Evaluation of Shear/Peel Bond Strengths of Orthodontic Attachments to Moist and Dry Enamel

BY

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A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfillment of the Requirements
for the Degree of

Master of Science

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THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES

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ABSTRACT

The purpose of this study was to evaluate the shear-peel bond strengths of orthodontic attachments bonded to enamel surfaces under varying conditions. A light-cured composite adhesive was compared to a cyanoacrylate adhesive and a composite hybrid adhesive. All enamel surfaces were etched and bonded either in moist or dry conditions according to the manufactures' instructions. Sixty, third molars were collected and mounted into cylindrical molds with a self-cured acrylic resin. All of the enamel specimens were cleansed and polished with nonfluoridated pumice (Preppies™, Whip Mix® Cooperation) and rubber prophylatic cups for 10 seconds. The teeth were then etched with phosphoric acid. Bondable orthodontic buttons with a known base surface area were bonded with Transbond™ XT [control](3M/Unitek), Smartbond® (Gestenco) or Assure™ (Reliance). The buttons were bonded according to the adhesive manufacturers' instructions. Half of the specimens (30 teeth, 60 buttons) were bonded under moist conditions (a thin layer of whole, unstimulated, fresh human saliva was applied prior to bonding) and half (30 teeth, 60 buttons) were bonded under dry (nonsaliva contaminated) conditions. The specimens were divided into six groups as follows: Group I.-20 bonded buttons under saliva contaminated conditions with Transbond™ XT, Group II.-20 bonded buttons under nonsaliva contaminated conditions with Transbond™ XT, Group III.-20 bonded buttons under saliva contaminated conditions with Smartbond®, Group IV.-20 bonded buttons under nonsaliva contaminated conditions with Smartbond®, Group V.-20 bonded buttons under saliva contaminated conditions with Assure™, Group VI.-20 bonded buttons under nonsaliva contaminated conditions with Assure™. The teeth were stored for 24 hours and 6 months at 37 °C in distilled deionized water. Once storage was complete, each sample was tested for shear-peel strength in a Zwick Materials Testing Machine Model #1445 (Zwick GmbH & Co., Ulm, Germany). The residual adhesive on the enamel surface was evaluated by two examiners (to assure interexaminer reliability) with the Adhesive Remnant Index (ARI) after debonding. The descriptive statistics, including the mean, standard deviation and minimum and maximum values for each of the six groups were recorded. A one-tailed analysis of variance (ANOVA) and a Tukey's multiple range test was used to analyze the data of the shear bond strength as a function of the adhesive type and surface condition at a 5% level of significance. A repeated measures ANOVA at the 5% level of significance was used to analyze the 24 hour and 6 month data. The shear-peel bond strengths in this study are stated as 24 hours vs. 6 months and were as follows: Transbond™ XT/dry (10.57 ± 2.83 MPa vs 12.23 ± 3.14 MPa), Assure™/dry (6.93 ± 2.2 MPa vs 8.18 ± 1.39 MPa), Smartbond®/dry (3.91 ± 1.17 MPa vs 4.11 ± 1.96 MPa), Transbond™ XT/moist (0.14 ± 0.31 MPa vs 0 ± 0 MPa), Assure™/moist (6.03 ± 1.77 MPa vs 6.86 ± 2.81 MPa), and Smartbond®/moist (3.22 ± 0.52 MPa vs 2.4 ± 0.96 MPa). There was a statistically significant difference ($p<0.05$) between 1) the different adhesives 2) the dry and moist conditions of Transbond™ XT. There was no statistically significant difference ($p>0.05$) between 1) the dry and moist conditions of Assure™ and Smartbond® 2) the 24 hour and 6 month time frame for all adhesives.

Key Words: Orthodontic Bonding, Sheer-Peel Bond Strength

Dedication

This thesis is dedicated

to

my wife Kari

and

my parents

Bob and Marianne.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation and gratitude to all individuals involved in making this project possible, particularly to:

My thesis advisors Dr. W.A. Wiltshire (Supervisor), Section of Orthodontics, University of Manitoba, Dr. T.D. Dumore (Internal Examiner), Section of Orthodontics, University of Manitoba, Dr. C.L.B. Lavelle (External Examiner), Department of Oral Biology, University of Manitoba.

Dr. P.T. Williams for his expert assistance with the experimental design.

Dr. P.J. Martins for her expert assistance with the statistical analysis.

My classmates and friends, Dr. Chris Woolaver and Dr. Brent Nickolaychuk.

3M Canada for donating the Transbond™ XT.

Gestenco for donating the Smartbond®.

Reliance for donating the Assure™.

GAC Canada for donating the bondable lingual buttons used in this study.

CONTENTS **Page Number**

2.1 Orthodontic Bonding

4.1 Shear-peel Bond Strengths

List of Figures **Page Number**

List of Tables **Page Number**

CHAPTER 1

INTRODUCTION

1.1 Foreword

Over the past twenty years there has been a shift in orthodontics from cemented bands to bonded brackets. Through the development of the acid etch technique (Buonocore, 1955), bonding brackets to enamel is possible with composite resins (Newman, 1965). Buonocore introduced the concept of bonding restorative materials to enamel by etching the enamel surface with 85% orthophosphoric acid (H_3PO_4).

The acid etch technique is widely used in clinical dentistry to restore fractured incisal edges, cervical abrasions, decay, and seal the caries susceptible occlusal surfaces of teeth (Proffit, 2000). This technique was first suggested for orthodontic use by Newman (1965) and is now widely accepted because there is less risk of enamel decalcification, less discomfort (no band seating or separation), easier plaque control, decreased irritation of the gingival tissues, improved esthetics, arch length is not increased, partially erupted teeth can be readily bonded, mesiodistal enamel reduction is possible during treatment, there are no band spaces to close at the end of treatment, lingual ("invisible braces") can be used, it is faster and simpler, it is easier to detect and treat dental caries, pretreatment separation of the teeth is eliminated, and chairside time is decreased. (Newman, 1964; Newman, 1965; Graber and Vanarsdall, 1994 a; Bishara et al, 1998 b)

The literature has reported that the bond strength values vary for adhesion of orthodontic brackets to enamel, but suggests that values greater than 5 MPa are suggested to be adequate for bonding (Reynolds, 1975; Proffit, Fields and Nixon, 1983; Reynolds and Von Fraunhofer, 1976; Bishara et al, 1998 b).

1.2 Motivation for this study

Clinical improvements from direct orthodontic bonding are the reduction of white spot lesions and the tolerance to moisture contamination during bonding to reduce the incidence of bond failures (Bishara et al, 1998 b). Previously, for composite resins to bond properly by the acid etch technique a dry field had to be maintained during bonding. Molar bonding has become more common, but the difficulty in maintaining a dry field remains a problem (Bishara et al, 1998 b). Orthodontists have been searching for new materials that do not require a dry field for bonding, which would simplify orthodontic bonding procedures chairside. Recently there have been a few new bonding agents (Smartbond®, Gestenco International, Goteborg, Sweden; Assure ™, Reliance Orthodontic Products, Inc., IL) released that manufactures claim do not require a dry field to yield sufficient bond strengths in orthodontics.

1.3 Purpose of this study

The purpose of this study was to evaluate the shear bond strengths of orthodontic attachments bonded to human enamel surfaces under varying conditions (saliva contaminated or nonsaliva contaminated). This evaluation will give the clinician an indication of which adhesive will produce a higher bond strength to human enamel under saliva contaminated conditions. A light-cured resin composite adhesive (Transbond™ XT (3M/Unitek, Monrovia, CA)) was compared to a cyanoacrylate adhesive (Smartbond® (Gestenco International, Goteborg, Sweden)) and a poly-acid modified composite adhesive (Assure ™ (Reliance Orthodontic Products, Inc., IL)). All enamel surfaces were etched and bonded either in moist (saliva contaminated) or dry (nonsaliva contaminated) conditions and the bond strengths were compared *in vitro*.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1 Orthodontic Bonding

2.1.1 Orthodontic bond strength

Orthodontic attachments must be able to withstand the forces (shear, shear-peel, tensile, and torsional) involved during orthodontic treatment. These include the patients' functional stresses, such as occlusion and mastication; and the operator forces, such those obtained from the orthodontic appliances. The orthodontist is not only concerned with whether or not the attachment will debond during treatment, but also the potential damage to the enamel that may occur when the attachment is debonded at the end of treatment. Bonding of orthodontic attachments to teeth is therefore a temporary procedure and upon the completion of treatment, the attachments must be removed without enamel damage. This is best achieved with a low bond strength, which is below the value where enamel fractures normally occur and has been reported to be as low as 13.8 MPa (Retief, 1974; Powers, Hwa-Bong, and Turner, 1997).

In vivo bond strength testing of orthodontic attachments to human enamel has been attempted, with only very limited success, due to the cumbersome use of dynamometers, difficulty in obtaining accurate measurements, and uncontrolled oral conditions eg. Saliva (Voss, Hickel, and Molkner, 1993). *In vitro* testing allows for more accurate and sensitive equipment to measure bond strength (Retief, 1991). In order to evaluate the bond strength of a particular bonding system, one must use an *in vitro* model although the results need ultimately to be confirmed *in vivo*. This *in vitro* model is preformed in a laboratory, where testing indicates the potential success of a bonding system *in vivo* by quantifying the strength of the system. (Retief, 1991)

The classical *in vitro* model (isolated substrate model for bond strength testing in orthodontics) involves bonding orthodontic attachments to extracted human teeth so that the adhesives or brackets can be studied independently (Powers, Hwa-Bong, and Turner, 1997). *In vitro* models play an important role in characterizing the bonding potential of new systems (Powers, Hwa-Bong, and Turner, 1997). Once cemented, the attachment may then be debonded using a universal testing machine. It is important to know the surface area of the attachment in order to obtain the bond strength, (ie. bond strength= the bond force divided by the area of the bonded interface). If the force, in Newtons, required to debond the attachment is divided by the surface area of the attachment (mm^2), the bond strength is given as N/mm^2 =MPa (megapascals). This value can then be compared to those from other studies, although the results are not exclusive. If the surface area is not taken into account, the data collected by one particular study can only be compared with the other materials in the same study and cannot be compared directly to standards or other studies.

Different types of bond strengths have been reported in the literature, where the forces include those of shear, tensile, torsional, and shear-peel (Ostertag et al, 1991; Powers, Hwa-Bong, and Turner, 1997). When reporting results of a laboratory study, the method of debonding used must be noted, since there are four discrete types of bond strengths:

Shear Bond Strength

When testing shear bond strength, a direct debonding force is applied parallel to the junction of the attachment and adhesive, "pushing" the attachment away from the adhesive interfaces. Clinically and experimentally, the debond force is most often applied, at least in part, to the attachment which transduces the force through the attachment, adhesive and enamel interfaces. True, pure shear bond strength is therefore impossible to determine in a practical and accurate manner. The results for this test are recorded in N/mm^2=MPa. (Fox, McCabe, and Buckley, 1994; Katona, 1994; Eliades and Brantley, 2000)

Shear-Peel Bond Strength

When testing shear-peel bond strength, a debonding force is applied at some distance from, but parallel to, the adhesive-attachment interface. This method results in a debond force being applied to the attachment, which transduces the force through the attachment, adhesive, and enamel interfaces. As a result, shear stress and peel force are applied to the adhesive and enamel interfaces. The amount of shear and peel thus depends on the distance the force is applied from the adhesive-attachment interfaces. It is difficult to quantify the amount of shear force and the amount of peel force being applied to the interfaces, in that many reported shear bond strengths are in fact shear-peel bond strengths. The results for this test are recorded in N/mm^2=MPa (Katona, 1994; Katona, 1997; Eliades and Brantley, 2000).

Tensile Bond Strength

When testing tensile bond strength, a debonding force is applied parallel to the enamel surface, "pulling" the attachment away from the adhesive interfaces. Again, when tensile bond strengths are reported, they are in fact tensile-peel bond strengths. Tensile-peel and shear-peel bond strengths are considered equivalent (Katona, 1997). The results for this test are recorded in N/mm^2=MPa (Katona, 1997; Thomas, de Rijik, and Evans, 1999; Eliades and Brantley, 2000).

Torsional Bond Strength

When testing torsional bond strength, a debonding force is applied in a torquing manner, "twisting" the attachment off at the adhesive-attachment interfaces. This method is less favorable due to the inability of most of the mechanical testing machines to evaluate such a parameter. The results of this test are recorded in N/m, and cannot be compared to shear, shear-peel, or tensile strengths (Katona, 1997; Eliades and Brantley, 2000).

Many researchers and orthodontists have criticized *in vitro* testing for not accurately reflecting the clinical debonding in an *in vivo* environment. It is important to remember that laboratory testing can give an indication of the potential clinical success of a bonding system *in vivo* by quantifying the bond strength of the system. (Solderholm, 1991; Fox, McCabe, and Buckley 1994; Katona, 1997; Powers, Hwa-Bong, and Turner, 1997)

As in all laboratory testing, care must be taken to control as many variables as possible. These variables include: type of tooth, fluoride content, storage medium, type of loading (debonding), crosshead speed, type of attachment, type of attachment base, bonding area of the attachment and storage duration. As a result, the ISO has provided guidelines on testing adhesion to tooth structure (ISO, 1994), although they are not universally accepted. First, tooth selection (bovine, human), storage (deionized water, ethyl alcohol, thymol), and preparation (ground or unground, % of phosphoric acid) differ among studies (Bishara et al., 1993; Bryant et al., 1987). Second, testing conditions (cross head speed (0.5 mm/min., .02 in/min, .05 in/min)) and application of force (bracket, bracket/adhesive interface) differ among studies (Bishara, Fehr, and Jakobsen, 1993; Bryant et al., 1987, Alexandre et al., 1981). Finally, data analysis and presentation (units (N/mm^2, kg/cm^2, Newtons), statistical analysis) differ among studies (Bishara, Fehr, and Jakobsen, 1993; Bryant et al., 1987, Alexandre et al., 1981). This makes it difficult to compare the results of one study to the results of others. Caution is therefore required when comparing the results of studies due the lack of standardized testing conditions (Eliades and Brantley, 2000).

2.1.2 Minimum bond strength

A bond strength from an *in vitro* study is of more value, since it can be correlated to a "acceptable" bond strength for clinical use. An acceptable range of bond strengths should be high enough so that inadvertent debonding during treatment should not occur, but low enough so when purposely debonded, it is easy to clean without damage to the enamel or any restorations. When obtaining *in vitro* bond strengths, the numbers are more meaningful when compared to that considered "acceptable" for an orthodontic attachment. It has been postulated that an acceptable minimum tensile bond strength to human etched enamel is in the range of 5.9 to 7.9 MPa (Reynolds, 1975; Reynolds and von Fraunhofer, 1976). Reynolds (1975), does not state any scientific data or method for deriving these values. Nonetheless, the minimum bond strength value of 6 to 8 MPa for shear, shear-peel and tensile-peel is reported in most of the literature (Reynolds, 1975; Greenlaw, Way, and Galil, 1989; Whitlock et al, 1994, Bishara, Fehr, and Jakobsen, 1993). Torsional bond strengths are reported in N and become N/m when divided by the attachment base area, which facilitates comparisons with the other types of *in vitro* debonding (Katona, 1997).

According to Powers, Hwa-Bong, and Turner (1997), the typical bracket has a nominal bonding area of 16 mm^2. They also state that the average force reported during mastication is between 40 and 120 N, thus the adhesive-bracket system should be able to withstand an applied stress of 6 to 8 MPa (Powers, Hwa-Bong, and Turner, 1997).

2.1.3 Maximum bond strength

Stronger bond strengths are not always the ultimate goal, in that there is a point at which the bond strengths become too high and cause enamel damage upon debonding. As the bond strength of the enamel-adhesive interface increases, the potential for damaged enamel surfaces on debonding also increases (Kusy, 1994). Enamel fractures have been reported in the literature with bond strengths as low as 13.8 MPa (Retief, 1974).

2.1.4 Bond Failure Location

Clinically, bond failure location of debonded orthodontic brackets is also important. If the bond failure location can be limited to the bracket and adhesive interface, enamel damage would be eliminated. The problem with this location is that more adhesive will remain on the tooth surface and therefore will necessitate more clean-up. The ideal clinical location, as far as clean-up is concerned, is the enamel and adhesive interface, but this location can also contribute to enamel fracture. Having minimal adhesive remaining on the tooth after debonding makes clean-up more efficient, but it exposes the tooth to higher incidences of damage. The bond failure sites can be measured using scales such as the Adhesive Remnant Index, which quantifies the amount of resin remaining on the tooth. (Powers, Hwa-Bong, and Turner, 1997)

The Adhesive Remnant Index (ARI) (Oliver, 1988) was developed to evaluate the enamel, adhesive, and attachment interfaces. The enamel surface is observed under a stereomicroscope at 20x magnification and assigned a rating that ranges from 1 to 5 (Table 1.1).

Table 1.1: *Adhesive Remnant Index (Oliver, 1988):*

ARI SCORE	DESCRIPTION
Score 1	*indicates that 100% of the composite remained on the enamel surface*
Score 2	*more than 90% of the composite remained on the enamel surface*
Score 3	*more than 10% and less than 90% of the composite remained on the enamel surface*
Score 4	*less than 10% of the composite remained on the enamel surface*
Score 5	*no composite remained on the enamel surface*

Acceptable or unacceptable ARI scores are controversial in that such scores are comprised of complex definitions of bond failures between the enamel, adhesive, and bracket base (Bishara et al, 1998 b).

2.2 Enamel Bonding

The development of the acid etch technique by Buonocore (1955) led to the direct bonding of orthodontic brackets with composite resin (Buonocore, 1963). Bonding to enamel relies on micro-mechanical interlocking, which is dependant on the undercuts of the attachment base and the enamel surface. Therefore, successful bonding in orthodontics requires careful attention to the tooth surface and its preparation, the design and type of the attachment base, and the bonding material itself. (Proffit, 2000; Eliades and Brantley, 2000)

Before bonding an orthodontic attachment, the enamel surface is prepared by the removal of surface contaminants so that an adequate bonding surface is obtained. The surface is usually pumiced to remove any surface contaminants and then etched with 20-50% phosphoric acid for at least 10 seconds (Zidan and Hill, 1986; Baharav et al, 1988; Bishara et al, 1998 a). Because longer etching times have proven to be counter productive, bond strengths are not improved by increasing the etching times (Kinch et al, 1988; Surmont et al, 1992; Olsen, Bishara, and Boyer, 1996). Similar penetration of enamel has been observed for liquid and gel etching agents (Baharav et al, 1988). Phosphoric acid removes a small amount of the softer interprismatic enamel and opens the pores between the enamel prisms. This allows the adhesive or bonding agent to penetrate the enamel surface, where penetration into the enamel irregularities creates a micro-mechanical bond (Baharav et al, 1988; Proffit, 2000; Graber and Vanarsdall, 1994 b).

Enamel, when examined by scanning electron microscopy (SEM), is described as having a featureless appearance with faint abrasion marks on the surface (Silverstone, 1974). Upon etching, a loss of a few microns of tissue substance takes place at the rod core, rod periphery, or a random loss of tissue substance takes place without prism dilineation (Silverstone, 1974, Silverstone et al., 1975). These three different methods of enamel tissue substance loss were classified by Silverstone et al (1975), as Types 1, 2, and 3 etching patterns respectively. Silverstone et al. (1975) studied the enamel surface of etched (unbuffered phosphoric acid 20-70% for 1-10 minutes) human enamel *in vitro* with SEM. In Type 1 etching pattern, the prism core material is preferentially removed, leaving the prism peripheries relatively intact. This results in a "honeycomb" appearance. Type 2 etching pattern results when the reverse pattern of Type 1 is observed. The peripheral regions of the prism are removed preferentially, leaving the prism cores remaining relatively unaffected. This results in a "cobblestone" appearance. In Type 3 etching pattern, there is a random pattern. Dissolution of the enamel occurs without delineation of the enamel prisms. Both Types 1 and 2 etching patterns are observed, along with regions in which the pattern of etching could not be related to prism morphology. This results in a "sandy" appearance. Silverstone et al. (1975) consider the Type 1 etching pattern to be the most common and retentive. All three of the etching patterns are often observed in adjacent areas of the same tooth produced by a single etching solution (Silverstone et al., 1975).

Not only must the tooth surface be capable of the micro-mechanical bonding, so must the base of the orthodontic attachment. Manufactures create mechanical interlocking capabilities of the attachment base with a fine wire mesh welded or cast to the bases of stainless steel attachments, or mechanically forming or casting undercuts to ceramic and plastic brackets. In contrast, chemical bonding can be created to ceramic brackets with the use of a silane coupling agent. (Maijer and Smith 1981; Proffit, 2000; Graber and Vanarsdall, 1994 d)

In order for adhesives used in orthodontics to be successful, they must be a) dimensionally stable; moderately viscous, so that it is capable of flowing into the undercuts in the base and the enamel; b) have sufficient tensile and compressive strengths to resist failure due to orthodontic forces; c) have the ability to wet the etched surface; nontoxic; d) have adequate working time and setting time, and be easy to use clinically. The manufacturers of orthodontic adhesives are continually trying to improve them and their properties, such as fluoride release, cost, bonding under contaminated conditions, bond strength, handling, and bonding to unetched enamel (Sheykholeslam and Brandt, 1977; Graber and Vanarsdall, 1994 c).

2.3 Bonding materials

Currently there are many different orthodontic adhesive bonding systems available. These systems can be broadly classified into five groups:

Resin Composites: Commercially available examples are Concise™ and Transbond™ XT (3M,Unitek), where the setting reaction takes place by free radial polymerization (Lloyd and Scrimgeour, 1993). These materials are available in either a two-paste chemical cure system (Concise™) or a one-paste light cure system with a bonding primer (Transbond™ XT). Also available are a one paste contact adhesive (right On) and powder/liquid acrylic system (Super C).

Glass-ionomers: A commercially available example is Fuji, which was first introduced by Wilson and Kent in 1972. The setting reaction takes place by an acid-base reaction in an aqueous phase (Mount, 1995), which has the benefits of chemical adhesion to tooth structure and fluoride leaching capabilities (Chadwick and Gordon, 1995). This material is available in powder and liquid form.

Resin-reinforced glass-ionomers: Commercially available is Fuji Ortho LC (GC). The setting reaction can be both chemical (acid-base reaction and the polymerization of a chemically activated resin, if in the aqueous phase) and light polymerization. This material is available in a powder and liquid form (Sidhu and Watson, 1995; Combe, Burke, and Douglas, 1999 c).

Poly-acid modified composite resins: Commercially available are Compoglass (Vivadent) and Assure™ where the setting reaction is chemical polymerization. This material is available as a one-paste system with a bonding primer in which the resins are "Compomers", ie composite resins containing some of the glass-ionomer constituents in the resin monomer which forms the matrix without the aqueous phase (Sidhu and Watson, 1995, Combe, Burke, and Douglas, 1999 f).

Cyanoacrylate adhesives: Commercially available is Smartbond® (Gestenco International, Goteborg, Sweden) which is a cyanoactylate ester. The setting reaction takes place through anionic polymerization (Combe, Burke, and Douglas, 1999 a).

2.3.1 Resin Composite Bonding Systems

A composite material is defined as a unified combination of two or more materials which are designed to have superior properties over the individual components. Composite resins are composed of: principal (high molecular weight) monomers, dilutent (low molecular weight) monomers, inorganic fillers, silane coupling agents, polymerization inhibitors, initiator/activator components, and ultra violet stabilizers. The setting reaction can be either chemical-cure or light-cure. (Combe, Burke, and Douglas, 1999 d)

The two-paste chemical cure composite orthodontic bonding system, Concise™ (3M, St. Paul, MN), is routinely used for bonding brackets and lingual retainers. Several researchers have studied the shear bond strength of orthodontic Concise™ to enamel. For instance, Surmont et al (1992) and Coriel et al (1990) reported Concise™ to have a shear bond strength to etched enamel of 16.7 ±3.7 MPa and 20.13 ± 4.98 MPa respectively. Chemically, Concise™ orthodontic is composed of 76% silanated quartz and submicron silica fillers, 17% 2,2-bis[4(2-hydroxy-3-methacryloyloxy-propyloxy)-phenyl] propane (BisGMA), 6% triethylene-glycol-dimethacrylate (TEGDMA) and <1% miscellaneous constituents such as peroxides, amine activators and quinines. (Material Safety Data Sheet c)

The one-paste light cure Bis-GMA resin system, Transbond™ XT (3M/ Unitek, Monrovia, CA) is also routinely used for bonding brackets and lingual retainers. Several researchers have studied Transbond™ XT's shear bond strength to enamel (McCourt, Cooley, and Barnwell, 1991; Martin and Garcia-Godoy, 1994). Since its introduction in 1994, several researchers have found it to have acceptable shear bond strengths to enamel *in vitro* (McCourt, Cooley, and Barnwell, 1991; Martin and Garcia-Godoy, 1994). Martin and Garcia-Godoy (1994) reported Transbond™ XT to have a mean shear bond strength to etched enamel of 19.6 ± 9.6 MPa for metal brackets and 28.8 ± 12.6 MPa for ceramic brackets. McCourt, Cooley, and Barnwell (1991) reported Transbond™ XT to have a shear bond strength to etched enamel at 24 hours of 11.35 ± 2.95 MPa. Chemically, Transbond™ XT is comprised of 76% 2,2-bis[4(2-hydroxy-3-methacryloyloxy-propyloxy)-phenyl] propane (BisGMA), 9% triethylene-glycol-dimethacrylate (TEGDMA) and <1% of miscellaneous constituents such as peroxides, amine activators and light activated quinines. (Material Safety Data Sheet d, Material Safety Data Sheet e)

To initiate the polymerization reaction, the activation system requires an initiator and an activator. The initiator breaks down to produce free radicals capable of breaking the double bonds of other compounds which results in cross-linking of the molecules {Benzoyl Peroxide ($C_6H_5COO\text{-}OOCC_6H_5$) breaks down into a free radical $2(C_6H_5COO)$ and then into $C_6H_5 + CO_2$}. In this system, visible light initiates free radicals. The photoinitiator molecule (camphoroquinone) and the amine activator (Diethyl-amino-ethyl-methactylate) are both contained in the paste. For the chemically activated composite resin systems, tertiary amine (N-N dimethyl-p-touidine) activator causes the decomposition of benzoyle peroxide and initiates polymerization. The initiator is in the polymer and the activator along with an inhibitor (hydroquinone) is in the monomer. (Combe, Burke, and Douglas, 1999 d)

There have been several studies that compare the shear bond strengths of chemical and light-cured composite resin systems. (Behrents et al, 1987; Greenlaw, Way and Galil, 1989; King et al, 1989; Bradburn and Pender, 1992; Wang and Meng, 1992; Chamda and Stein, 1996) Some of the studies found that the bond strengths achieved by the light-cured system were comparable to the chemically cured systems *in vitro* (Wang and Meng, 1992; Behrents et al, 1987; Chamda and Stein, 1996).

Wang and Meng (1992), compared the shear bond strength of Concise™ to Transbond™ XT at three different light intervals of 20, 40 and 60 seconds with constant etchant concentration (phosphoric acid gel, concentration not listed) and etching time (15 seconds) to etched human enamel. They found that Transbond™ XT cured for 40 and 60 seconds had values of 9.02 ± 1.0 MPa and 10.5 ± 2.2 MPa respectively. The results of this study suggest that bond strengths of light-cured Transbond™ XT, excluding the cases with the light exposure of 20 seconds (6.1 ± 1.1 MPa), were stronger than that of chemical-cured Concise™ (7.1 ± 1.4 MPa).

Behrents et al (1987), found the bond strengths to enamel of various light-cured resins to be clinically comparable to those obtained with chemical-cured systems. This was a clinical study, in which Heliosit Orthodontic composite resin was used to bond attachment bases used on the lingual of etched teeth *in vivo* and bonded through transillumination. This was compared to their clinical experience with chemically cured agents. Chamda and Stein (1996), found that the sheer-peel bond strengths for the chemical-cured system (Concise) were initially low, but these increased with time. Results were as follows: 2 minutes- 0.93 ± 0.59 MPa, 5 minutes- 4.11 ± 0.67 MPa, 10 minutes- 5.76 ± 2.01 MPa, 60 minutes- 9.57 ± 2.39 MPa, and 24 hours- 10.03 ± 3.28 MPa. The light-cured samples (Transbond) displayed initial bond strengths of sufficient magnitude. Results were as follows: 2 minutes- 6.50 ± 1.13 MPa, 5 minutes- 7.07 ± 1.74

MPa, 10 minutes- 7.08 ± 1.76 MPa, 60 minutes- 8.38 ± 1.48 MPa, and 24 hours- 11.46 ± 2.49 MPa. There was no significant difference ($p>0.05$) in shear-peel bond strengths achieved with both systems at the 10 minute, 60 minute and 24 hour intervals.

King et al (1987), found that although it is possible to use transillumination to bond metal orthodontic brackets to etched (37% phosphoric acid for 60 seconds) bovine teeth, the 24 hour bond strengths produced by the light-cure systems were lower than those produced by chemical-cure systems. The chemically cured composite resins were right On and Concise and they exhibited mean shear bond strengths of 66 ±10 kg/cm^2 and 61 ± 7 kg/cm^2 respectively. The light-cured composite resins were Silux, Heliosit, and Heliosit Orthodontic. They exhibited mean shear bond strengths of 56 ±10 kg/cm^2, 49 ± 9 kg/cm^2, and 57 ±11 kg/cm^2 respectively. Greenlaw, Way, and Galil (1989), compared the bond strengths of both chemical-cure and light-cure systems to human etched enamel with metal brackets (43% phosphoric acid gel for 60 seconds) 1 hour and 30 hours after setting. They found that the average shear bond strengths for the light-cured resin (Heliosit Ortho, 1 hour-16.9 ± 3.5 kg/cm^2;30 hour-66.3 ± 10.6 kg/cm^2) was 50% less than those for chemically-cured system (Unite, 30-hour 142 ± 26.9 kg/cm^2). Despite the lower bond strengths for the light-cured system, Greenlaw, Way, and Galil (1989) supported the assertion by Reynolds (1975), that an *in vitro* bond strength of 5.9 to 7.9 MPa would be sufficient for clinical applications (fixed orthodontic procedures), which both achieved.

2.3.2 Glass ionomers

Glass ionomer (polyalkenoate) cements contain ion leachable glass (usually fluoroaluminosilicate, FAS glass), which can react with water-soluble polymeric acid to yield a cement (Combe, Burke, and Douglas, 1999 b). In the glass structure, alumina enters the silica network (Combe, Burke, and Douglas, 1999 b). The ratio of Al_2O_3 to SiO_2 is critical to produce the correct reactivity. This cement sets with an acid-base reaction. Glass ionomer cements have shown poor bond strengths to etched human enamel with metal brackets in the range of 2.37 ± 1.0 MPa to 5.5 ± 2.2 MPa (Fajen et al, 1990; Wiltshire, 1994). These low bonds strengths also result in greater failure rates (Miguel, Almeida, and Chevitarese, 1995). Miguel, Almeida, and Chevitarese (1995), found a failure rate of 50.89% for glass ionomer (Ketac-Cem), compared to a failure rate of 7.96% for composite (Concise) over the course of one year. Both were bonded with metal brackets to etched human enamel (37% phosphoric acid for 60 seconds). Norevall, Marcusson, and Persson (1996), reported a failure rate, *in vivo,* of 36% for glass ionomer (AquaCem) bonded brackets to etched human enamel (37% phosphoric acid for 30 seconds) and a failure rate of 15% for composite (Unite) bonded brackets to etched human enamel (37% phosphoric acid for 30 seconds). Miller et al (1996), reported a similar failure rate over three years of 33% for glass ionomer (Ketac-fil) and 15 % for composite (Rely-a-bond) bonded to metal brackets on etched human enamel (polyacrylic acid of an unknown % for 10 seconds). The disadvantages of extra bracket failures appears to outweigh the potential advantages when considering glass ionomer cement for the routine bonding of orthodontic brackets (Miller et al, 1996). It has however, lead to adhesive systems that take advantage of what glass ionomers have to offer. Resin modified glass ionomers are one example of an adhesive system that takes advantage of fluoride release and chemical adhesion (Wilson and Kent, 1972).

Some case reports and studies have suggested that glass-ionomer cements could be used in moist conditions, in the absence of etching (Cacciafesta et al, 1998; Silverman et al, 1995; Cook, 1990). Bishara et al (1998 b) concluded that with unetched human enamel, the shear bond strength *in vitro* (2000 cycles of thermal cycling between 5°C ± 2 and 50°C ± 2) of resin reinforced glass-ionomers is significantly reduced by one-third to one-half. They used Fuji Ortho LC adhesive system. The results were as follows: No etch+water= 3.5 ± 1.9 MPa, Etch (37% phosphoric acid gel for 30 seconds)+water= 8.1 ± 2.8 MPa, No etch+saliva= 5.8 ± 2.4 MPa, Etch (37% phosphoric acid gel for 30 seconds)+saliva= 7.3 ± 1.9 MPa. This reduction in bond strength is critical, because the residual bond strength might not be able to withstand the forces produced during routine clinical orthodontic procedures and mastication.

2.3.3 Resin-modified glass-ionomers

Resin-modified glass-ionomer materials were developed to overcome some of the problems of traditional glass-ionomers. They provide a potential solution to the problem of wettability and fluoride depletion (Cook, 1990; Graber and Vanarsdall, 1994 c). This material, invented by Wilson and Kent in 1972, is a hybrid of the silicate and polycarboxylate cements that bond physiochemically to both enamel and dentin, potentially eliminating the need for acid etching (Kent, Lewis, and Wilson, 1973). These materials are more hydrophilic than resin-based materials and are capable of tolerating moisture contamination (Sidhu and Watson, 1995). Additional advantages of orthodontic resin-based glass-ionomers include the release of fluoride ions over a period of time and the capability to absorb fluoride from sources of fluoride such as tooth pastes, stanneous and sodium fluoride, acting as rechargeable slow release fluoride devices (Cook and Youngson, 1988; Hatibovic-Kofman and Koch, 1991). Hatibovic-Kofman and Koch (1991), reported on glass ionomer (Vitrebond, Ketac-Fil, and ChemFill II) restorations placed in primary teeth of preschool children. These children had a salivary fluoride concentration of 0.04 ppm prior to the restorations being placed. After three weeks it had increased to 0.8 ppm and the level remained as high as 0.6 ppm even after 1 year. They also found that these glass ionomer cements showed the capacity to absorb fluoride from tooth paste and then release it. The levels after fluoride toothpaste exposure (at week 11) neared 24 hour values: Vitrebond(24 hour)-37.0 ± 2.1 ppm, week 11-1.1 ± 0.9 ppm, week 12 after exposure-31.3 ± 3.3 ppm, Ketac-Fil(24 hour)-18.9 ± 0.3 ppm, week 11-0.8 ± 0.2 ppm, week 12 after exposure-15.3 ± 1.0 ppm, and ChemFil II(24 hour)-15.1 ± 1.2 ppm, week 11-0.2 ±0.9 ppm, week 12 after exposure-11.2 ± 1.2 ppm.

Wiltshire and Janse van Rensburg (1995), determined the *in vitro* fluoride release from four light-cured orthodontic adhesives. Two fluoride (FluorEver and Light-Bond) and two nonfluoride (Heliosit Orthodontic and Transbond) orthodontic adhesives were included. Specimens (10 disks, with a volume of 56.57 mm^3 and surface area of 0.94 cm^2) were stored in 1 ml distilled water at 37°C. By means of the potentiometric analytical method, the fluoride release of each resin was determined daily for 7 days and thereafter weekly for one month and then monthly until week 85. The fluoride release of all the resins were characterized by an initial burst of fluoride release during the first day, followed by a tapering down in magnitude. The fluoride release of the nonfluoride containing adhesives could only be determined up to 29 days, thereafter the fluoride release was too small to be accurately determined. Total fluoride release at 36 days was as follows: FluorEver-56.33μg, Light-Bond-8.73μg, Heliosit Orthodontic-0.88μg , and Transbond-0.74μg . FluorEver outperformed the other adhesives in all aspects of fluoride release and continued to release fluoride for up to 85 weeks. They suggest that fluorapatite formation resulting in fluoride release from orthodontic adhesives could be more advantageous in reducing decalcification during fixed appliance treatment than other preventive modalities.

These properties make such materials an attractive alternative for conventional banding and direct bonding of orthodontic brackets. The adhesives set by two mechanisms, polymerization of the monomer (light-cure or chemical-cure) and an acid-base reaction (Combe, Burke, and Douglas, 1999 c). Compton et al (1992) reported that a light cured glass ionomer (Zionomer) had bond strengths of: 1 hour-16.7 ± 3.0 MPa; 24 hour- 17.2 ± 6.2 MPa, and a chemical cured glass ionomer (Ketac-Bond) to have bond strengths of: 1 hour- 8.8 ± 1.8 MPa; 24 hour-11.8 ± 2.5 MPa. Because of the convenience of on demand setting reactions of light-cured materials and their higher initial and sustained shear bond strengths, they were suggested as a direct bonding alternative to the traditional composite resins (Compton et al, 1992). Charles (1998), strongly recommends the use of resin-modified glass-ionomer materials for bonding orthodontic brackets due to a very low incidence of enamel decalcification. Seven individuals in different local orthodontic practices, over the period of six years, bonded 99% of their metal orthodontic brackets to etched (10% polyacrylic acid for 15 seconds) human enamel using glass ionomer cement (brand not listed). They reported a 6.5% decalcification appearance (visual inspection upon deband) over the 6 years, while Gorelick, Geiger, and Gwinett (1982) indicated decalcification with composite resin at 50%. Widely varying shear bond strengths of resin-modified glass-ionomer materials have been reported, ranging from 5.39 MPa to 18.9 MPa (McCourt, Cooley, and Barnwell, 1991; Ewoldsen et al, 1995; Cacciafesta et al, 1998; Fricker, 1998; Lippitz, Staley, and Jakobsen, 1998; Meehan, Foley, and Mamandras, 1999).

2.3.4 Poly-acid modified composite resins

Polyacid modified resin composites are commonly known as "compomers", which can be considered composite resins with the addition of some glass-ionomer components such as an acid-decomposable glass to form a matrix. The glass-ionomer characteristics are insufficient to promote acid-base reactions typical of glass-ionomer materials. Thus compomers do not set in the dark, and visible light activation of polymerization is required. (Combe, Burke, and Douglas, 1999 f)

The original aim of the manufactures of the earliest compomers was to produce a material which bonded to the tooth surface without acid etching. This has proven unsuccessful

(Combe, Burke, and Douglas, 1999 f). Bond strengths, with acid etch, have been reported in the range of 7.3 MPa to 11.97 MPa, which are "acceptable" bond strengths according to Reynolds, 1975. (Ashcraft, Staley, and Jakobsen, 1997; Rock and Abdullah, 1997; Meehan, Foleyn, and Mamandras, 1999).

2.3.5 Cyanoacrylate adhesives

Commercially available is Smartbond®, which is a cyanoacrylate ester. Previous cyanoacrylate adhesives have failed to gain acceptance. Crabb and Wilson (1971) studied three cyanoacrylate adhesives and reported that after 24 hours of storage at 37°C in saline, the bond strengths of Cyanodont, Eastman 910, and Permabond were reduced to near zero. Howell and Jones (1989), reported on another cyanoacrylate orthodontic adhesive (pre-production sample, name not listed) and found that the material was more susceptible to deterioration after storage in water. The bond strengths after one hour of storage were 124 N. After 7 days of storage, the bond strengths dropped to 26 N with an even further drop after 98 days of storage to 6N. This adhesive was never commercially marketed.

2.4 Bond Failure Rates

In the clinical situation, bond failure rates of glass ionomer (Fuji II LC and Ketac-Cem) range from 1.6% to over 50% for 12 months *in vivo* (Fricker, 1994; Miguel, Almeida, and Chevitarese 1995). Lower failure rates have been reported for conventional composite resins compared to resin-modified glass-ionomers. Fricker (1992), reported 5% and 20% failure rates for composite resins (System I) and resin-modified glass-ionomers (Fuji II LC) respectively over a 12 month period *in vivo*. Miguel, Almeida, and Chevitarese (1995), report much higher rates (Ketac-Cem) 7.96% and (Concise) 50.89% respectively. Cacciafesta et al (1998) and Silverman et al (1995), both found excellent long-term adhesion using resin-modified glass-ionomers in the absence of enamel etching. Silverman et al (1995), bonded 150 cases with a light-cured resin-reinforced glass-ionomer (Fuji Ortho LC) to unetched saliva contaminated enamel *in vivo*. The success of the material to date (time not listed) was 96.8%. Bishara et al (1998 b), advises etching in order to achieve sufficient bond strengths and to reduce bond failures. Bishara et al (1998 b) concluded that with unetched human enamel, the shear bond strength *in vitro* (2000 cycles of thermal cycling between 5 °C ± 2 and 50 °C ± 2) of resin reinforced glass-ionomer (Fuji Ortho LC) is significantly reduced by one-third to one-half. The results were as follows: No etch+water= 3.5 ± 1.9 MPa, Etch (37% phosphoric acid gel for 30 seconds)+water= 8.1 ± 2.8 MPa, No etch+saliva= 5.8 ± 2.4 MPa, Etch (37% phosphoric acid gel for 30 seconds)+saliva= 7.3 ± 1.9 MPa. This reduction in bond strength is critical, because the residual bond strength might not be able to withstand the forces produced during routine clinical orthodontic procedures and mastication (Bishara et al., 1998 b).

2.5 Moisture Contamination

The biggest disadvantage of bonding to etched enamel with resin-based materials is its technique-sensitivity (Combe, Burke, and Douglas, 1999 e). Due to their hydrophobic properties and the absence of chemical adhesion, conventional Bis-GMA adhesives require etched, washed, and dried enamel for mechanical adhesion. Moisture contamination is considered the most common reason for bond failure (Zachrisson, 1977; Gwinnett, 1988). The majority of the studies suggesting moisture contamination as the prime reason for bond failure are, however, either anecdotal reports or limited to restorative dentistry (Zachrisson, 1977; Gwinnett, 1988).

Buonocore (1971), Hormati, Fuller, and Denehy (1980), and Silverstone (1984), suggest that the acid-etched enamel absorbs saliva to reduce the surface energy which renders the surface unfavorable for bonding. Other studies agree that when changes such as reduced surface energy, lack of wettability, and impared resin penetration occur the bonding mechanism maybe interfered with (Meurman, 1976; Gwinnett, 1976).

Hormati, Fuller, and Denehy (1980), evaluated shear bond strengths of a composite resin (Concise) to etched enamel exposed to saliva. They revealed a significant difference in bond strengths between the group bonded to wet saliva and other treatment groups (saliva which was air dried or the samples that were re-washed or re-etched). The results after bonding and 24 hour storage in a humid atmosphere at 37°C are as follows: Group 1: No moisture contamination and acid etch (37% phosphoric for 60 seconds)-24.92 kg; Group

2: Acid etch (37% phosphoric for 60 seconds) and exposure to saliva for 60 seconds- 12.25 kg; Group 3: Acid etch (37% phosphoric for 60 seconds), exposure to saliva for 60 seconds and dried with air for 15 seconds- 20.88 kg; Group 4: Acid etch (37% phosphoric for 60 seconds), exposure to saliva for 60 seconds, washed with water for 15 seconds, and dried for 15 seconds- 22.10 kg; Group 5: Acid etch (37% phosphoric for 60 seconds), exposure to saliva for 60 seconds, washed with water for 15 seconds, dried for 15 seconds, re-etched for 10 seconds, rewashed, and redried- 24.90 kg; Group 6: Acid etch (37% phosphoric for 60 seconds), exposure to saliva for 60 seconds, washed with water for 15 seconds, dried for 15 seconds, re-etched for 60 seconds, rewashed, and redried- 26.40 kg; Group 7: Acid etch (37% phosphoric for 60 seconds with cotton pledget rubbing), washed with water for 15 seconds, dried for 15 seconds-23.80 kg. The samples exposed to saliva contamination generally had an adhesive failure of the bond resulting in fracturing at the enamel-resin surface. The fractures which occurred at the interface in each group were as follows: Group 1- 25%, Group 2 and 3- 100%, Group 4-67%, Group 5- 33%, Group 6 and 7- 42%. The uncontaminated samples most frequently had cohesive bond failure, leaving the bond intact. Cohesive bond failures occurred at fracture sites as follows: Group 1- 75%, Group 2 and 3- 0%, Group 4-33%, Group 5- 76%, Group 6 and 7- 58%. The authors speculated that the lack of bond strength on the saliva contaminated enamel could be due to their lack of wettability. When etched enamel is wet, most of the porosities become plugged and impair the penetration of the resin into the enamel. This results in resin tags of insufficient number and length (Hormati, Fuller, and Denehy, 1980).

Silverstone, Hicks, and Feathersone (1985), reported that washing alone did not completely remove the oral fluid remnants from etched enamel surfaces contaminated with saliva for 1 second. They suggested re-etching of such enamel surfaces once saliva contamination occurs. This study concurred with the previous study by Evans and Silverstone (1981). They conducted an *in vitro* study of salivary contamination on etched (Either 30% or 37% phosphoric acid for 60 seconds) human enamel. The samples were randomly exposed to fresh whole saliva for 60, 30, 10, 5, 1, 0.5 and 0.1 seconds. The surfaces were vacuum coated for examination with a Joel JSM 35C SEM. Examination of these surfaces by SEM revealed a tenacious coating, which blocked the enamel porosities. With 0.5 second exposure time to saliva, washing seemed to restore the etched surface. Whether washed or unwashed, only the samples with the 0.1 second exposure time appeared to have an etching pattern similar to the controls (etched enamel, uncontaminated). One limitation of this study is that the effect of this short exposure to saliva on shear bond strengths was not evaluated. They did postulate that the adherent coating must affect the bonding of resins.

Cacciafesta et al (1998), evaluated the shear bond strengths of Fuji Ortho LC, a light-cured resin reinforced glass ionomer used for bonding orthodontic brackets under four different bovine enamel surface conditions: A) nonconditioned and dry, B) conditioned with polyacrylic acid 10% (for 10 seconds and rinsed with water for 30 seconds) and moistened with saliva, C) conditioned with polyacrylic acid (for 10 seconds and rinsed with water for 30 seconds) and moistened with water, and D) nonconditioned and wet (water). The shear bond strengths were recorded after 24 hours of storage in tap water using the bracket types indicated. Transcend 6000 (ceramic bracket)- A: 12.7 ± 2.9 MPa, B: 12.9 ± 2.0 MPa, C:20.9 ± 2.8 MPa, D: 10.4 ±1.9 MPa; Ultratrim (stainless steel bracket)- A: 12.0 ± 4.7 MPa, B: 23.8 ± 2.9 MPa, C:15.7 ±2.2 MPa, D: 9.8 ± 1.8 MPa; Fascination (ceramic bracket)- A: 16.9 ± 2.1 MPa, B: 16.9 ± 2.1 MPa, C:25.4 ± 2.6 MPa, D: 7.3 ± 1.8 MPa. The highest bond strength was produced with the stainless steel brackets, subgroup B at 23.8 ± 2.9 MPa, which was significantly higher ($p<0.05$) than all other samples tested. They concluded that the shear bond strength of Fuji Ortho LC is significantly enhanced by contaminating the enamel surface with either saliva or water after conditioning. They also concluded that water contamination of nonconditioned enamel surfaces does not seem to preclude clinically acceptable bond strengths.

Although the acid etch technique is widely accepted, many orthodontists are concerned about decalcification or white spot lesions that develop around the bracket margins within a few weeks (Ceen and Gwinnett, 1981; Gorelick, Geiger, and Gwinnett, 1982). Since salivary contamination of etched enamel surfaces may have adverse effects on the bond strength, re-etching is often necessary (Graber and Vanarsdall, 1994 b). As the fluoride concentration is the highest in the surface of the enamel and lowest in the bulk, re-etching of the enamel may make the enamel surface even more susceptible to decay (Brudevold, Gardner, and Smith, 1956). This may be avoided by using bonding systems such as resin-modified glass-ionomers or poly-acid modified composites that are claimed to adhere to the unetched tooth enamel by chemical adhesion or minimized by bonding systems that are able to be bonded to contaminated surfaces.

2.6 Water Immersion

The absorption and desorption of water by a polymer matrix of composite could cause debonding of the filler-matrix (Bowen, 1979; Soderholm, 1982) or hydrolytic degradation of fillers and loss of bond strength (von Fraunhofer and Hammer, 1984; Fan et al, 1985; Soderholm et al, 1984). Orthodontic composites consist of 24% to 72% inorganic fillers (Smith and Williams, 1982). Soderholm (1983) investigated the leakage of filler elements from Concise after storage in water. He reported that when the different filler elements are bonded to resin matrices and immersed in water, the matrices swell and tensile stresses are induced on the filler interfaces. This produces a strain on the Si-O-Si bonds. This makes the filler particles susceptible to stress corrosion. He also noted that the greater the water immersion, the greater the leakage of the composite.

During a two to three year orthodontic treatment period, the composite is essentially immersed in water and saliva, where it can both absorb and desorb water. This could cause the filler-matrix to debond or hydrolytic degradation of the filler and affect bond strength, hardness, and wear resistance. The changes in bond strength following water immersion, depends on the duration of water immersion. Meng et al (1995) found that the greatest loss in bond strength occurs initially, followed by a period of relative stabilization, and then a weaker reduction in bond strength after 32 weeks. They bonded 100 metal brackets to etched (Concise etchant, concentration not noted (pH: 0.21) for 15 seconds) human enamel *in vitro*. They recorded bond strengths at 1, 2, and 3 days and 1, 2, 4, 8, 16, 24, and 32 weeks. Bond strengths were as follows: Day 1-0.73 ± 0.14

kg/mm^2, Day 2-0.72 ± 0.02 kg/mm^2, Day 3-0.72 ± 0.01 kg/mm^2, Week 1-0.69 ± 0.14 kg/mm^2, Week 2-0.67 ± 0.11 kg/mm^2, Week 4-0.58 ± 0.06 kg/mm^2, Week 8-0.62 ± 0.09 kg/mm^2, Week 16-0.60 ± 0.14 kg/mm^2, Week 24-0.48 ± 0.13 kg/mm^2, and Week 32-0.46 ± 0.24 kg/mm^2. They concluded, that the greater the time in water immersion, the less the bond strength and the greater the destruction of the composite resin. Newman, Snyder, and Wilson (1968); Mirua, Nakagawa, and Masuhara (1971); and Williams, von Fraunhofer, and Winter (1974) are all in agreement with Meng et al, that the bond strength of acrylic cement showed a tendency to decrease over time with water immersion. Newman, Snyder, and Wilson (1968) studied methyl methacrylate (100% or 20%, unknown brand). They reported that peak shear bond strengths in water immersion is 1 hour after bonding, then found the decrease to be proportional to the logarithm after the peak strength had been attained. Mirua, Nakagawa, and Masuhara (1971) studied the bond strengths of Z6030: Methayacryloxyprophyl-tri-methoxysilane to etched human enamel *in vitro*. They reported 1 day bond strengths of 52.0 kg/cm^2, 30 days of 50.0 kg/cm^2, 90 days of 48 kg/cm^2, 180 days of 45 kg/cm^2 without reference to standard deviations. Williams, von Fraunhofer, and Winter (1974) studied Nuva-Seal and Epoxylite 9075 bonded to etched human enamel (50% orthophosphoric) *in vitro*. The teeth were bonded and stored in tap water for 7 days or 6 months. Bond strengths were significantly decreased over the 7 day and 6 month storage times. Nuva-Seal from 25 ± 7.5 kg/cm^2 at 7 days to 20 ± 8.5 kg/cm^2 at 6 months and Epoxylite 9075 from 42.5 ± 22 kg/cm^2 at 7 days and 35 ± 12 kg/cm^2 at 6 months.

Cohl, Green, and Eick (1972), found slight increases in bond strength after 1 day and 60 days. They studied a bonding adhesive developed by Buonocore as a fissure sealant (name not listed). They did mention that it was composed of three parts by weight of the reaction product of besphenol-A and glycidyl methacrylate and one part by weight of methyl methacrylate monomer. Two percent of benzoin methyl ether was added to the adhesive just prior to use to obtain an ultraviolet sensitive mixture. The brackets (clear polycarbonate) were bonded to etched (50% phosphoric acid for 90 seconds) human enamel *in vitro*. They reported one day shear bond strengths of 49.6 ± 7.3 kg/cm^2 and 60 days shear bond strengths of 57.7 ± 8.1 kg/cm^2. Beach and Jalay (1980), reported increases in shear bond strength with primer and decreases in bond strength without primer after six months. They studied Direction Orthodontic Adhesive with and without primer. They reported mean shear bond strengths of Direction Orthodontic Adhesive with primer to etched (unknown concentration for 60 seconds) human enamel *in vitro*: 1 day- 10 ± 2.5 MPa, 3 months- 12.5 ± 1 MPa, and 6 months- 12.5 ± 2.5 MPa. They reported mean shear bond strengths of Direction Orthodontic Adhesive without primer to etched (unknown concentration for 60 seconds) human enamel *in vitro*: 1 day- 11 ± 3.5 MPa, 3 months- 12 ± 2 MPa, and 6 months- 7.5 ± 2 MPa. The reason for the increase in shear bond strength with primer may be that it reduces the susceptibility of the bond to attack by water. It is possible that the thickness of the primer may have an affect on bond strength. Meng et al (1995), suggested that as the primer is applied, if it is too thick, it may act as a separating agent and the bond strength may decrease.

Matasa (1995), reported that composites used in orthodontic bonding adhesives have a polymeric matrix that can host and nurture a variety of aerobic and anaerobic microorganisms, like Streptococcus mutans, Pseudomonas aeruginosa, Pseudomonas diminuta, Veillonella, Peptostreptococcus magnus, and Propionibacterium acnes. He evaluated four, two-part, chemically curable adhesives: Advantage, Phase II, Genie, and Maxibond. He also evaluated Bis-GMA. A visual inspection of the incubated cultures and the adhesive foils was preformed. Most of the adhesives exhibited unusual alterations of surface character (pockets and channels, uniform pale-yellow discoloration and high porosity, and pocketing next to the bracket interface). He also noted loss of weight varying between 0.1% and 1%. The loss of weight was highest for the pure polymer (Bis-GMA), medium for Phase II, Genie, Maxibond, and lowest for Advantage (exact weights not noted). He suggests that this accumulation of microorganisms may lead to weakening of the bond due to the porosity and loss of composite.

2.7 Objective of the study

This study was therefore designed:

1. To determine the shear-peel bond strength to human enamel at 24 hours and 6 months of 3 different orthodontic adhesives (Smartbond®, Transbond™ XT, and Assure™).
2. To determine the effect that storage in 37°C water for 6 months will have on the shear-peel bond strength of orthodontic attachments bonded to enamel.
3. To determine the effect that whole human unstimulated saliva will have on the shear-peel bond strength of orthodontic attachments on enamel.

2.8 Null Hypothesis

The null hypothesis for this study states that there are no statistically significant differences in the orthodontic shear-peel bond strengths resulting from various orthodontic adhesives. The null hypothesis also states that storage of the samples in water for 6 months will have no effect on the shear-peel bond strengths of the orthodontic attachments bonded to enamel. Finally it states, that whole human unstimulated saliva will have no effect on the shear-peel bond strength of orthodontic attachments to enamel.

CHAPTER 3

MATERIALS AND METHODS

Page Numbers

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3.1 Experimental Design

The materials used in this study are listed in Table 3.1.

Sixty erupted human third molars were collected after extraction and stored in distilled deionized water.

The 60 samples were divided into groups of 10 and received one of the following surface treatments:

1. Pumice polish + Phosphoric acid etch
2. Pumice polish + Phosphoric acid etch + flooded with whole human unstimulated saliva

Two stainless steel, curved base orthodontic buttons (GAC) were bonded to each sample with one of the following three orthodontic adhesives:

1) Transbond™ XT (3 M Dental Products St.Paul, MN, USA)
2) Assure™ (Reliance Orthodontic Products, Inc. IL, USA)
3) Smartbond® (Gestenco International Goteborg, Sweden)

Transbond™ XT

Transbond™ XT adhesive paste is a light-cured, hybrid resin. The resin base is Bis-GMA and TEGDMA in a ratio of 1:1, with 82% 3μm silica particles. The primer is composed of 50% Bis-GMA and 50% TEGDMA. The gel etchant is composted of 34% phosphoric acid. (Material Safety Data Sheet d, Material Safety Data Sheet e)

Assure™

Assure™ is a poly-acid modified composite resin. It is composed of 8-30% hydroxyethyl methacrylate, 60-99% glass frit, and 1-5% sodium fluoride. The adhesive primer is composed of 15-40% biphenyl dimethacrylate and 40-70% acetone. The liquid etchant is 37% phosphoric acid. (Material Safety Data Sheet a, Material Safety Data Sheet b)

Smartbond®

Smartbond® is a cyanoacrylate ester. It consists of 85-90% ethyl cyanoacrylate, 5-10% poly (methylmethacrylate), 5-50% amorphous silica, and 0.1-0.5% hydroquinone. The gel etchant is composed of 37% phosphoric acid. (Material Safety Data Sheet f)

The manufactures of both Assure™ and Smartbond® claim to bond to wet teeth (Technical Specification Sheet a, Technical Specification Sheet b).

Sheer-peel bond strength testing was performed, with one button of each sample being tested at 24 hours and the other button being tested at 6 months. Storage of the bonded samples was in an incubator (Thelco/Canlab Model 2, Precision Scientific Co., Chicago

Ill.) at 37°C in distilled and deionized water. Light-optical stereomicroscope evaluation of the fracture sites was performed in order to evaluate the amount of adhesive remaining and enamel damage after each button was debonded. This was preformed by two examiners to assure interexaminer reliability.

Table 3.1
Materials, Manufacturers and Batch Numbers

Material	Manufacturer	Batch Number
Transbond™ XT Adhesive Paste and Primer; 34% Tooth Conditioning Gel	3 M Dental Products St.Paul, MN, USA	#9AD 712-035 #9D 712-034 #9903191
Assure™ Fluoride Releasing Light-cured Orthodontic Adhesive Paste and Light-cured Sealant; Assure™ Etching Agent	Reliance Orthodontic Products, Inc. IL, USA	#069238 #059188 #069038
Smartbond® Instant Adhesive Smartbond® Etching Gel	Gestenco International Goteborg, Sweden	#98B SM-002 #32 SM-003
Preppies® Flour of Pumice	Whip Mix Corporation Louisville, Kentucky, USA	#D0403400Q
Lingual Curved Buttons	GAC International Central Islip, NY, USA	#30-000-01 Lot 1099

3.2 Enamel Samples

One hundred erupted human third molars were collected and stored in distilled deionized water for a maximum of two months. Once collected, the roots were removed with a high speed hand piece and a cross cut bur (Midwest Dental Products Corp. Des Plaines, IL, USA; Bur No.FG 556) under a running spray of water and air. Upon removal of the roots, the teeth were rinsed with distilled deionized water and stored in a covered glass container of distilled deionized water. Of the one-hundred teeth, sixty were selected based on the following criteria: intact buccal enamel, no pretreatment chemical agents such as hydrogen peroxide, and no caries or cracks caused by the extraction forceps (Bishara et al,1998 b). A binocular microscope at 20X magnification was used for this determination (Nikon SM2-10, Tokyo, Japan). The teeth were again bench stored in distilled deionized water (Wiltshire, 1994).

3.3 Mounting Procedure

The teeth were then embedded in cold cure acrylic (Fast White Polymer, Great lakes Ortho. Ltd., Tonawanda, NY; Self-curing orthodontic resin (Pink), Dentsply Limited, England) in stainless steel mounting rings (Figure 3.1). A surveyor was used to ensure the specimens were mounted so that the facial surface (height of contour) being tested would be parallel to the shearing blade. This allowed the facial surface to be parallel to the force during the shear-peel strength test (Figure 3.2).

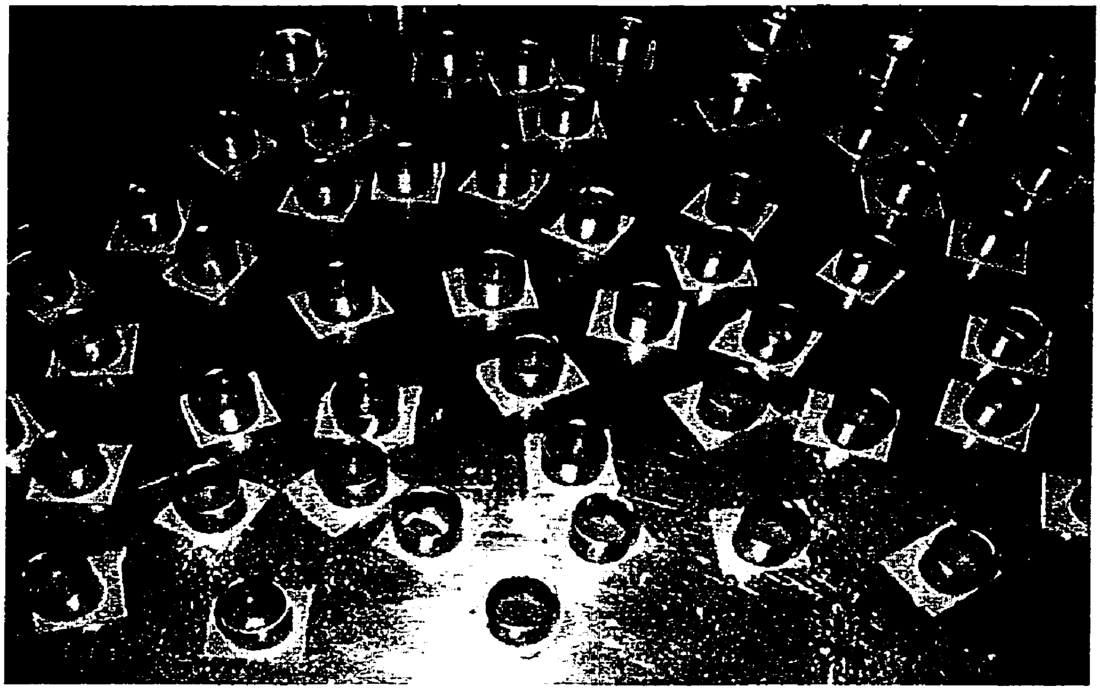


Figure 3.1: *Rings with first layer of cold cure acrylic.*

Figure 3.2: *Teeth mounted in rings with cold cure acrylic, stored in distilled deionized water.*

3.4 Pumice Polish

All of the enamel specimens were cleansed and polished with residue free, nonfluoridated, nonflavored pumice (Preppies®) in a pumice and water slurry for 10 seconds with a slow speed dental hand piece and rubber prophylatic cup (Figure 3.3) (Bishara, 1998 b). The samples were then thoroughly rinsed with tap water and dried with oil free compressed air for 30 seconds.

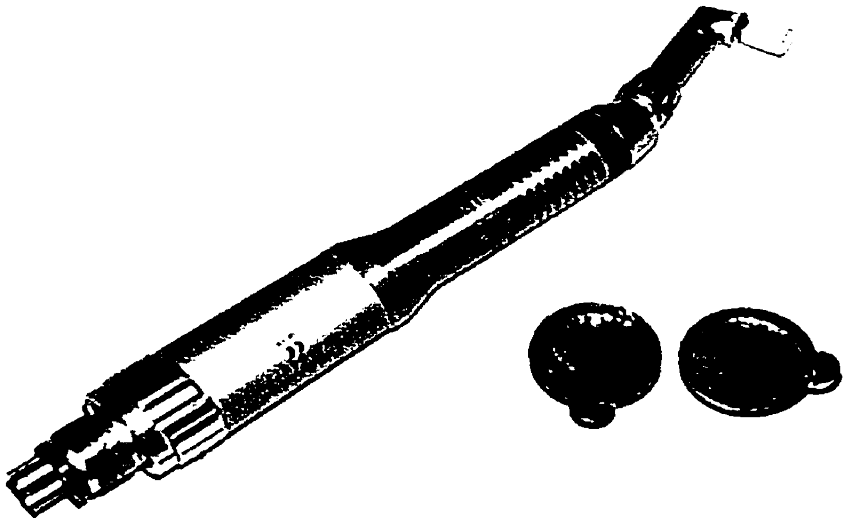


Figure 3.3: *Slow speed hand piece and pumice polish.*

3.5 Acid Etch

All selected molars were then randomly assigned to one of the six groups. The teeth were then etched by dabbing a brush with each of the manufactures' etching agents (see etchant concentrations in 3.1 Experimental Design) on the enamel surfaces for 30 seconds and then rinsed for 20 seconds with a water spray and dried with an oil free air source for 20 seconds. The enamel surfaces of the teeth were visually inspected and all appeared chalky white in color.

3.6 Bondable Lingual Orthodontic Buttons

The teeth from each group were chosen to ensure that the round bondable orthodontic buttons with a curved base (#30-000-01, GAC International, Central Islip, NY) could be bonded to the enamel surfaces in close proximity. (Figure 3.4) The base surface areas of 20 randomly selected buttons were measured 5 times each using a digital micrometer calipers (Mitutoyo Digital Micrometer, Tokyo, Japan). The nominal base area was calculated using the formula $A=\pi r^2$. The buttons were found to have a mean nominal surface area of 10.18 mm^2. This base area was used to calculate the stress in N/mm^2 or MPa at shear-peel bond failure.

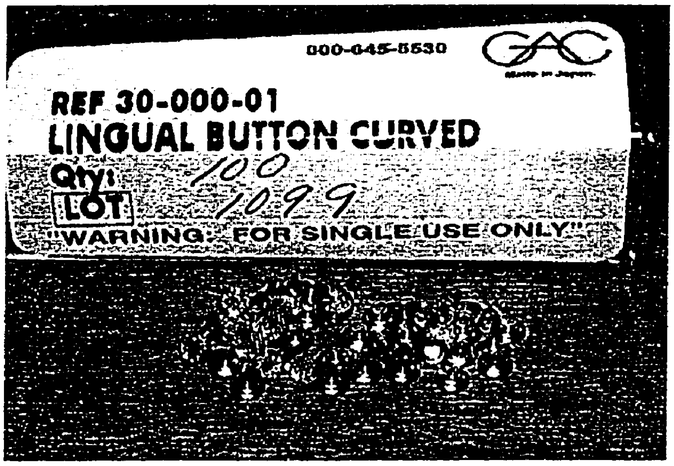


Figure 3.4: *Bondable lingual buttons (#30-000-01, GAC International, Central Islip, NY).*

3.7 Bonding Materials

The buttons were then boned to the samples with either Transbond™ XT [control](3M/Unitek, Monrovia, CA), Smartbond® (Gestenco International, Goteborg, Sweden) or Assure™ (Reliance Orthodontic Products, Inc., IL.) (Figures 3.5-3.7). The buttons were bonded according to the adhesive manufactures' instructions as follows:

Transbond™ XT Light Cured Primer was applied to the enamel surface in a thin layer. Transbond™ XT Adhesive Paste was applied and worked into the base of the button.

Assure™ sealant was applied in 2 coats, after waiting 10 seconds, the sealant was lightly dried with contaminant free air and cured for 10 seconds. Assure™ paste was applied and worked into the base of the button.

Smartbond® required a moistened surface with distilled water. The enamel was moistened with tap water by an applicator tip. The Smartbond® adhesive was applied and worked into the base of the button.

The buttons were then placed so the buccal surface of the tooth was along the long axis of the crown. A force of 500 gm was applied to each button using the Bencor™ Multi-T testing apparatus to assure complete seating and excess bonding resin was removed using an explorer under close visual inspection (Delport and Grobler, 1988; Driesen et al, 1989) (Figures 3.8-3.9). The Transbond™ XT and Assure™ adhesives were then cured for 30 seconds with a 3M Unitek Ortholux™ XT Visible Light Cure Unit (3M Dental Products, St. Paul, MN, USA) (Figure 3.10) and the Smartbond® samples were allowed to set for 5 minutes. Half of the specimens (30) with two buttons on each tooth (total of 60 buttons) were bonded under moist conditions (a thin layer of whole, unstimulated, fresh human saliva was collected and applied to coat the tooth surface prior to bonding) and half (30 teeth and 60 buttons) were bonded under dry (nonsaliva contaminated) conditions (Chung, Cuozzo, and Mante, 1999). The salvia was collected using the spit method (Aufricht et al, 1992; Sreeby and Zhu, 1996).

Transbond XT™ -	Group I.	20: Moist field bonding
	Group II.	20: Dry field bonding
Assure™-	Group III.	20: Moist field bonding
	Group IV.	20: Dry field bonding
Smartbond®-	Group V.	20: Moist field bonding
	Group VI.	20: Dry field bonding

Each of the samples were bonded according to the manufacturers' instructions.

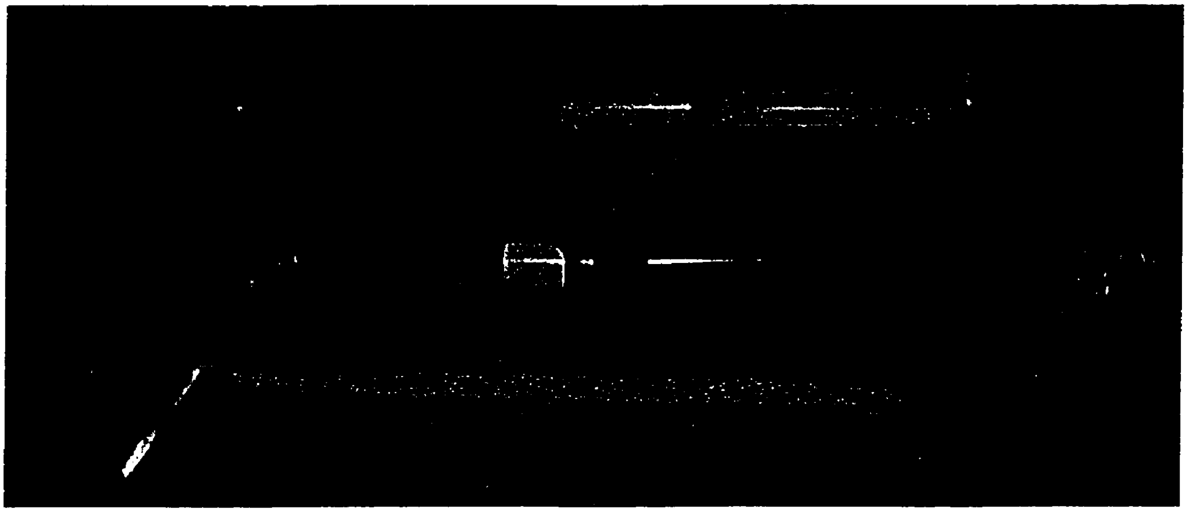


Figure 3.5: *Transbond™ XT (3M/Unitek, Monrovia, CA) light-cured orthodontic adhesive paste, Transbond™ XT light-cured adhesive primer, 34% tooth conditioning gel.*

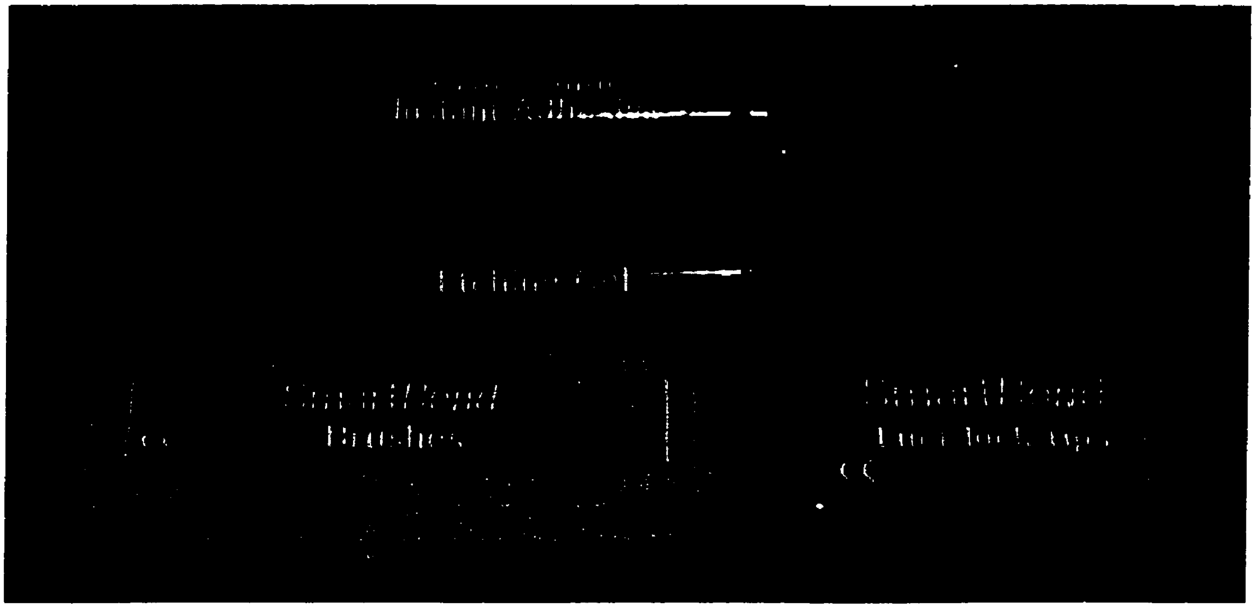


Figure 3.6: *Smartbond® (Gestenco International, Goteborg, Sweden) instant orthodontic adhesive, Smartbond® etching gel.*

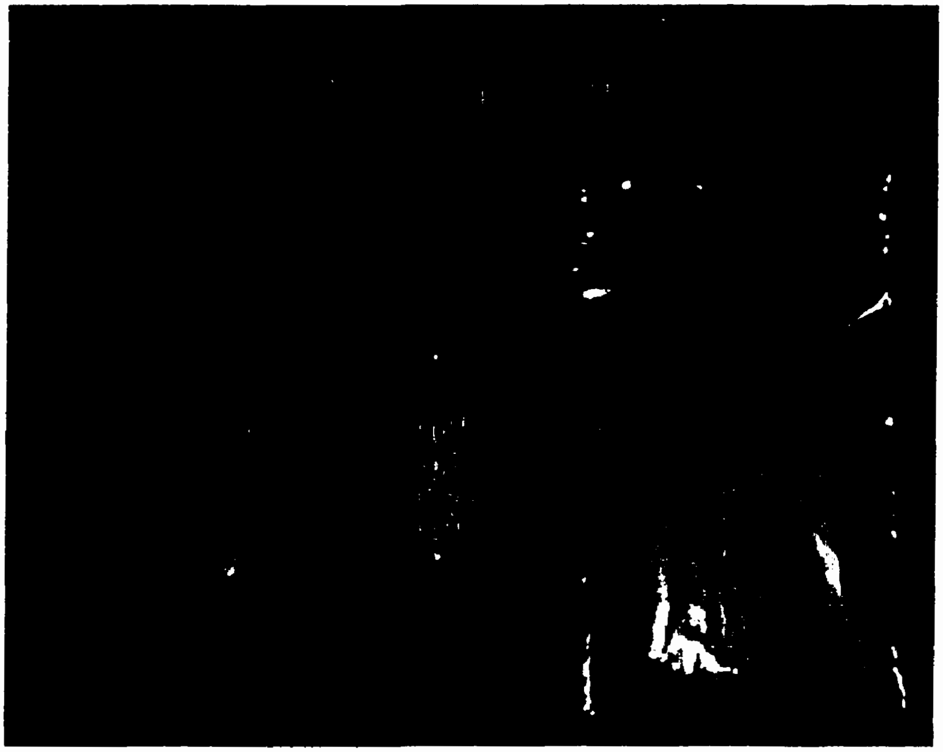


Figure 3.7: *Assure™ (Reliance Orthodontic Products, Inc., IL.) fluoride releasing light-cured orthodontic adhesive paste, Assure™ light-cured sealant, Assure™ etching agent.*

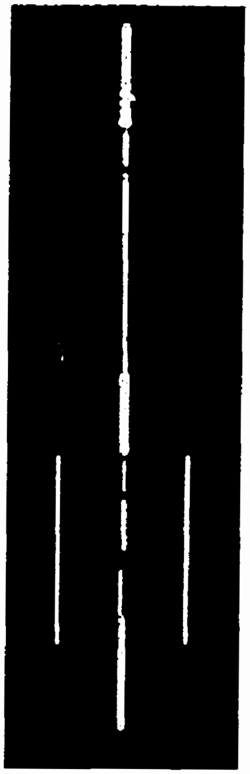


Figure 3.8: *Button with 500 gm attachment in a Bencor™ Multi-T (Danville Engineering, San Ramon, CA, USA) testing apparatus to assure complete seating.*

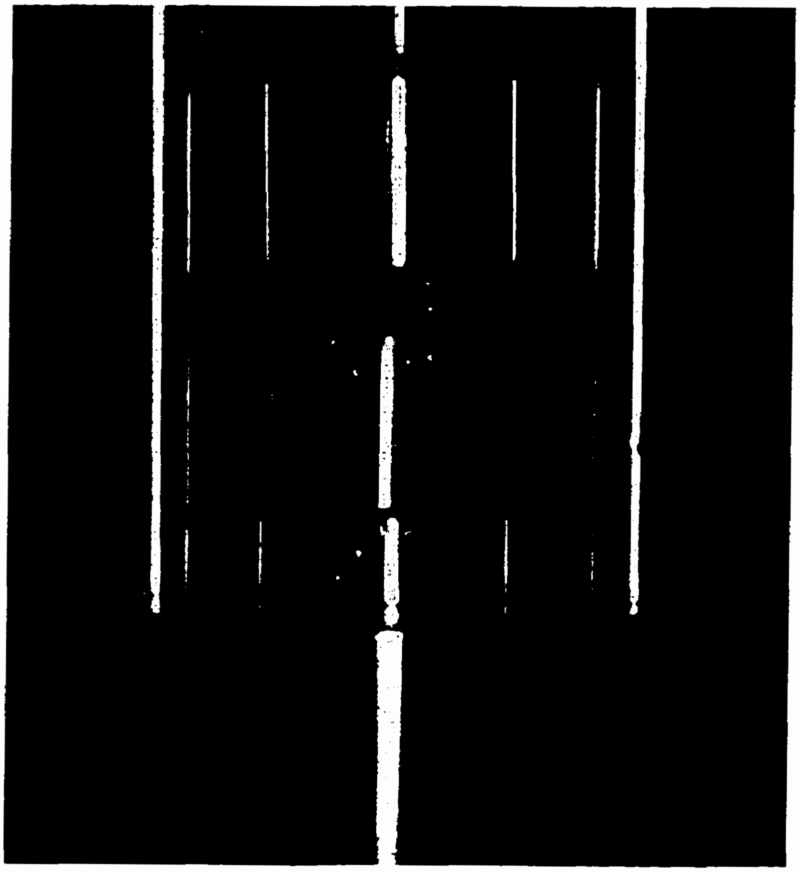


Figure 3.9: *Buttons seated with 500 gm weight in a Bencor™ Multi-T (Danville Engineering, San Ramon, CA, USA) testing apparatus (Close-up).*

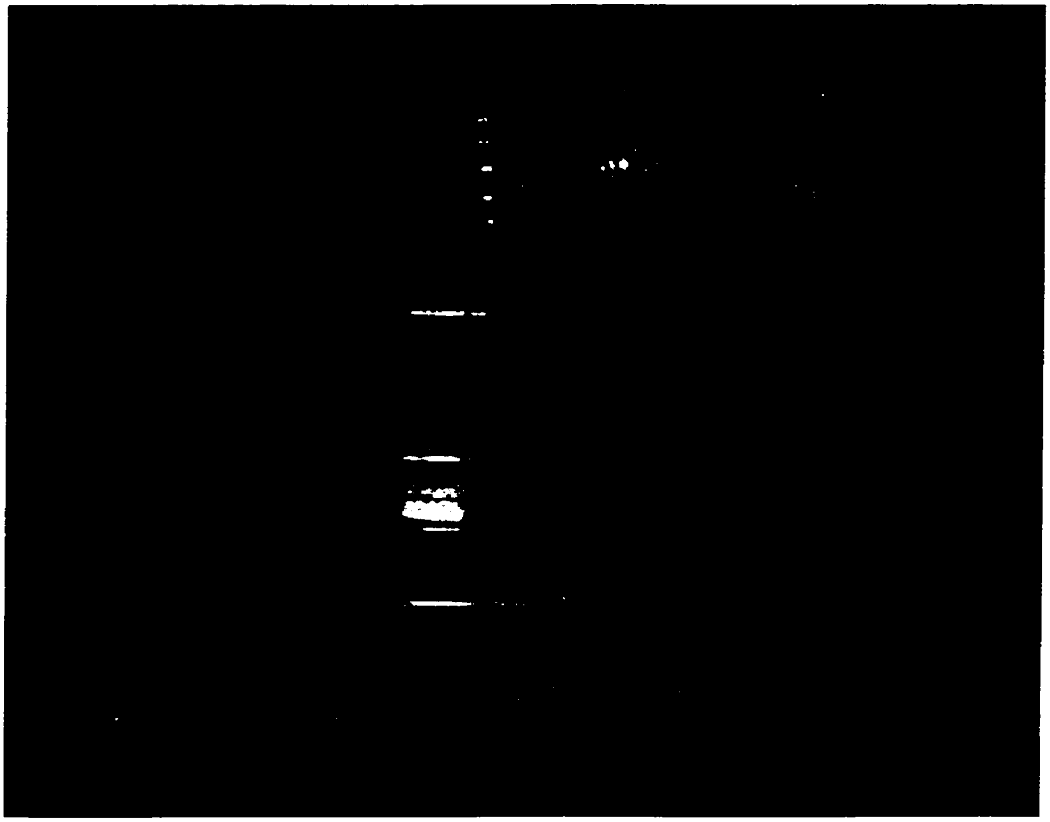


Figure 3.10: *3M/Unitek Ortholux™ XT Visible Light Curing Unit (3M Dental Products, St. Paul, MN, USA).*

3.8 Storage of the Samples

Immediately after bonding, the samples were covered and stored in distilled deionized water (100% humidity) for 24 hours at 37°C in an incubator. Upon completion of the 24 hour period, the 24 hour shear-peel bond strength measurements were taken. Immediately after the 24 hour debonding procedure, the samples with one remaining button were returned to the 37°C water where they were stored for 6 months (minus one day), after which the 6 month debonding procedure was performed (ISO, 1994) (Figure 3.11).

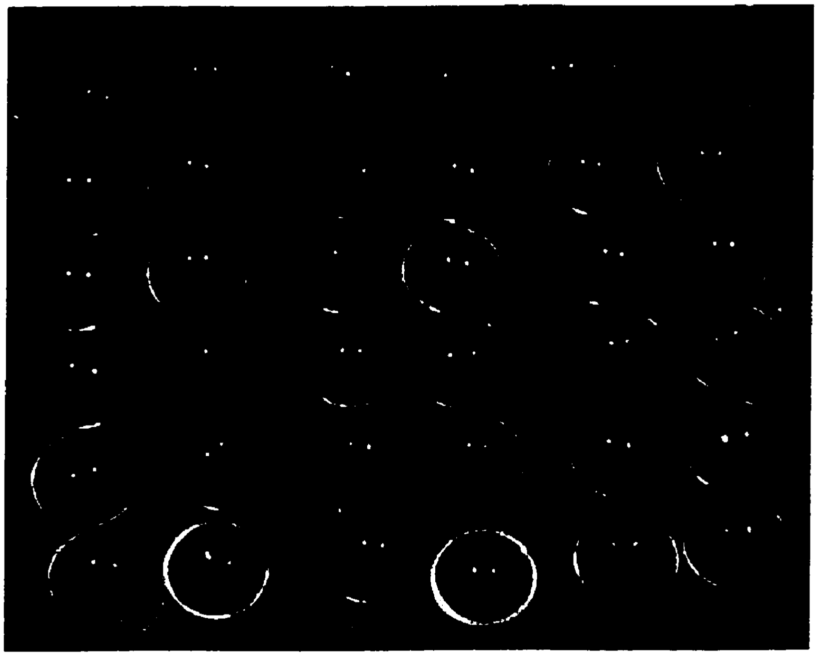


Figure 3.11: *Teeth with lingual buttons stored in distilled deionized water.*

3.9 Debonding Procedure

After storage for 24 hours or 6 months the embedded samples were mounted into the shear-peel testing device (Bencor™ Multi-T, Danville Engineering, San Ramon, CA, USA) in a Zwick Universal Testing Machine (#1445, Zwick GmbH & Co. Ulm, Germany) (Figure 3.12). The debond load was applied occlusogingivally, with a crosshead speed of 0.5 mm/minute using a 10kN load cell. The load was applied to the enamel-adhesive-attachment interface using a custom straight edge shearing blade aligned parallel to the test surface (height of contour). The samples were loaded until bond failure. The Zwick computer required the input of the surface area of the base of the button. With this information, and the load upon failure, it recorded the shear-peel bond strength in MPa (megapascals). The debonding procedures were carried out by one operator (to avoid interexaminer error). (ISO, 1994)

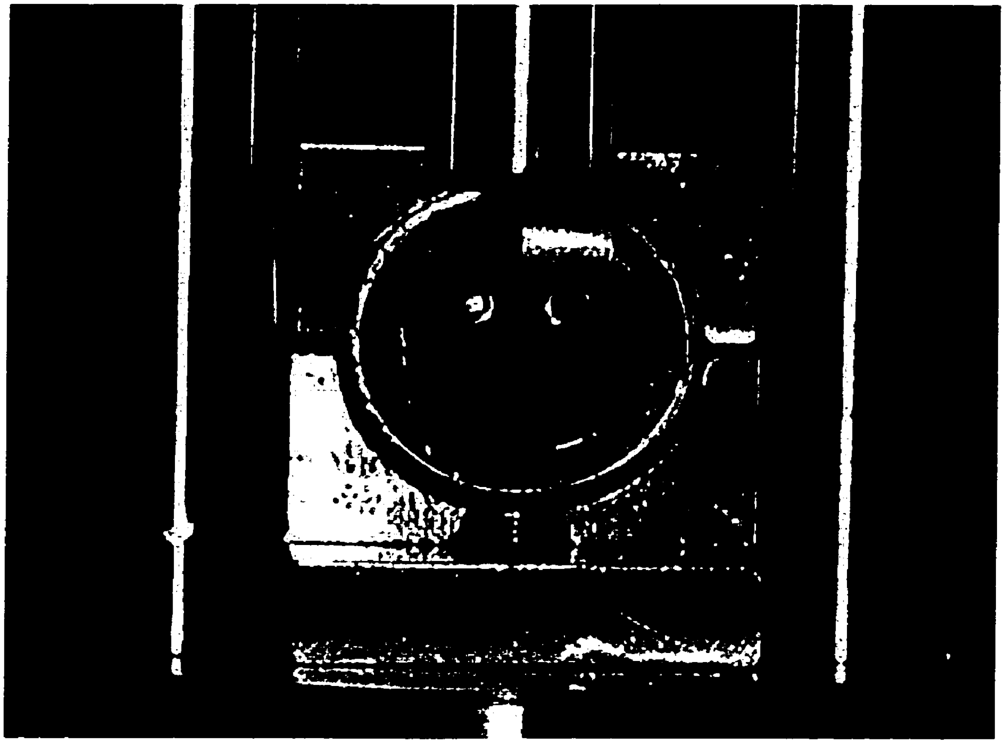


Figure 3.12: *Bencor™ Multi-T testing apparatus (Danville Engineering, San Ramon, CA, USA) with a knife-edged shearing blade positioned parallel to the test interface at the enamel-bracket junction.*

3.10 Evaluation of Fracture Sites

The surfaces of each group were examined under a light-optical stereomicroscope at 20x magnification (Nikon SM2-10, Tokyo, Japan). The residual adhesive on the enamel surface was evaluated by two independent examiners (to assure interexaminer reliability) after debonding. The Adhesive Remnant Index (ARI) of Oliver, 1988 was used to evaluate the enamel. The ratings assigned to each tooth range from 1 to 5.

Adhesive Remnant Index (Oliver, 1988):
Score 1= indicates that all of the composite remained on the enamel surface.
Score 2= more than 90% of the composite remained on the enamel surface
Score 3= more than 10% and less than 90% of the composite remained on the enamel surface
Score 4= less than 10% of the composite remained on the enamel surface
Score 5= no composite remained on the enamel surface

Representative samples of the debonding surfaces of each of the five ARI scores were selected to undergo magnified photography to further evaluate the surface characterization of the enamel and fracture interface.

3.11 Statistical Analysis of Data

The descriptive statistics, including the mean, standard deviation, and minimum and maximum values for each of the twelve groups were recorded. The results of shear-peel bond strength testing at 24 hours and at 6 months were evaluated using a one-tailed analysis of variance (ANOVA) at the 0.05 level of significance to determine if differences exist among the mean bond strengths of the samples cemented with the various adhesives and conditions. The means were then compared by Tukey's multiple range test to determine where statistically significant differences existed among the various surface preparations.

The 24 hour and 6 month bond strengths for each adhesive were then compared using a repeated measures ANOVA and a paired t-test for each group at the 0.05 level of significance to determine if significant differences existed between 24 hour and 6 month bond strengths, adhesives, and moist vs. dry conditions. (Hassard, 1991)

The Adhesive Remnant Index scores of the six samples were compared using the one-tailed analysis of variance (ANOVA) at the 0.05 level of significance to determine incidences of each of the 5 scores from the different adhesives, surface preparations, and storage time.

CHAPTER 4

RESULTS

4. RESULTS

4.1 Shear-peel Bond Strengths

4.1.1 Twenty-four hour bond strengths

The highest mean shear-peel bond strengths were obtained in the samples bonded with Transbond™ XT/ Dry (10.57 ± 2.83 MPa). Using the ANOVA analysis and a Tukey's test, statistically significant differences were found between the six treatment groups at the 5% level of confidence ($p<0.05$). The Transbond™ XT/ Dry bond strength was significantly greater ($p<0.05$) than that of the other two adhesives in this study. The bond strengths of Assure™ Dry (6.93 ± 2.20 MPa) and Assure™ Moist (6.03 ± 1.77 MPa) were significantly higher ($p<0.05$) than Smartbond® Dry (3.91 ± 1.17 MPa) and Smartbond® Moist (3.22 ± 0.52 MPa). Assure™ Dry and Moist did not exhibit any statistically significant differences ($p<0.05$) between each other, neither did Smartbond® Dry or Moist ($p<0.05$). Bonding of Transbond™ XT under saliva contaminated (moist) conditions was virtually unsuccessful providing only meager average bond strengths (0.141 ± 0.31 MPa).

Individual shear-peel bond strengths of each sample, as well as mean shear-peel bond strengths, maximum, minimum, standard deviations and coefficients of variance for each group are listed in Tables 4.1-4.6. The comparative data for the mean shear-peel bond strengths and standard deviations are listed in Figure 4.1.

Under dry conditions, Transbond™ XT provided the highest shear-peel bond strengths of all the materials with a mean value of 10.57 ± 2.83 MPa. The highest and lowest values were closely associated with the mean (15.7 MPa and 7.1 MPa). (Table 4.1) Under moist conditions however, a completely different trend was observed. Transbond™ XT moist, provided the lowest shear-peel bond strengths of all materials with a mean value of 0.14 ± 0.31 MPa. The highest and lowest values were closely associated with the mean (0.82 MPa and 0 MPa). Eight of the samples did not bond to the tooth, producing shear-peel bond strengths of 0 MPa. (Table 4.4)

Under dry conditions, Assure™ provided a mean shear-peel bond strength of 6.93 ± 2.20 MPa. The highest and lowest values were 10.93 MPa and 3.18 MPa. The highest and lowest values were substantially higher or lower than the second highest and lowest values (9.53 MPa and 5.16 MPa), which are more closely associated with the mean. (Table 4.2) Under moist conditions, Assure™ provided a mean shear-peel bond (6.03 ± 1.77 MPa) that was closely related with Assure™ dry (6.93 ± 2.20 MPa). The highest and lowest shear-peel bond strengths were 7.94 MPa and 2 MPa respectively. This large range seem to be attributed to the lowest shear-peel bond strength (2 MPa) being substantially lower than the second lowest of 3.93 MPa. (Table 4.5)

Under dry (nonsaliva contaminated) conditions, Smartbond® provided a mean shear-peel bond strength of 3.91 ± 1.17 MPa. The highest and lowest values were closely associated with the mean (5.77 MPa and 2.22 MPa). (Table 4.3) Under moist conditions, Smartbond® provided a mean shear-peel bond strength of 3.22 ± 0.52 MPa. This value is closely related to Smartbond® dry (3.91 ± 1.17 MPa). The highest and lowest values were closely associated with the mean (4.24 MPa and 2.68 MPa). (Table 4.6)

Table 4.1

24 Hour Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Transbond™ XT Under Dry Conditions

24 Hour Transbond™ XT/Dry Sample No.	Shear-Peel Bond Strength in MPa
1	10.12
2	9.32
3	9.22
4	12.74
5	8.27
6	9.98
7	8.39
8	7.1
9	14.4
10	15.73
Minimum	**7.1**
Maximum	**15.73**
Mean	**10.57**
Standard Deviation	**2.83**
Variance	**8.00**

Table 4.2
24 Hour Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Assure™ Under Dry Conditions

24 Hour Assure™/Dry Sample No.	Shear-Peel Bond Strength in MPa
1	5.16
2	7.2
3	6.05
4	6.46
5	9.53
6	5.64
7	10.93
8	7.8
9	3.18
10	7.31
Minimum	**3.18**
Maximum	**10.93**
Mean	**6.93**
Standard Deviation	**2.20**
Variance	**4.84**

Table 4.3
24 Hour Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Smartbond® Under Dry Conditions

24 Hour Smartbond®/Dry Sample No.	Shear-Peel Bond Strength in MPa
1	5.58
2	2.22
3	5.77
4	2.74
5	4
6	4.76
7	3.92
8	3.1
9	3.23
10	3.73
Minimum	2.22
Maximum	5.77
Mean	3.91
Standard Deviation	1.17
Variance	1.37

Table 4.4
24 Hour Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Transbond™ XT Under Moist Conditions

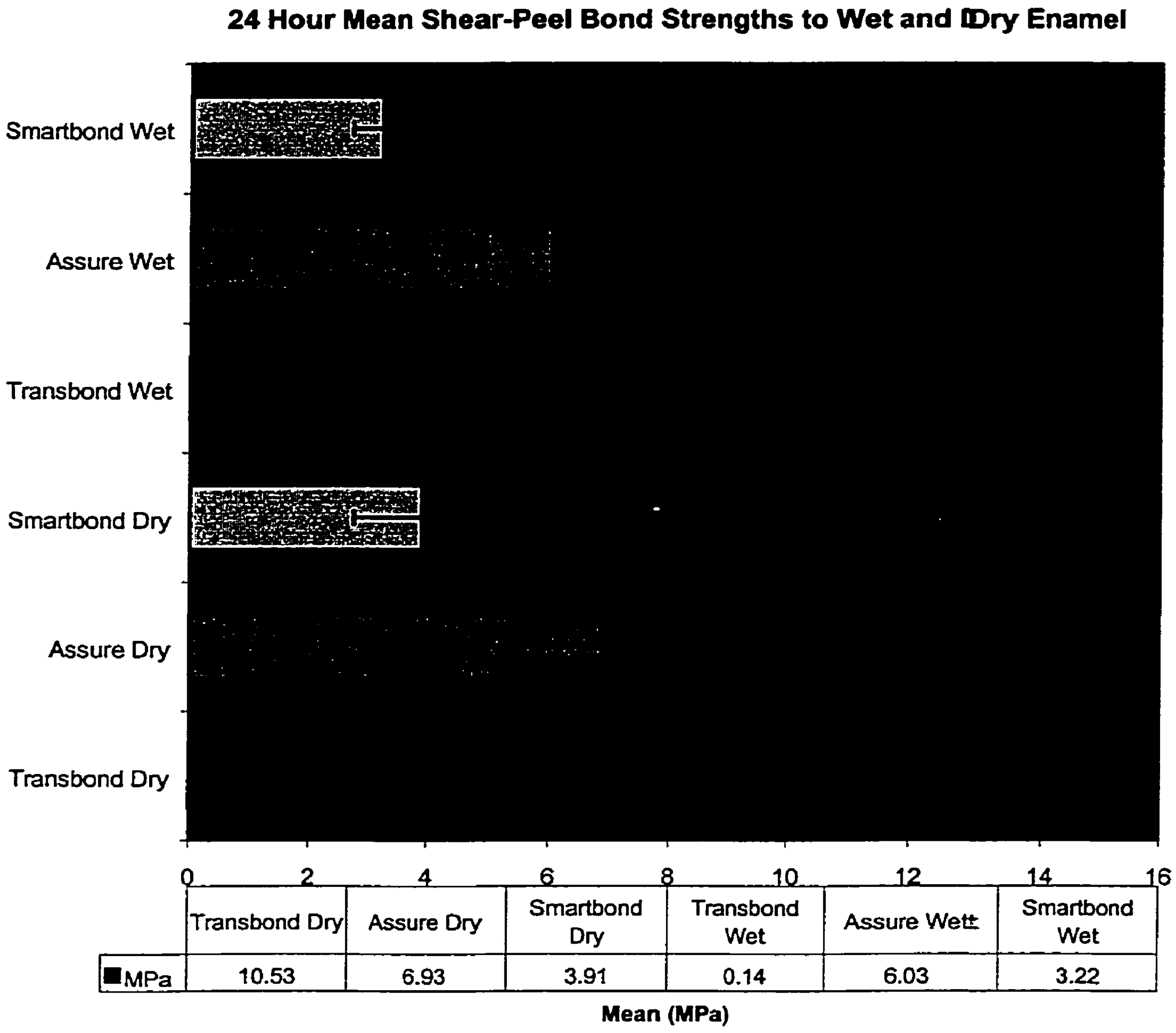
24 Hour Transbond™ XT/Moist Sample No.	Shear-Peel Bond Strength in MPa
1	0.52
2	0.89
3	0
4	0
5	0
6	0
7	0
8	0
9	0
10	0
Minimum	0
Maximum	0.89
Mean	0.14
Standard Deviation	0.31
Variance	0.1

Table 4.5
24 Hour Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Assure™ Under Moist Conditions

24 Hour Assure™/Moist Sample No.	Shear-Peel Bond Strength in MPa
1	7.94
2	7.2
3	2
4	7.32
5	6.82
6	6.56
7	3.93
8	6.32
9	6.01
10	6.18
Minimum	2
Maximum	7.94
Mean	6.03
Standard Deviation	1.77
Variance	3.15

Table 4.6
24 Hour Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Smartbond® Under Moist Conditions

24 Hour Smartbond®/Moist Sample No.	Shear-Peel Bond Strength in MPa
1	2.96
2	3.01
3	3.91
4	4.24
5	3.35
6	2.68
7	3.26
8	3.31
9	2.68
10	2.79
Minimum	2.68
Maximum	4.24
Mean	3.22
Standard Deviation	0.52
Variance	0.27



	Transbond Dry	Assure Dry	Smartbond Dry	Transbond Wet	Assure Wett	Smartbond Wet
■MPa	10.53	6.93	3.91	0.14	6.03	3.22

Figure 4.1: *Graph comparing 24 hour mean shear-peel bond strengths (±standard deviations shown with error bars).*

4.1.2 Six month bond strengths

The highest mean shear-peel bond strengths (12.23 ±3.14 MPa) were again obtained in teeth treated with Transbond™ XT without saliva contamination. Using the ANOVA analysis and a Tukey's test statistically significant differences were found between the treatment groups at the 5% level of confidence ($p<0.05$). The bond strength of Transbond™ XT under dry conditions (12.23 ± 3.14 MPa) was significantly greater ($p<0.05$) than that of the other two adhesives in this study. The bond strengths of Assure™ (saliva contaminated and dry) (6.86 ± 2.81 MPa and 6.18 ± 1.39 MPa respectively) were significantly higher ($p<0.05$) than Smartbond® (saliva contaminated and non saliva contaminated) (2.4 ± 0.96 MPa and 3.94 ± 1.96 MPa respectively). Assure™ (saliva contaminated (6.86 ± 2.81 MPa) and dry (8.18 ± 1.39 MPa)) did not exhibit any statistically significant differences ($p<0.05$) between each condition (non-saliva contaminated and saliva contaminated), neither did Smartbond® (saliva contaminated (2.4 ± 0.96 MPa) and non saliva contaminated (3.94 ± 1.96 MPa). Bonding of Transbond™ XT under wet or saliva contaminated conditions was unsuccessful (0 MPa). Assure™ produced the highest shear-peel bond strengths when bonded under dry or non saliva contaminated conditions (8.18 ± 1.39 MPa).

Individual shear-peel bond strengths of each sample, as well as mean shear-peel bond strengths, maximum, minimum, standard deviations and coefficients of variance for each group are listed in Tables 4.7-4.12. The comparative data for the mean shear-peel bond strengths, standard deviations and coefficients of variation are listed in Figure 4.2.

Under dry conditions, Transbond™ XT provided the highest shear-peel bond strengths of all the materials with a mean value of 12.23 ± 3.14 MPa. The highest and lowest values were 17.67 MPa and 9.1 MPa. (Table 4.7) Under moist conditions however, a completely different trend was observed. Transbond™ XT moist or saliva contaminated, provided the lowest shear-peel bond strengths of all materials with a mean value of 0 ± 0 MPa. The highest and lowest values were the same as the mean (0 MPa). None of the ten samples bonded to the teeth. (Table 4.10)

Under dry conditions, Assure™ provided a mean shear-peel bond strength of 8.18 ± 1.39 MPa. The highest and lowest values were closely associated to the mean (10.84 MPa and 6.41 MPa.). (Table 4.8) Under moist conditions, Assure™ provided a mean shear-peel bond (6.86 ± 1.77 MPa) that was closely related with Assure™ dry (8.18 ± 1.39 MPa). The highest and lowest shear-peel bond strengths of Assure™ moist were 10.78 MPa and 2.23 MPa respectively. This large range seemed to be attributed to the lowest shear-peel bond strength (2.23 MPa) being substantially lower than the second lowest of 3.81 MPa. (Table 4.11)

Under dry (nonsaliva contaminated) conditions, Smartbond® provided a mean shear-peel bond strengths of 3.94 ± 1.96 MPa. The highest and lowest values were 8.98 MPa and

1.49 MPa. The highest value (8.98 MPa) is substantially higher than the second highest value (4.67 MPa). This could contribute to the high standard deviation. (Table 4.9) Under moist conditions, Smartbond® provided a mean shear-peel bond strength of 2.4 ± 0.956 MPa. This value is closely related to Smartbond® dry (3.94 ± 1.96 MPa). The highest and lowest values were 3.4 MPa and 0 MPa. The high standard deviation may be attributed to the lowest value of 0 MPa. The second lowest value is 2.1 MPa, which is closely associated with the mean. (Table 4.12)

Table 4.7

6 Month Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Transbond™ XT Under Dry Conditions

6 Month Transbond™ XT/Dry Sample No.	Shear-Peel Bond Strength in MPa
1	12.88
2	9.1
3	11.99
4	11.04
5	12.52
6	17.67
7	10.88
8	9.35
9	9.28
10	17.58
Minimum	9.1
Maximum	17.67
Mean	12.23
Standard Deviation	3.14
Variance	9.87

Table 4.8
6 Month Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Assure™ Under Dry Conditions

6 Month Assure™/Dry Sample No.	Shear-Peel Bond Strength in MPa
1	**6.41**
2	**8.8**
3	**7.3**
4	**9.28**
5	**8.76**
6	**7.29**
7	**7.31**
8	**10.84**
9	**9.05**
10	**6.75**
Minimum	**6.41**
Maximum	**10.84**
Mean	**8.18**
Standard Deviation	**1.39**
Variance	**1.92**

Table 4.9

6 Month Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Smartbond® Under Dry Conditions

6 Month Smartbond®/Dry Sample No.	Shear-Peel Bond Strength in MPa
1	**4.36**
2	**3.16**
3	**4.67**
4	**4.27**
5	**4.56**
6	**3.6**
7	**1.49**
8	**2.89**
9	**3.16**
10	**8.98**
Minimum	**1.49**
Maximum	**8.98**
Mean	**3.94**
Standard Deviation	**1.96**
Variance	**3.86**

Table 4.10
6 Month Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Transbond™ XT Under Moist Conditions

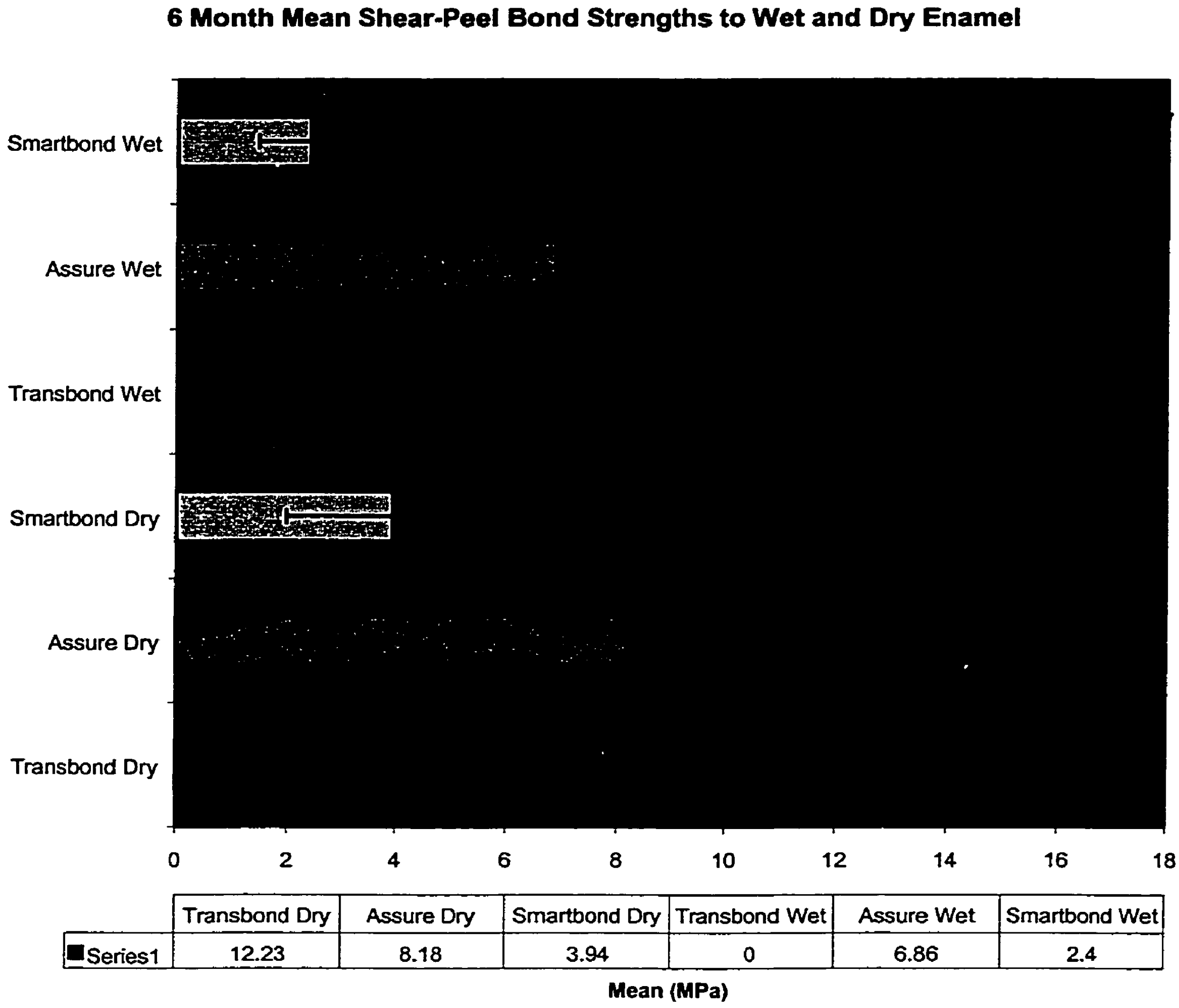
6 Month Transbond™ XT/Moist Sample No.	**Shear-Peel Bond Strength in MPa**
1	**0**
2	**0**
3	**0**
4	**0**
5	**0**
6	**0**
7	**0**
8	**0**
9	**0**
10	**0**
Minimum	**0**
Maximum	**0**
Mean	**0**
Standard Deviation	**0**
Variance	**0**

Table 4.11
6 Month Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Assure™ Under Moist Conditions

6 Month Assure™/Moist Sample No.	Shear-Peel Bond Strength in MPa
1	**6.85**
2	**3.81**
3	**4.39**
4	**5.38**
5	**8.76**
6	**10.78**
7	**7.98**
8	**9.88**
9	**2.23**
10	**8.5**
Minimum	**2.23**
Maximum	**10.78**
Mean	**6.86**
Standard Deviation	**2.81**
Variance	**7.9**

Table 4.12
6 Month Shear-Peel Bond Strengths in MPa of Enamel Samples Bonded with Smartbond® Under Moist Conditions

6 Month Smartbond®/Moist Sample No.	Shear-Peel Bond Strength in MPa
1	**2.88**
2	**2.1**
3	**2.49**
4	**0**
5	**3.4**
6	**3.31**
7	**2.57**
8	**2.12**
9	**2.83**
10	**2.25**
Minimum	**0**
Maximum	**3.4**
Mean	**2.4**
Standard Deviation	**0.956**
Variance	**0.915**



	Transbond Dry	Assure Dry	Smartbond Dry	Transbond Wet	Assure Wet	Smartbond Wet
■Series1	12.23	8.18	3.94	0	6.86	2.4

Figure 4.2: *Graph comparing 6 month mean shear-peel bond strengths (standard deviations shown with error bars).*

4.1.3 24 hour vs 6 month shear-peel bond strengths

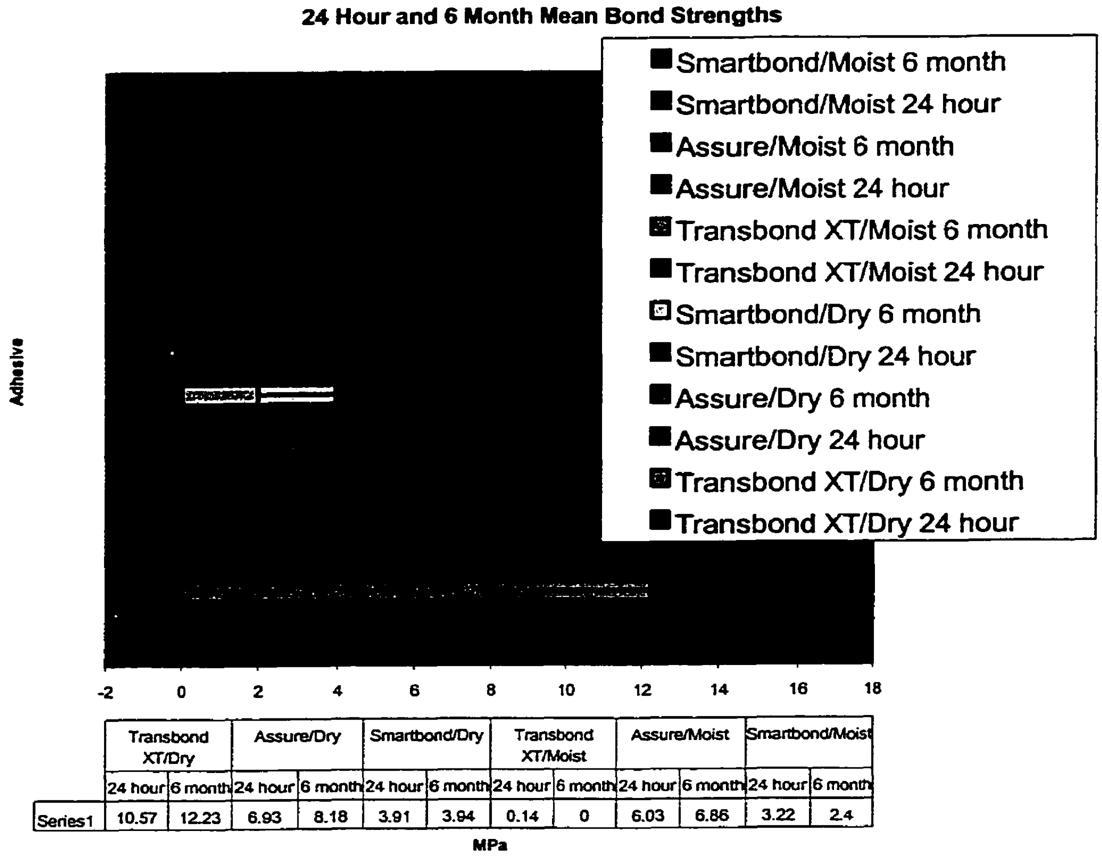
Using a repeated measures ANOVA and a paired t-test for each group at the 5% level of confidence, the bond strengths at the 24 hours and 6 months were found to have no significant differences between all groups. This includes time, bonding adhesive/time, and bonding adhesive/time/ dry-moist. The mean shear-peel bond strengths are as follows: Transbond™ XT/dry (10.57 ± 2.83 MPa vs 12.23 ± 3.14 MPa), Assure™/dry (6.93 ± 2.2 MPa vs 8.18 ± 1.39 MPa), Smartbond®/dry (3.91 ± 1.17 MPa vs 4.11 ± 1.96 MPa), Transbond™ XT/moist (0.14 ± 0.31 MPa vs 0 ± 0 MPa), Assure™/moist (6.03 ± 1.77 MPa vs 6.86 ± 2.81 MPa), and Smartbond®/moist (3.22 ± 0.52 MPa vs 2.4 ± 0.96 MPa). The magnitude of the mean bond strengths increased in all groups from 24 hours to 6 months, except for Transbond™ XT/moist and Smartbond® moist, but these increases or decreases were not significant ($p>0.05$). It is important to note that there may be a slight trend of moist and dry samples to act differently over time, that is, for moist samples to bond less effectively than dry samples ($p=0.08$), but this too was not statistically significant.

The comparative data for the mean sheer-peel bond strengths, standard deviations and coefficients of variance are listed in Table 4.13 and Figure 4.3.

Table 4.13

Comparative Data for 24 Hour and 6 Month Bond Strengths

Adhesive		Shear-Peel Bond Strengths (MPa)	Standard Deviation (MPa)	% Change
Transbond XT/Dry	24 hour	10.57	2.83	
	6 month	12.23	3.14	+15.7%
Assure/Dry	24 hour	6.93	2.2	
	6 month	8.18	1.39	+15.3%
Smartbond/Dry	24 hour	3.91	1.17	
	6 month	3.94	1.96	+0.761%
Transbond XT/Moist	24 hour	0.14	0.31	
	6 month	0	0	-14.0%
Assure/Moist	24 hour	6.03	1.77	
	6 month	6.86	2.81	+12.1%
Smartbond/Moist	24 hour	3.22	0.52	
	6 month	2.4	0.96	-34.2%



	Transbond XT/Dry		Assure/Dry		Smartbond/Dry		Transbond XT/Moist		Assure/Moist		Smartbond/Moist	
	24 hour	6 month	24 hour	6 month	24 hour	6 month	24 hour	6 month	24 hour	6 month	24 hour	6 month
Series1	10.57	12.23	6.93	8.18	3.91	3.94	0.14	0	6.03	6.86	3.22	2.4

Figure 4.3: *Graph Comparing 24 Hour and 6 Month Mean Bond Strengths (standard deviations shown with error bars).*

4.2 Adhesive Remnant Index (ARI) Scores

The adhesive remnant index scores calculated for each group are listed in Table 4.14.

Overall, the most common debond was Type 3, which had more than 10% and less than 90% of the adhesive remaining on the enamel (Figure 4.4), occurring in 37.5% (45/120) of the samples. The second most common was Type 4, which has less than 10% of the adhesive remaining of the enamel (Figure 4.5), occurring in 25% (30/120) of the samples. Type 5, no adhesive remaining on the enamel (Figure 4.6), occurred in 19.2% (23/120) of the samples. Type 1, all of the adhesive remaining on the enamel (Figure 4.7), occurred in 12.5% (15/120) of the samples and type 2, more than 10% and less than 90% of the adhesive remaining on the enamel (Figure 4.8), occurred in 5% (7/120) of the samples.

The different adhesives/conditions (moist/dry) time periods were analyzed using a repeated measure ANOVA and a Tukey's multiple comparison test. Using these analyses, statistically significant differences were found between the treatment groups at the 5% level of confidence ($p<0.05$). The means taken for each group were analyzed. Statistical differences ($p<0.05$) were noted between adhesive and condition (moist/dry). Transbond™ XT /Dry (24 hours and 6 months-2.6 ± 1.58 and 2.1 ± 1.60 respectively) is statistically ($p<0.05$) different from Smartbond®/Dry (24 hours and 6 months-3.5 ± 0.71 and 3.4 ± 0.70 respectively) and Transbond XT/Moist (24 hours and 6 months-5 ± 0 and 5 ± 0 respectively). Assure™/Dry (24 hours and 6 months-2.8 ± 1.35 and 3 ± 1.05 respectively), Assure™/Wet (24 hours and 6 months-2. ± 0.88 and 3.3 ± 0.95

respectively) and Smartbond®/Moist (24 hours and 6 months-3.3 ± 0.83 and 3 ± 0 respectively) are different from Transbond™ XT/Moist (24 hours and 6 months-5 ± 0 and 5 ± 0 respectively), but not themselves. Smartbond®/Dry (24 hours and 6 months-3.5 ± 0.71 and 3.4 ± 0.70 respectively) is statistically ($p<0.05$) different from Transbond™ XT/ Moist (24 hours and 6 months-5 ± 0 and 5 ± 0 respectively) and Transbond XT/Dry (24 hours and 6 months-2.6 ± 1.58 and 2.1 ± 1.60 respectively). Transbond™ XT/Moist (24 hours and 6 months-5 ± 0 and 5 ± 0 respectively) is different from all of the groups. There were no statistical differences ($p>0.05$) between the adhesive/time, moist-dry/time, moist/dry, or adhesive/time/moist-dry. The samples bonded with Transbond™ XT/Moist (24 Hour and 6 Month) had no occurrences of adhesive remnants (Score 5). Smartbond® /Moist (6 Months) had consistent scores of 3. None of the groups exhibited any trends and the ARI scores seemed to be random. No enamel fractures were noted.

Table 4.14
Adhesive Remnant Index (ARI) Scores

Sample Number	ARI	Score		Sample Number	ARI	Score
	24 Hour	6 Month			24 Hour	6 Month
Transbond™/Dry-1	1	1		Transbond™/Moist-1	5	5
Transbond™/Dry-2	1	4		Transbond™/Moist-2	5	5
Transbond™/Dry-3	1	1		Transbond™/Moist-3	5	5
Transbond™/Dry-4	4	4		Transbond™/Moist -4	5	5
Transbond™/Dry-5	2	5		Transbond™/Moist -5	5	5
Transbond™/Dry-6	5	1		Transbond™/Moist -6	5	5
Transbond™/Dry-7	4	1		Transbond™/Moist -7	5	5
Transbond™/Dry-8	1	2		Transbond™/Moist -8	5	5
Transbond™/Dry-9	3	1		Transbond™/Moist -9	5	5
Transbond™/Dry-10	4	1		Transbond™/Moist -10	5	5
Mean	2.6±1.58	2.1±1.60			5±0	5±0
Assure™/Dry-1	2	1		Assure™/Moist-1	4	4
Assure™/Dry -2	3	3		Assure™/Moist -2	3	4
Assure™/Dry -3	1	2		Assure™/Moist -3	3	3
Assure™/Dry -4	4	3		Assure™/Moist -4	1	1
Assure™/Dry -5	4	4		Assure™/Moist -5	2	4
Assure™/Dry -6	1	3		Assure™/Moist -6	3	4
Assure™/Dry -7	3	2		Assure™/Moist -7	3	3
Assure™/Dry -8	4	4		Assure™/Moist -8	4	4
Assure™/Dry -9	3	4		Assure™/Moist -9	3	3
Assure™/Dry -10	3	4		Assure™/Moist -10	3	3
Mean	2.8±1.35	3±1.05			2.9±0.88	3.3±0.95
Smartbond®/Dry-1	4	5		Smartbond®/Moist-1	4	3
Smartbond®/Dry -2	4	3		Smartbond®/Moist -2	3	3
Smartbond®/Dry -3	4	3		Smartbond®/Moist -3	3	3
Smartbond®/Dry -4	4	3		Smartbond®/Moist -4	4	3
Smartbond®/Dry -5	4	3		Smartbond®/Moist -5	3	3
Smartbond®/Dry -6	4	4		Smartbond®/Moist -6	3	3
Smartbond®/Dry -7	3	3		Smartbond®/Moist -7	3	3
Smartbond®/Dry -8	3	3		Smartbond®/Moist -8	3	3
Smartbond®/Dry -9	2	3		Smartbond®/Moist -9	4	3
Smartbond®/Dry -10	3	4		Smartbond®/Moist -10	3	3
Mean	3.5±0.71	3.4±0.70			3.3±0.48	3±0

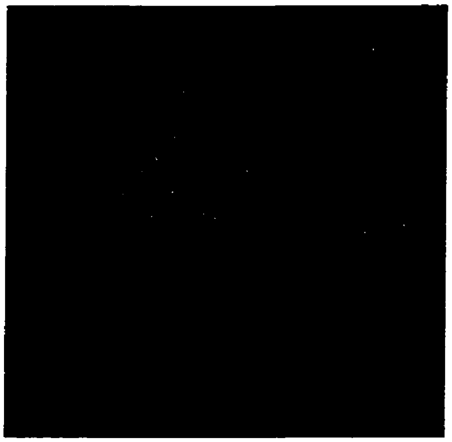


Figure 4.4
Typical debond (X20) at the enamel adhesive junction with an ARI Score of 1 (100% of the composite remained on the enamel surface).

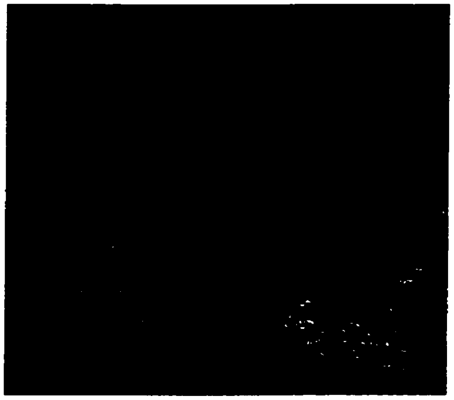


Figure 4.5
Typical debond (X20) at the enamel adhesive junction with an ARI Score of 2 (more than 90% of the composite remained on the enamel surface).

Figure 4.6
Typical debond (X20) at the enamel adhesive junction with an ARI Score of 3 (more than 10% and less than 90% of the composite remained on the enamel surface).

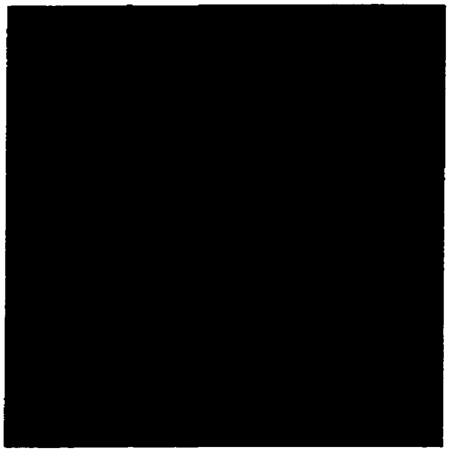


Figure 4.7
Typical debond (X20) at the enamel adhesive junction with an ARI Score of 4 (less than 10% of the composite remained on the enamel surface).

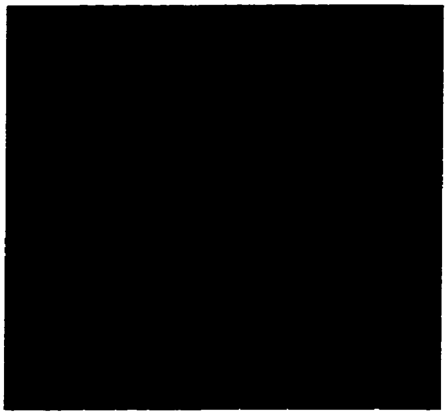


Figure 4.8
Typical debond (X20) at the enamel adhesive junction with an ARI Score of 5 (no composite remained on the enamel surface).

CHAPTER 5

DISCUSSION

5. DISCUSSION

5.1 Twenty-four Hour Bonds Strengths

Bonding orthodontic attachments has historically necessitated a dry field. This can be challenging in the mouth as a whole, but is especially difficult in the posterior regions of the mouth. Contamination from saliva and water are very common, leading to an increase in the incidence of bond failure with many adhesives (Zachrisson, 1977). Zachrisson (1977) bonded a total of 705 orthodontic attachments to a total of forty-six children ages 11-14 years of age *in vivo* and monitored the failure rates over the course of 17 months. He reported that when patients with marked hypersalivation were bonded with orthodontic attachments, considerable problems developed and had an increased incidence of bond failures. The four patients with hypersalivation, were the only four patients to have 4 or more debonded brackets. Zacharisson (1977) also noted that the there was a striking difference between bond failure rates of first and second premolars. Maxillary first premolars exhibited a 10.0% failure rate, maxillary second premolars exhibited a 21.4% failure rate, mandibular first premolars exhibited a 8.1% failure rate, and mandibular second premolars exhibited a 24.2% failure rate. This difference was attributed to the fact that many of the second premolars were in various stages of eruption at the time of bonding and that they had difficulty in maintaining a dry field due to the position of the bracket being closer to the gingival sulcus and therefore more likely to be contaminated from gingival-crevicular fluid. It is time consuming for both the patient and the clinician to rebond orthodontic attachments. Recently there has been the introduction of adhesive systems that are less sensitive to contamination and which, according to the manufacturers, still provide clinically acceptable bond strengths. Assure™ and Smartbond® represent two such products which were tested in the present study.

As mentioned earlier, no standardized protocols exist for bond strength testing in orthodontics (Eliades and Brantley, 2000). This makes it difficult to draw meaningful conclusions by comparing one study to another. However, a comparison of previously published studies to the results of this study reveal some common trends.

In the present study, there were statistically significant differences ($p<0.05$) in the mean shear-peel bond strengths of the different adhesives. The highest mean shear-peel bond strengths were obtained when the samples were bonded with Transbond™ XT under dry conditions. The samples treated with Assure™, both moist and dry, were not statistically different from one another ($p>0.05$), but were significantly greater ($p<0.05$) than Smartbond® (dry and moist). The bond strengths of both Assure™ (saliva contaminated and dry) and Transbond™ XT (dry) adhesives were greater than the 5 to 8 MPa considered by Reynolds and von Fraunhofer (1976) to be "desirable" minimum values. The bond strengths of Transbond™ XT (dry) at 10.57 ± 2.83 MPa was significantly greater than that of the other two adhesives in this study and was also greater than that noted by Bishara et al. (1998 b) for Transbond™ XT (dry/24 hours) of 7.2 ± 3.1 MPa. The bond strengths of Assure™ (saliva contaminated and dry) were significantly ($p<0.05$) higher than Smartbond® (saliva contaminated and non saliva contaminated). Assure™

saliva contaminated (6.03 ± 1.77 MPa) and dry (6.93 ± 2.20 MPa) did not exhibit any statistically significant ($p<0.05$) difference between each other, neither did Smartbond® saliva contaminated (3.22 ± 0.52 MPa) and non-saliva contaminated (3.91 ± 1.77 MPa). Bonding of Transbond™ XT under moist (saliva contaminated) conditions was virtually unsuccessful (0.141 ± MPa).

Willems, Carels, and Verbeke (1997) reported shear-peel bond strengths of Transbond™ XT bonded to acid etched human premolar teeth of 8.4 ± 0.8 MPa after 24 hours of storage in distilled water at 37°C. McCourt, Cooley, and Barnswell (1991) reported shear bond strengths of Transbond™ XT bonded to premolar teeth of 9.19 ± 3.80 MPa after 24 hours. Bishara et al (1999 a) reported shear bond strengths of Transbond™ XT bonded to molars on uncontaminated etched enamel. They reported a mean shear bond strength of 10.4 ± 2.8 MPa after 48 hours. All of the values listed are in the range of the mean shear-peel bond strength of Transbond™ XT (Dry) of 10.57 ± 2.83 MPa reported in the present study.

Bishara et al (1998 b) reported shear bond strengths of Transbond™ XT bonded to molars on uncontaminated etched enamel. They reported a mean shear bond strength of 7.2 ± 3.1 MPa after thermal cycling between 5° ± 2° C and 50° ± 2° C for a total of 2000 cycles. This bond strength is slightly lower than that of Transbond™ XT (Dry) reported in this study. This could be due to the thermal cycling. Test periods of 2000 cycles would be equivalent to a 40-day exposure to these temperature changes (Bishara et al, 1998 b).

Meehan, Foley, and Mamandras (1999) reported shear bond strengths of Transbond™ XT bonded to premolars on uncontaminated etched enamel. They reported a mean shear bond strength of 11.23 ± 4.66 MPa after 30 days. This bond strength is slightly higher than that of Transbond™ XT (Dry) reported in this study.

Rock and Abdullah (1997) reported a shear bond strength of Transbond™ XT to premolar teeth of 18.17 ± 3.19 MPa after 24 hours. This value is much higher than the value obtained in this study. This difference in magnitude of bond strengths can probably be attributed to different testing conditions, methods, and materials.

Orthendahl and Ortengren (2000) reported shear bond strengths of Smartbond® bonded to premolars on uncontaminated etched enamel. They reported mean shear bond strengths of 18 to 26 MPa, (depending on the bracket) after 24 hours. These bond strengths were substantially higher than that of Smartbond® (saliva contaminated or not contaminated) of 3.22 ± 0.52 MPa and 3.91 ± 1.17 MPa respectively, reported in this study. Their higher values could be due to differences in their testing protocol. (Orthendahl and Ortengren, 2000)

Assure™ failed to show clinical or statistical differences from each other with either the moist or dry protocols. Currently no studies have been published on the bond strengths of Assure™.

Fresh, whole human saliva is an acceptable material in testing saliva contamination (Evans and Silverstone, 1981; Silverstone, Hicks, and Feathersone, 1985). Koulourides, Feigin, and Pigman (1965), found that the ability of saliva to reharden softened enamel surfaces varies between persons, but tends to be consistant for the same individual. This finding may not be relevant for this study, but one can assume that there is minimal or no variability in bond strengths when the saliva sample is collected from one individual, as accomplished in the present study.

5.2 Six Month Bond Strengths

The highest mean bond strengths were again obtained in teeth treated with Transbond™ XT without saliva contamination 12.23 ± 3.14 MPa. Using the ANOVA analysis and a Tukey's test statistically significant differences were found between the treatment groups at the 5% level of confidence ($p<0.05$). The bond strength of Transbond™ XT (dry) at 12.23 ± 3.14 MPa was significantly greater than that of the other two adhesives in this study. The bond strengths of Assure™ (saliva contaminated and dry) (6.86 ± 2.81 MPa and 8.18 ± 1.39 MPa respectively) were significantly higher than Smartbond® (saliva contaminated and non saliva contaminated) (2.4 ± 0.96 MPa and 3.94 ± 1.96 MPa respectively). Assure™ saliva contaminated (6.86 ± 2.81 MPa) and dry (8.18 ± 1.39 MPa) did not exhibit any statistically significant ($p<0.05$) differences between each other, neither did Smartbond® saliva contaminated (2.4 ± 0.96 MPa) and non-saliva contaminated (3.94 ± 1.96 MPa). Bonding of Transbond™ XT under wet or saliva contaminated conditions was unsuccessful (0 MPa). The bond strengths of Assure™ (saliva contaminated and dry) and Transbond™ XT (dry) adhesives fall within the values of 5 to 8 MPa considered by Reynolds and von Fraunhofer (1976) to be desirable minimum values.

No previously published studies could be found in the English orthodontic literature investigating bond strengths of these adhesives to enamel at 6 months.

Meehan, Foley, and Mamandras (1999) reported shear bond strengths of Transbond™ XT bonded to premolars on uncontaminated etched enamel. They reported a mean shear bond strength of 11.23 ± 4.66 MPa after 30 days. This bond strength is slightly lower than that of Transbond™ XT (Dry) of 12.23 ± 3.14 MPa, reported in this study, but still within the same order of magnitude.

McCourt, Cooley, and Barnwell (1991) reported shear bond strengths of Transbond™ XT bonded to premolar teeth of 11.35 ± 3 MPa after 4 weeks, which was a slight increase in relation to the 24 hour bond strength reported as 9.19 ± 3.30 MPa. This 4 week value is similar the present study which showed a 6 month value of 12.23 ± 3.14 MPa. This also represents an increase in comparison to the bond strength in the present study reported at

24 hours of 10.57 ± 2.83 MPa. The increase in shear-peel bond strengths from 24 hours to 6 months in the present study and that reported by McCourt, Cooley, and Barnswell (1991) from 24 hours to 4 weeks were not statistically significant ($p>0.05$).

Orthendahl and Ortengren (2000) reported shear bond strengths of Smartbond® bonded to premolars on uncontaminated etched enamel. They reported a mean shear bond strength of 18 to 26 MPa, (depending of the bracket) after 24 hours. This bond strength is substantially higher than that of Smartbond® (saliva contaminated or not contaminated) of 2.4 ± 0.96 MPa and 3.94 ± 1.96 MPa respectively, reported in this study. Their higher results could be due to their laboratory protocol, which was not elucidated.

The Assure™ samples failed to show statistical differences ($p>0.05$) from each other with either the moist or dry protocols. The values obtained in the present study for Assure™ saliva contaminated were (6.86 ±2.81 MPa) and dry were (8.18 ± 1.39 MPa). Currently, no studies have been published in the English orthodontic literature that report on the bond strengths of Assure™.

5.3 ARI Scores

The ARI scores (Adhesive Remnant Index) indicated that there were differences between the groups. However, there were similarities between the Assure™ (saliva contaminated and dry). The Transbond™ XT (saliva contaminated) group all exhibited a score of 5 in which no composite remained on the enamel surface. It is also important to note that no enamel fractures occurred.

Willems, Carels, and Verbeke (1997) reported ARI scores of Transbond™ XT bonded to premolar teeth on uncontaminated etched enamel after 24 hours. The mean ARI score reported for Transbond™ XT was 2.08. The mean ARI reported in the present study after 24 hours for Transbond™ XT was 2.6 ± 1.58. The two studies had similar values, but the standard deviation is too large to have a significant meaning.

Millett et al (1999) reported ARI scores of Transbond™ XT bonded to premolar teeth on uncontaminated etched enamel after 24 hours. The mean ARI score indicated that in all of the samples the adhesive remained on the tooth. The difference of this value from that in the present study could be attributed to different testing conditions or methods, such as variations in the cross head speed.

Ortenhdahl and Ortengren (2000) reported ARI scores for Smartbond® bonded to premolars on uncontaminated etched enamel after 24 hours. They studied 8 different bracket systems. The mean ARI scores they reported range from ~1.9 to 4.6. The mean ARI reported in this study after 24 hours for Smartbond® was 3.5 ± 0.71. This is in the range reported by Ortenhdahl and Ortengren (2000). Their mean was 3.25, which is very close to our mean of 3.5 ± 0.71. Considering both studies had similar results, the amount of adhesive remaining on the tooth must not vary substantially after 24 hour *in vitro* shear-peel bond failure.

Currently there are no studies that have been published that report on the ARI scores of Assure™.

It is important to note that the samples in this study were debonded in shear-peel mode. It is rare, in the clinical situation, that a shear-peel situation would occur when an orthodontic attachment was intentionally or traumatically debonded. It is incorrect to assume a direct relationship between *in vitro* and *in vivo*. The differences in ARI scores of *in vitro* studies is probably due to differences in test configuration and loading characteristics. It is difficult to draw meaningful conclusions when ARI scores are scored differently in different studies, when there is limited data from which to compare and where there is limited information on what to expect clinically. Nonetheless, judging from the results of the present study it can be speculated that clean-up is easiest for Transbond™ XT saliva contaminated. That is because the bond to enamel was unsuccessful, leaving no adhesive on the tooth. This however is impractical due to the fact that the adhesive did not adhere to the tooth. Assure™ and Smartbond® had ARI scores close to one another (Assure™ non-saliva contaminated 2.8 ± 1.35 (24 hours), 3 ± 1.05 (6months); Assure™ saliva contaminated 2.9 ± 0.88 (24 hours), 3.3 ± 0.95 (6months); Smartbond® non-saliva contaminated 3.5 ± 0.71 (24 hours), 3.4±0.70 (6months); Smartbond® saliva contaminated 3.3 ± 0.48 (24 hours), 3.0 ± 0 (6months)). From these results it can be speculated that the clean-up for these two products would be relatively similar. Transbond™ XT non-saliva contaminated [ARI score of 2.6 ± 1.58 (24 hours) and 2.1 ± 1.60 (6 months)] would entail slightly more clean-up than Smartbond® or Assure™.

5.4 Evaluation of the Null Hypothesis

From the results of this study the null hypothesis which states that there are no statistically significant differences in the orthodontic shear-peel bond strengths resulting from various orthodontic adhesives is rejected because there is a statistically significant difference ($p<0.05$) between the shear-peel bond strengths of each of the different adhesives.

The null hypothesis which states that the storage of the samples in water for 6 months will have no effect on the shear-peel bond strengths of the orthodontic attachments bonded to enamel is accepted because there were no statistically significant differences ($p>0.05$) between the shear-peel bond strengths of each of the different adhesives from 24 hours to 6 months.

Finally, the null hypothesis which states, that whole human unstimulated saliva will have no effect on the shear-peel bond strength of orthodontic attachments to enamel is rejected for Transbond™ XT because there was a statistically significant difference ($p<0.05$) between Transbond™ XT non-saliva contaminated and Transbond™ XT saliva contaminated. However, this hypothesis is accepted for Assure™ and Smartbond® because there was no statistically significant difference ($p>0.05$) between Assure™ non-saliva contaminated and Assure™ saliva contaminated; and Smartbond® non-saliva contaminated and Smartbond® saliva contaminated.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

Page Numbers

6. CONCLUSIONS AND RECOMMENDATIONS

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From this study, the following conclusions can be made:

1. Orthodontic attachments can be successfully bonded *in vitro*.

2. Transbond™ XT (non-saliva contaminated), tested at 24 hours and 6 months, resulted in the highest shear-peel bond strengths. Statistically Transbond™ XT's shear-peel bond strengths were greater than Assure™ and Smartbond® under all conditions.

3. Assure™ (saliva and non-saliva contaminated), tested at 24 hours and 6 month, all provided what is considered "adequate bond strengths" *in vitro* with no statistically significant differences in mean shear-peel bond strengths.

4. Smartbond® (saliva and non-saliva contaminated) provided statistically significant ($p<0.05$) lower mean shear-peel bond strengths than Assure™ (saliva and non-saliva contaminated) and Transbond™ XT (non-saliva contaminated). However, no statistically significant differences in mean shear-peel bond strengths existed between Smartbond® (saliva and non-saliva contaminated) at 24 hours and 6 months.

5. There were no statistically significant differences ($p>0.05$) between the 24 hour and 6 month shear-peel bond strengths for each group. This suggests that over a 6 month time frame, the shear-peel bond strength does not decrease.

6. Transbond™ XT, under saliva contaminated conditions, cannot be bonded successfully.

7. Transbond™ XT, Assure™ and Smartbond® among all conditions [(saliva contaminated and non-saliva contaminated) and time periods (24 hours and 6 months)] did not exhibit any enamel fracture.

8. The *in vitro* data from this study may not accurately reflect the clinical situation and should be interpreted with caution.

6.2 Recommendations

1. Normally orthodontic attachments need to remain in function for periods longer than 24 hours. When interpreting studies, consideration should be given to include a sample group that is stored in water long term (24-36 months), to better simulate the clinical duration of most orthodontic treatments.

2. In the quest to facilitate the orthodontist in bonding orthodontic attachments to enamel, manufactures should continue their effort to explore materials that can be bonded in the presence of saliva and even in the absence of acid etching.

3. Standardization of laboratory *(in vitro)* testing in biomaterials remains a problem. Future efforts should be directed at standardizing laboratory testing which would improve the data interpretation when comparing dissimilar studies.

4. Future efforts may also be directed at reproducing the clinical oral environment *in vitro*. This includes both thermal stress and mechanical stress.

5. It could be inferred that Assure™ would obtain "adequate" bond strengths *in vivo* (clinically) under saliva and non-saliva contaminated conditions. This could be useful when bonding second molars where complete isolation is challenging.

CHAPTER 7

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7. REFERENCES

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