albeit lower mean bond strengths.

The application of Assure [R] Universal Bonding Resin did not significantly enhance bond strengths of either adhesive system. Both A3 and B3 demonstrated a slight decrease compared to their respective controls, but neither decrease was significant. The decrease in bond strength of Group A3 was such that it was significantly lower than Groups B1, B2, and B3. It can be concluded from this study that Assure [R] Universal Bonding Resin may not be indicated when higher bond strengths are desired using either the Light Bond[tm] or Transbond[tm]XT adhesive system to normal enamel, although further investigation would be needed. It should be noted that Group A3 also had the most inconsistent bond strengths with the highest standard deviation of all groups (4.79). It must be noted that Enhance[tm] LC and Assure [R] Universal Bonding Resin are marketed to enhance bonding to a variety of surfaces including normal enamel, and different effects may occur when bonding to non-enamel or irregular enamel surfaces.

For adhesive left on enamel, Groups A1 and B1 had low ARI scores on average, meaning that less adhesive remained on the tooth and more was left on the bracket. As controls without any adhesion promoters, the ARI scores for A1 and B1 indicate that the majority of failure took place between enamel and adhesive. Groups A2 and B2 were not significantly different from their respective controls; thus, the addition of Enhance$^{tm}$ LC did not appear to have a significantly different effect on ARI scores, as was consistent with findings from previous studies (Hoogan et al., 2011; Vijayakumar et al., 2010; and Vicente et al., 2006). Groups A3 and B3 had higher and significantly different ARI scores from their respective controls; the use of Assure $^{R}$ Universal Bonding Resin appeared to have an effect such that more adhesive remained on the enamel and less on bracket base. It should be kept in mind that the statistical significance was for differences in ARI score, and not on the actual amounts of adhesive left. The actual amount is indirectly related to the ARI score, since the score covers a range of amounts.

It is of interest to note, that although groups A3 and B3 did not have significantly different SBS from their respective controls, their location of failure was significantly different from the controls. It is possible that, upon loading, the adhesive pastes did not infiltrate the bracket bases as efficiently in Groups A3 and B3 as compared to Groups A1, B1, A2, and B2. This scenario appears unlikely since only one operator loaded all 140 brackets with adhesive in the same manner; moreover, failure to infiltrate the bracket bases with resin would have resulted in a lack of mechanical retention of the bracket and significantly lower bond strengths would be apparent. This was not the case in this present study; slightly lower, but not significant bond strengths were seen in Groups A3 and B3 with respect to their controls.

Since Assure $^{R}$ Universal Bonding Resin has not been previously tested in the literature, only further investigation can shed light as to why the samples in A3 and B3 left more adhesive on the enamel. One can propose that the theoretical action of adhesion promoters of facilitating adhesive into the enamel may cause a pull away from the bracket base upon polymerization shrinkage during curing. As groups bonded with Enhance$^{tm}$ LC did not demonstrate a significant ARI difference than the controls, perhaps the elimination of the separate priming step when using Assure $^{R}$ Universal Bonding Resin allowed for better adhesion between enamel and adhesive. It could be proposed that the use of a high intensity LED curing light in this present study may have influenced polymerization patterns and thus effected ARI scores. Although further investigation of Assure $^{R}$ Universal Bonding Resin is needed to investigate these properties, what has been demonstrated in this present study is that Groups A3 and B3, in these bonding conditions, would require more effort to remove the adhesive from the enamel after debonding. Some authors propose that more adhesive left on the enamel meant that the failure between adhesive and bracket protected enamel from higher potential stresses (Bishara et al., 2008). It could be concluded from this present study, that the use of Assure $^{R}$ Universal Bonding Resin may result in better protection of the enamel upon debonding with the disadvantage of more adhesive to remove mechanically. It must be stressed that these effects may be different in an in vivo or clinical setting.

The single test that had a total composite ARI score (bracket and tooth) of more than 4, had a bond strength of 19.7 MPa. This was much higher compared to its group mean of 15.7 MPa. This sample, with a large cohesive failure element, was the second highest shear bond strength in its group. This is consistent with the concept that a total cohesive failure represents the highest bond strengths achieved between adhesive and enamel. The adhesion between the interfaces of the separate materials was so strong, that the fracture propagated length wise within the layer of adhesive. Unfortunately, only 1 of these samples demonstrated this and further investigation of the relationship between cohesive failures and higher bond strengths with regard to adhesion promoters is needed.

Group C had similar ARI scores to A3 and B3, leaving more adhesive left on the enamel and significantly different from Groups A1 and B1. One might expect that conventional etching would prepare the enamel surface more thoroughly than a self-etching technique allowing for more mechanical retention into the enamel; however, this was not the case in this present study. These results in this study regarding ARI of a self-etching primer are consistent with those by Mirzakouchaki et al. (2012) leaving more adhesive on enamel than conventional technique, but different from results presented by Hosein et al., (2004), who found less adhesive on enamel with self-etching primer than conventional bonding. Further investigation is needed to ascertain as to why differences are seen in literature, but one may speculate that the ARI scores may relate to the technique sensitivity of how the self-etching primer was applied with regard to duration, location, speed and force upon application.

It can be concluded as a whole that SBS and ARI values in this present study did not show a significant correlation. However, it should be noted that, individually, Groups A2 and A3 showed weak but significant negative correlations between SBS and ARI scores for teeth, demonstrating that higher bond strengths were associated with less adhesive remaining on the enamel. Perhaps the application of either Enhance$^{tm}$ LC or Assure $^{R}$ Universal Bonding Resin to the Light Bond$^{tm}$ adhesive system causes some association between SBS and less adhesive remnant on enamel; however, the correlations, although significant, were relatively weak at r = -0.536 and r = -0.494 for Groups A2 and A3, and further investigation is needed to corroborate results. Whether the presence or absence of these correlations was related to the failure of adhesion promoters to enhance bond strengths will require further exploration.

Enamel fractures tended to be of higher bond strengths, since 16 of the 21 were above their respective averages. However, it is difficult to conclude that lower bond strengths preclude enamel from fracturing, since one had occurred as low as 13.1 MPa. In addition, 18 of the fractures were within 1 standard deviation of their respective means, while only 3 were above and beyond 1 standard deviation. Ten of the fractures occurred in the control groups (A1, B1, and C), while the remaining 11 fractures occurred in the 4 test groups (A2, A3, B2, and B3). The total fracture rate of 15% can appear alarming if this were expressed clinically. Many investigators have concluded that the higher enamel fracture rate than what is seen clinically has been an artifact of in vitro conditions. While some have concluded that this higher frequency is due to influence of storage medium (Gittner, Muller-Hartwich & Jost-Brinkmann, 2010), others have attributed in vitro enamel fracture rates as high as 50% in a single group to excessive enamel stresses during extraction (Fernandes et al., 2012). As the relationship between SBS and enamel fracture is not immediately apparent, clinicians should always discuss the possibility of enamel fracture with patients during informed consent whenever any type of orthodontic bonding is to be done.

## Limitations to this Study

Every sample in this present test was within or well above the suggested values of 5.9 and 7.8 MPa of shear bond strength as sufficient for clinically effective bonding (Reynolds, 1975). However, while in vitro studies allow for more standardized procedures by limiting variables, caution should be taken when interpreting absolute magnitudes of SBS of an artificial test environment and applying them to clinical settings. The substrate storage, length of storage, disinfecting solution, extra-oral bonding process, lack of periodontal ligament, crosshead speed, direction and magnitude of force are among the many artificial variables not experienced in vivo. Furthermore, comparing absolute magnitudes of SBS between other in vitro tests should be done with caution, since the variables differ from test to test. Extreme variety exists in SBS test setups, teeth, and bracket selections, making comparison across studies almost impossible (Akhoundi & Mojtahedzadeh, 2005). The main disadvantage of in vitro orthodontic bonding is that complete replication of in vivo conditions has not been possible yet (Akhoundi & Mojtahedzadeh, 2005). It should be pointed out that while in vivo randomized control trials can provide the most clinically relevant information, in vitro studies still hold great value for initial screening of products to be tested in a clinical setting, as well as actual measurement of SBS of adhesive products.

Currently, there is no standard protocol for evaluating shear bond strength in orthodontics like there exists an International Organization for Standardization (ISO) for Dental Materials – Testing of adhesion to tooth structure (2003). A reason for this lack of standardization is that there are multiple components involved in orthodontic bonding; whereas restorative adhesives can be tested on flat enamel surfaces, mimicking clinical orthodontic bonding requires adhering to the rounded buccal surfaces of teeth and involves the properties and complexities of the bracket base. All of this variability is further enhanced by the variety of products, both adhesives and brackets, available on the market. Unlike restorative testing of adhesives where bonding is meant to be permanent, orthodontic bond testing must consider that the attachments must be reversible, and no consensus has been made on the ideal bond strength. It is difficult to compare data across several studies due to these variables. While it is not feasible to compare absolute SBS values from 1 study to another, a systematic review on in vitro orthodontic bond strength revealed that 3 experimental conditions consistently and significantly affect in vitro bond strength testing; water storage decreased bond strength on average by 10.7 MPa, and each second of photopolymerization time and each millimeter per minute of greater crosshead speed increased bond strength by 0.077 and 1.3 MPa respectively (Finnema, Ozcan, Post, Ren, & Dijkstra, 2010).

In this study, efforts were made to best minimize the effects of these variables; however, there is currently no ideal substitute for mimicking an in vivo setting. Possible limitations in this in vitro study were:

**Initial storage solution:**

The initial storage solution in this study contained a 1:10 part solution of Acclean Chlorhexidine Gluconate 0.12% (Henry Schein, Melville, NY) and distilled water. A storage solution was needed to keep the samples hydrated as well as maintain a bacteriostatic environment when being collected, without alteration of the enamel. The mechanism of action of chlorohexidine is an immediate and short lived bactericidal effect, followed by a prolonged bacteriostatic action (Jenkins, Addy & Wade, 1988). Although no similar study to this current one had used such a solution for initial tooth storage, there were no significant differences in SBS when chlorohexidine mouth rinse had been applied to teeth prior to orthodontic bonding (Demir, Malkoc, Sengun, Koyuturk & Sener, 2005). This was consistent with a study that demonstrated that chlorohexidine varnish prior to etching did not significantly affect bond strengths (Bishara, Vonwald, Zamtua & Damon, 1998). However, despite these findings, the effects of long term storage with a diluted chlorohexidine solution do not replicate in vivo settings. One study found that various storage media may have effect on enamel fracture rate (Gittner et al., 2010). Their study found that a 0.1% thymol solution showed significantly less enamel fractures than teeth stored in 96% ethanol solution, and that the enamel fracture rate exhibited by the thymol group appears to be higher than that in vivo. This may help explain the occurrence of fractures in this study, although more investigation needs to be done on the effects of chlorohexidine in orthodontic adhesive studies.

**Disinfecting solution:**

Formalin is composed of formaldehyde, methyl alcohol and sodium acetate in water. Formalin is considered the only disinfectant solution that penetrates the pulp chamber of teeth and a minimum exposure time of 2 weeks is required (Tate & White, 1991). An alternative to this method is autoclaving of the tooth samples. One study found that formalin storage resulted in a lower microleakage of class V restorations than the control of distilled water, compared to a higher microleakage of those that were autoclaved (Attam, Talwar, Yadav, & Miglani, 2009). The effects of formalin on enamel in conjunction with orthodontic adhesives have not been seen in the literature. In addition, the carcinogenicity of formalin further enhances the artificial differences not experienced in vivo.

**Storage duration:**

The samples used in this study had varying times of storage duration in the initial storage solution (1 – 4 months) as well as in the post disinfection solution of distilled water (2-11 months). The reason for this discrepancy was the periodic but irregular collection of samples from multiple sources throughout the greater Las Vegas area, combined with the limited access to formalin for sterilization. One study found that there were no significant differences in SBS when bonding composite to enamel for specimens stored at 24 hours, 3 months, and 5 years (Williams & Svare, 1984). However, any type of storage does not truly imitate a tooth in the oral cavity, surrounded externally by saliva, crevicular fluid, and other oral fluids, and internally by a living neurovascular pulp.

**Teeth selection:**

Upper and lower premolars with intact buccal enamel were used for this study. Although a universal premolar bracket base was used, variation exists in the contour of these teeth between individuals. In addition, variation can occur within individuals between first and second premolars, as well as between upper and lower premolars. Linklater and Gordon (2001) concluded that the differences in shear bond strength found between different tooth types may relate to gross anatomical variability and that this highly variable morphology can demonstrate inconsistent adhesive film thickness. Variability is encountered regularly in a clinical situation, as the same shape bracket bases are used routinely for the same types of teeth and in different individuals.

It is important to note that the history of the tooth samples is unknown. Unless it was obvious to the investigator, the samples used for this study may contain premolars with a previous history of orthodontic bonding. Bonding to these teeth may more accurately represent a rebonding scenario. It has been shown that rebonded teeth have significantly lower and inconsistent shear bond strengths compared to new teeth (Bishara, Vonwald, Laffoon & Warren, 2000). In addition, teeth that were extracted may have abnormally high stresses applied to the enamel during the extraction process; this may explain why a higher amount of enamel fractures were seen when debonding than what might be observed clinically (Fernandes et al., 2012; Rix, Foley, & Mamandras, 2001). Also, instructions were given to the various clinicians to place the freshly extracted teeth in the initial storage solutions, which were provided by the investigator of this study. There may exist an unknown amount of instances where directions were not followed and teeth may have been allowed to dry or were treated with other disinfecting solutions without the investigator's knowledge.

**Extra oral bonding process:**

The bonding process was completed by one investigator for all 140 samples. In the absence of an oral cavity, the bonding represented an ideal isolation scenario. While this eliminates many variables, this experimental model may be different from in vivo bonding in some clinically significant ways. Since all of the flash was carefully removed with the aid of magnification to keep the amount of adhesive constant between samples, this may not always be possible in vivo. Extra adhesive, otherwise known as flash, may actually help in retention of the bracket by increasing the surface area of the attachment.

Clinicians tend to remove as much extra adhesive as possible, as it can negatively affect the gingiva and enamel by harboring plaque. In addition, the extra oral bonding allowed the investigator to have adequate access to light-cure the bracket base/adhesive system. The investigator was able to light-cure the mesial and distal sides of the bracket for the recommended amount of time without obstruction of teeth or other oral structures. Clinically, when light-cure access is perceived to be limited, some orthodontists light-cure these teeth longer. As was previously mentioned, bond strength increased by 0.077 MPa with each increase in seconds of light-curing (Finnema et al., 2010). In this present study, light intensity was checked periodically and revealed no loss of intensity. However, these periodic checks did not occur in regular intervals, and it is possible that fluctuations in light intensity may have occurred undetected. In addition, even in a theoretically perfect isolation environment, human error in the bonding process is always a possibility.

**Debonding procedure:**

In a true oral cavity, bond failure occurs as a result of a combination of shear, tensile and torsion forces in a dynamic masticatory complex. Among many other variables involved in vivo include non-stationary teeth bound by periodontal ligaments, orthodontic forces applied by the wire, and different types of food being chewed on. In this present study, shear forces were applied to a truly stationary tooth. Forces that would have otherwise been applied to the bracket or absorbed by components in the oral cavity are not present.

Unlike restorative shear tests, orthodontic shear tests typically involve a combination of shear and peel forces because the force is applied at a distance from the bonding interface (Klocke & Kahl-Nieke, 2005). A study by Klocke and Kahl-Nieke (2005) looking at the influence of force location achieved statistically different SBS when force application was changed from the base of the bracket, to the ligature groove, and to the bracket wings. Investigators in this present study chose to apply the force at the ligature groove, between the wings and base, for consistency, stability and accuracy. Applying the force at the bracket base may incur tooth contact, while force applied to the wings could result in some force absorbed by distortion of the wings. Any distance away from the tooth surface is not a purely shear force; however, whether the bracket base, ligature groove, or wings are used, studies still justify that the force applied is shear in nature, due to the parallel direction of force, proximity to the enamel surface, and testing feasibility.

Most orthodontic SBS tests in vitro are using very slow crosshead speeds to accurately and consistently collect data. It must be stressed that these crosshead speeds lack correspondence to clinical conditions. In this present study, a constant, unidirectional force of .01 in/min was applied to each sample. While some investigators found that crosshead speed variation between 0.1 and 5mm/min does not significantly influence SBS (Klocke & Kahl-Nieke, 2005), a recent systematic review found that each millimeter per minute of greater crosshead speed increased bond strength by 1.3 MPa (Finnema et al., 2010). Regardless of the speed chosen for SBS tests, caution must be taken when drawing clinical conclusions from in vitro models.

**ARI scoring:**

Many studies that have utilized the adhesive remnant index have looked at the adhesive remaining in the bracket only. By subtracting this adhesive percentage of the bracket from 100%, investigators are able to infer how much adhesive was left on the enamel. The reason for this method is the difficulty in determining adhesive margins on tooth structure due to color, and lack of a bracket base outline on the enamel surface to delineate the total area of adhesion. This present study looked at adhesive remnant for both bracket base and enamel. While this is one method to verify complimentary ARI scores between bracket base and enamel surface, this does increase the opportunity for human error. Under magnification, a scaler was used for detection of margins while a wire shaped into a bracket base outline demarcated the total area of the debonded attachment. The investigator of this study felt that this dual ARI score was more robust than previous utilizations of the index, since air voids and large cohesive fractures could be detected. There exist even more accurate methods to observe the adhesive remaining on enamel, such as 3-D scans of the teeth (Shamsi, Cunningham, Lamey, & Lynch, 2006). However, regardless of how the ARI is determined, the biggest disadvantage is the inability to determine fracture initiation and its progress during propagation. The ARI only details the final end result of failure.

The original iteration of the ARI as was described by Artun and Bergland (1984) used a 4-point scale for scoring no adhesive remaining on the tooth, less than 50%, more than 50%, and all the adhesive remaining on the tooth. While the advantage of this method is ease of scoring to the human eye, a large drawback is the inability to differentiate between samples with very little adhesive remaining on the surface, 10% for example, from samples that slightly less than 50% of adhesive remaining, which would both have received the same ARI score. In this present study, a 5-point scale was utilized to more accurately scale the ARI scores to represent differences in adhesive remnant remaining; thus, a sample having 10% of adhesive remaining, would receive a different score from a sample having 50% of adhesive remaining. It should be noted that the higher the point scale used, the more difficulty there is in quantitatively assigning a percentage and resulting ARI score.

**Limitations conclusions:**

With the wide variability of products and testing procedures, there is no overview on tests regarding bracket bond strengths from which general conclusions can be drawn (Finnema et al., 2010). Since there is a lack of standardization of orthodontic SBS testing, in vitro studies that are published can only be evaluated individually; this present study is no different. Even with the efforts to minimize limitations, it would be unreasonable to draw direct clinical conclusions from this in vitro study.

## Recommendations for Future Research

Although this present study did not find any significant increases in SBS of adhesion promoters with respect to their controls, there are many more avenues to explore. Testing Enhance$^{tm}$ LC or Assure $^{R}$ Universal Bonding Resin in similar conditions to this present study with different adhesion systems or bracket bases could reveal more information about their properties, performance and product compatibility. Replicating these testing conditions while modifying bonding protocol, such as etch time, light-cure time, and number of coats of adhesion promoter may shed more light on the results of this present study as well. One method that may reduce human variation in loading the brackets is to utilize a bracket system that is pre-coated with adhesives; the disadvantage, however, would be a more limited scope of products that can be tested, and an inability to test different adhesives with the same bracket base. Even though there appears to be some disagreement in previous in vitro studies whether or not Enhance$^{tm}$ LC increases SBS, it may be possible that this adhesion promoter has different effects in vivo from some clinical-specific variables that are not reproducible in a bench top model. Refining in vitro studies to more closely resemble the oral cavity will yield more clinically applicable results.

It should be noted that the manufacturer of Enhance$^{tm}$ LC or Assure $^{R}$ Universal Bonding Resin has claimed that enhanced bond strength can be achieved to a variety of surfaces; this present study utilized normal enamel only. Testing adhesion promoters in vitro to non-enamel surfaces, such as alloy, composite, and porcelain, may mimic clinical settings more accurately, since the major biological component of enamel and its variables are removed from the equation. Future studies such as these may more clearly define the strengths and weaknesses of adhesion promoters.

Of recent success has been Enhance$^{tm}$ LC's effect on fluorosed enamel (Adanir et al., 2009). Increased bond strengths to fluorosed and irregular enamel may be a niche for adhesion promoters if future studies continue to show success. More in-depth evaluation on these successes may clarify the behavior of adhesion promoters to normal enamel.

## Hypothesis Evaluation

The five null hypotheses of this study were derived from the secondary research questions. The research questions, null hypothesis and evaluation of the hypotheses are listed below. Statistical significance for determination of rejection or acceptance of the hypothesis was taken from the statistical comparisons.

1) Does Enhance$^{tm}$ LC increase bond strength compared to conventional bonding without an adhesion promoter?

Hypothesis:

Shear bond strengths using Enhance$^{tm}$ LC will be significantly higher than those achieved with conventional bonding without an adhesion promoter.

The hypothesis for question one is rejected, since no significant increase in SBS was demonstrated with the application of Enhance$^{tm}$ LC in either adhesive system.

2) Does Assure $^{R}$ Universal Bonding Resin increase bond strength compared to conventional bonding without an adhesion promoter?

Hypothesis:

Shear bond strengths using Assure $^{R}$ Universal Bonding Resin will be significantly higher than those achieved with conventional bonding without an adhesion promoter.

The hypothesis for question two is rejected, since no significant increase in SBS was demonstrated with the application of Assure $^{R}$ Universal Bonding Resin in either adhesive system.

3) How does shear bond strength using Enhance$^{tm}$ LC compare to bonding utilizing Assure $^{R}$?

Hypothesis:

Shear bond strengths using Enhance$^{tm}$ LC will be similar to those achieved when bonding with Assure $^{R}$ Universal Bonding Resin.

The hypothesis for question three is accepted, since no significant differences in SBS were demonstrated between groups bonded with Enhance$^{tm}$ LC and groups bonded with Assure $^{R}$ Universal Bonding Resin.

4) Does Enhance$^{tm}$ LC or Assure $^{R}$ Universal Bonding Resin demonstrate a preference for one adhesive system over another – Transbond $^{tm}$ XT or Light Bond $^{tm}$?

Hypothesis:

Both Enhance$^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin will be adhesive specific to the Light Bond $^{tm}$ system and show higher bond strengths than with those using the Transbond $^{tm}$ XT adhesive system.

The hypothesis for question four is rejected, since neither Enhance$^{tm}$ LC nor Assure $^{R}$ Universal Bonding Resin showed a significant increase and subsequent preference for an adhesive system.

5) How does Enhance$^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin rate on the adhesive remnant index compared to non-adhesion promoter bonding?

Hypothesis:

Bonding with Enhance$^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin will have similar ARI values with each other, with more adhesive remaining on the tooth surface compared to bonding without the use of an adhesion promoter.

The hypothesis for question five is rejected, since groups bonded with Assure $^{R}$ Universal Bonding Resin had significantly more adhesive remaining on the tooth surface than groups bonded with Enhance$^{tm}$ LC and groups without an adhesion promoter.

## Conclusions

1) The application of adhesion promoters, Enhance$^{tm}$ LC and Assure $^{R}$ Universal Bonding Resin, did not demonstrate a significant increase in SBS compared to non-adhesion promoter bonding with either adhesive system (Transbond $^{tm}$ XT and Light Bond$^{tm}$). Shear bond strengths with the self-etching primer were comparable to conventional bonding with and without adhesion promoters.

2) The adhesion promoters did not demonstrate a material-specific predilection for one adhesive system over another.

3) The self-etching primer group, as well as groups bonded with Assure $^{R}$ Universal Bonding Resin had significantly higher ARI scores than control groups and groups bonded with Enhance$^{tm}$ LC, signifying more adhesive remnant left on the tooth following debonding, requiring more adhesive removal.

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