ABSTRACT

Title of Thesis: The Effect on Final Bond Strength of Bracket Manipulation Subsequent to Initial Positioning

David A. Beebe Masters of Science in Oral Biology, 2011

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The shear bond strength of light activated orthodontic adhesives varies according to the composition of the material, placement protocol, and time prior to light curing. Manipulating brackets after their initial placement on a tooth can disrupt the adhesive's polymerization and compromise final bond strength. No previous research has investigated how a specific degree of manipulation, and the amount of time elapsed prior to curing, under specific lighting conditions, affects the orthodontic adhesives shear bond strength. Victory Series®, MBT prescription, premolar (3M Unitek, Monrovia, CA) orthodontic brackets were bonded using three different adhesives to sixty (60) bicuspids and varying the time after bracket manipulation before curing. The shear bond strength was calculated for each specimen. The brackets were debonded and the same teeth were rebonded with new, identical brackets, using the same protocol and under the same conditions. The results showed a statistically significant difference between the shear bond strength of Transbond XT and Grengloo, with Transbond XT having the highest strength. There was also a statistically significance difference in bond strength between the group cured 30 seconds after manipulation and the groups manipulated at different intervals prior to curing, with the 30 second group having the highest bond strength. This

study confirms that various orthodontic adhesives have different bond strengths depending on manipulation and varying times prior to curing each adhesive.

The Effect on Final Bond Strength of Bracket Manipulation Subsequent To Initial Positioning

by

David A. Beebe

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The Effect on Final Bond Strength of Bracket Manipulation Subsequent to Initial Positioning

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INTRODUCTION

The evolution from securing orthodontic attachments to teeth utilizing circumferential bands to the direct bonding of individual orthodontic brackets has occurred during the past thirty-five years. Unfortunately, brackets can loosen during treatment, and the median rate of bond failure for practitioners in the United States is currently around 5% (Graber et al., 2005). Bond failures interrupt the biomechanical force system and prolong active treatment. Reducing the frequency of bond failures should be a primary objective for the orthodontist, since replacing loose brackets is inefficient, time-consuming, and costly (Graber et al., 2005) Most of these failures have been attributed to errors occurring during the bonding procedure itself, and not with the actual materials or quality of the brackets. Many studies have evaluated bond strength while manipulating one independent variable such as time prior to curing, but no study has evaluated the effect of bracket manipulation prior to curing, under controlled lighting conditions.

LITERATURE REVIEW

Evolution from Banding to Bonding

Numerous advancements in dental materials and techniques have allowed orthodontists to prepare tooth enamel for effective and reliable bonding with dental adhesives. The initial use of phosphoric acid to condition the enamel of a tooth's surface, as demonstrated by Buonocore in 1955, was the beginning of bonding orthodontic brackets directly to teeth. This preparation of the enamel made the surface more accessible for acrylic resin bonding (Buonocore 1955). The first reports of direct bonding emerged during the mid to late 1950s, and used epoxy resins. These resins were quickly replaced by epoxy acrylates in the early 1960s (Brantley and Eliades 2001). In 1962, Bowen introduced and patented a bisphenol A-glycidyl dimethacrylate (bis-GMA) resin which combined the dimensional stability of epoxy with the versatility and strength of acrylic resin (Bowen 1962). Researchers continued to search for improvements in the mechanical and chemical properties of resins in order to produce more stable and reliable bonds between the tooth surface and the bracket base. Once significant physical properties were verified in the laboratory, the emphasis shifted to developing quality resins that could survive in the oral environment.

Chemically Cured Adhesives

Orthodontic adhesive systems can be classified into one of the three major groups currently used today: chemically cured, light-cured, and dual-cure systems. The chemically cured group includes two subgroups. These are the two-paste and the no mix systems. The two-paste system requires the mixing and application of two liquid bonding resins to the enamel, and the mixing of two pastes which are applied to the bracket base.

This process is time consuming and increases the oxygen exposure to the materials which can ultimately inhibit polymerization (Brantley and Eliades 2001; Gange 2006). Mixing the materials together can also lead to defects in the material and create voids that would lessen the strength of the material. Development of the no-mix system succeeded the two-paste system. The polymerization initiation of the no-mix system begins with the application of a liquid primer (catalyst) and a single paste. The primer is applied to the enamel and the paste is placed on the bracket base. The primer and paste mix directly on the tooth, and allow for a more efficient application and reduce time requirements.

Light Cured Adhesives

Tavas and Watts first described the use of visible light to cure the composite resins used to bond orthodontic appliances to enamel in 1979. “Visible light-cured composites provide ease of use, extended working time, improved bracket placement, easier cleanup, and faster cure of the composite” (Jonke et al., 2008). Light cured adhesive systems have been commercially available in the United States since the early 1980s. These adhesives are polymerized by a reaction between the catalyst in the adhesive and the photons emitted by the light source (Gange 2006). The wavelength of the light emitted from the curing light must be appropriate for the catalyst to initiate the reaction. According to Gange, the greatest advances in light-curing technology have been made with the curing lights, rather than the composites themselves. Light curing units have evolved from heavy, bulky, corded units with halogen lamps to lightweight, portable, light-emitting diode (LED) units. The advantages of light-cured systems include an increased working time to help ensure proper bracket placement, the ability to place arch wires immediately, and the more efficient use of staff (Brantley and Eliades

2001; Gange 2006). Previous orthodontic adhesive systems needed at least five to ten minutes of curing time to allow sufficient bond strength to develop before arch wires could be tied in the brackets.

Dual Cured Adhesives

The third category of orthodontic adhesives consists of the dual-cured adhesives. These adhesives incorporate an initial polymerization by light exposure and then the reaction continues through a chemical cure. The main advantage of the dual cure system is that the operator has additional working time (as long as four minutes) to place brackets and remove excess adhesive. These materials have shown increased bond strength, which may or may not be clinically relevant when compared to light-cured adhesives (Brantley and Eliades 2001; Gange 2006). As a result, the light-cured composites have maintained the highest popularity among orthodontists today.

Bonding Protocol

The successful bonding of orthodontic brackets to teeth involves a series of steps to ensure proper bracket placement and the strongest bond strength between the tooth and the bracket. Typical steps involved in the direct bonding of orthodontic attachments include enamel conditioning, sealing, bracket placement, and curing. Cleaning of the tooth surface with pumice or an initial etch removes any plaque and the organic pellicle that covers the tooth. After cleaning, the teeth are isolated to control moisture, and the tooth is etched with phosphoric acid for 15 to 30 seconds, depending upon the manufacturer's recommendation. The etching material is then rinsed with a warm stream of water and the tooth is dried. The resin primer is placed on the tooth and a gentle air burst is applied to help thin the coating. This primer is an intermediate resin placed to help achieve proper bond strength and improve resistance to micro leakage (3M Unitek 2010). The above protocol is known as a two-step system. Self-etching primers have recently gained popularity due to their convenience and ease of use. The self-etching primers combine the enamel conditioning and priming into one step since the two processes occur simultaneously. The single-use package for these self etching primers consists of three compartments. The first compartment contains methacrylated phosphoric acid esters that dissolve calcium from the hydroxyapatite, photosensitizers, and stabilizers; the second compartment contains water and soluble fluoride; and the third compartment contains a micro brush applicator (3M Unitek 2010). Components in the first two compartments are mixed by squeezing the package. The contents are then applied to the tooth's surface with the micro brush, and the liquid is rubbed into the surface for at least 3 seconds.

Graber (2005) recommend the following steps for bonding: transfer, positioning, fitting, and removal of excess adhesive. During the transfer, the dental auxiliary gives the bracket to the clinician who applies the adhesive to the bracket. The orthodontist then positions the bracket on the tooth and pushes the bracket firmly on the tooth surface. "The tight fit will result in good bond strength, little material to remove on debonding, optimal adhesive penetration into bracket binding, and reduced slide when excess material extrudes peripherally" (Graber 2005). Small adjustments are then made to locate the bracket in the most clinically ideal position, the excess adhesive is removed, and the adhesive is light cured. The amount of time required to cure the adhesive depends on the manufacturer's recommendation and the wavelength emitted by the curing light.

Bond Strength

A review article by Reynolds in 1975, determined that a clinically acceptable value for bond strength is 6 to 8 MPa. Numerous studies have been performed since this time to test bond strength. A recent systematic review by Finnema et al., performed a meta-analysis on 24 of 121 studies (2010). The review found that storage conditions of the teeth prior to testing, photo polymerization time, and crosshead speed, (speed of the shearing blade used to debond the brackets), of the testing machine significantly influenced bond strength values. From the 24 studies included in Finnema's study, the shear bond strengths ranged from 3.5 to 27.8 MPa (mean 13.4; SD, 5.7). On average, tap water storage decreased bond strength by 10.7 MPa, each second of photo polymerization time increased bond strength by 0.077 MPa, and when crosshead speed increased by 1mm per minute, bond strength increased by 1.3 MPa. Most in-vitro bond strength studies use distilled water as a storage solution, 40 seconds of light exposure for polymerizing the adhesive, and a crosshead speed of 0.5mm per minute (Finnema 2010). The test parameters derived from the meta-analysis and adopted for this study included distilled water storage of specimens, a crosshead speed of 0.5mm per minute, and six seconds of polymerization time as recommended by 3M Unitek.

Bracket Positioning and Manipulation

Clinically, brackets are placed and then, if necessary, adjusted to a more ideal position after some period of time has elapsed. The bond strength may be affected by time elapsed prior to curing, the amount of bracket manipulation, and the ambient light in the dental operatory (Brantley 2001). A study by Murfitt et al. (2006), showed that multiple manipulations of the bracket prior to curing had very little effect on the failure rate of a two step etch and prime/bond system, but the bracket failure rate of the self-etching primer group doubled when the brackets were manipulated greater than three times. In the Murfitt study, the results measured the failure rates and categorized whether the bracket was manipulated less than or equal to three times or greater than or equal to four times. The amount of movement was not quantified, it was just described as minor movement. 3M Unitek (2010) recommends that once the bracket has been seated and the excess adhesive has been expressed, further manipulation should be avoided. If the bracket is moved after this time, there may not be complete adhesive coverage under the bracket, resulting in bond disruption, decalcification, or bond failure.

Lighting Conditions

Lighting conditions in the dental operatory, including ambient light, can affect the ultimate shear bond strength of orthodontic adhesives. The current ISO standard uses a 10,000 lux light source to test dental material sensitivity to operatory light. In a study by Martin (2008), the working time of three popular orthodontic adhesives was evaluated using two different techniques. Utilizing a Polymerization Exotherm Analysis (PEA), Martin found the tested adhesives to have a mean working time of 64 seconds, with a range of 45-90 seconds. For the PEA, the working time was defined as the time when the temperature of the adhesive rose by more than 0.1 degrees Celsius and did not return to baseline values more than once. Polymerization of the material considered to begin when this increased in temperature occurred. A second test of working time was evaluated by utilizing Homogeneity Monitoring. The mean working time with this test was 46 seconds, with a range of 22-69 seconds. In this test, working time was defined as the period of time from initial light source activation until clefts or voids first appeared with the material during manipulation. Martin determined the working times under three different lighting conditions: ambient light (1,200 lux), standard operatory light (10,000 lux) and high intensity operatory lighting (20,000 lux). This current study used the same three adhesives that were used by Martin (2008): Grengloo, Light Bond, and Transbond (Figure 1).

Martin (2008) also found that orthodontic operatory lights have a bi-modal lighting distribution that ranges from 10,000 lux to 20,000 lux when bonding is occurring. It was the intent of the present study to include both the standard operatory and high intensity operatory lighting conditions. By including both types of lighting conditions, the present study would cover the range of lighting conditions encountered in all orthodontic offices.

The effect of bracket manipulation after varying time periods, on the shear bond strength of orthodontic brackets, under controlled light conditions, has never been reported in a single study.

PURPOSE OF THE PRESENT STUDY

The purpose of this study is to examine whether final bond strength is reduced by bracket manipulation subsequent to initial placement under controlled lighting conditions.

HYPOTHESES

Null Hypothesis Testing Data Validity

H_0: There is no significant difference in the shear bond strength between the first sixty (60) bicuspids tested compared to the same sixty (60) teeth used again for a second trial.

Primary Null Hypotheses

$H_{0:}$ There is no significant difference in the shear bond strength between the following three orthodontic adhesives: Transbond XT, Grengloo, and Light-Bond.

H_0: Adjustments to bracket position at 15 seconds, 30 seconds, 1 minute, and 3 minutes after initial bracket placement, under controlled light conditions, will not decrease the shear bond strength of orthodontic brackets to clinically unacceptable levels.

H_0: There is no significant interaction between working time and the brand of orthodontic adhesive on the effect of shear bond strength.

Research Hypotheses

H_1: There is a significant difference in the shear bond strength between the first sixty (60) bicuspids tested compared to the same sixty (60) teeth used again for a second trial.

H_1: There is a significant difference in shear bond strength between the following three orthodontic adhesives: Transbond XT, Grengloo, and Light-Bond.

H_1: Adjustments to bracket position beyond 15 seconds after initial bracket placement will decrease the shear bond strength of orthodontic brackets to clinically unacceptable levels.

H_1: There is a significant interaction between working time and type of orthodontic adhesive on the effect of shear bond strength.

MATERIAL AND METHODS

Procedures

Sixty (60) extracted human premolar teeth with intact buccal surfaces were collected and stored in a plastic tube containing distilled water. One week prior to data collection, all teeth were mounted in dental die stone. All mounted teeth were then separated into four groups with each group having fifteen (15) specimens. Each tooth was marked on the midpoint of the buccal cusp tip with a fine tip, black permanent marker. A protractor was then used to mark exactly 10° from the midpoint line, which was parallel to the long axis of the tooth. These two marks established the amount each bracket would be turned after the allotted time.

Initially a bonding trial utilizing twelve brackets was performed under 20,000 lux ambient light. Four samples of each adhesive were bonded, one for each time group (15 seconds, 30 seconds, 1 minute, and 3 minutes). Under the 20,000 lux lighting condition, each of the three adhesives auto polymerized prior to manipulating the bracket and curing with the LED light, after waiting 3 minutes. Based on this trial, we elected to utilize a lighting environment of 10,000 lux, which was verified by the use of a lux meter (Figure 2). Therefore, all procedures were done under 10,000 lux ambient lighting conditions. Once the lighting source had been adjusted to provide a value of 10,000 lux, it was maintained for each test group.

The buccal surface of each tooth was polished mechanically with a slow speed hand piece using 1st & Final® pumice (Reliance Orthodontic Products, Itasca, IL) and rubber cup for 5 seconds. The pumice was then rinsed with an air/water spray for 5 seconds, followed by an air spray for 5 seconds. Once the tooth surface was properly prepared, Transbond® Plus Self Etching Primer was activated and applied to the tip of the primer brush. The primer was then rubbed on the center of the buccal surface of each tooth for 3-5 seconds. The primer brush was then placed back into the primer package and a gentle air burst was applied to the tooth for 2 seconds to produce a thin film. Cotton pliers were then used to pick up and place a Victory Series®, MBT prescription; premolar bracket (3M Unitek, Monrovia, CA). One of the adhesives to be tested was then placed on the back of each bracket, the bracket was fully seated with the cotton pliers, and the excess adhesive was removed. The bracket was then untouched and exposed to 10,000 lux lighting conditions until the following times had elapsed (15 seconds, 30 seconds, 1 minute, 3 minutes). After the appropriate time, the bracket was moved 10°. The bracket adhesive was then cured with an Ortholux® Luminous Curing Light (3M Unitek, Monrovia, CA) for 6 seconds, according to manufacturer's specifications. This included 3 seconds of curing on the mesial and 3 seconds on the distal. After storage for 24 hours in distilled water, at a controlled temperature of 37° Celsius, the brackets were debonded using an Instron® universal testing machine (Figures 3,4).

Prior to the second round of tests, all orthodontic adhesive material was removed from the tooth surface using a multi-fluted bur in a high-speed hand piece. Once the adhesive was removed from the 60 teeth, they were retreated with the same protocol used in the first series of tests. The teeth were placed in the same 4 groups, with 15 teeth in each group. Running the test again under the same conditions, resulted in 30 teeth per each time group, for each of the three adhesives.

Statistical analysis

A power analysis was performed and determined that ten teeth were required for each of the three adhesives and each of the elapsed times prior to curing, for a total of N=120. With an N of 10 in each group, a P value of .05, a one tailed test, and an effect size of 6, power was equal to 1.00. Because the same sixty (60) teeth were reused in the current study, a one-way analysis of variance (ANOVA) was used to determine if there were significant differences in bond strength between the first trial run and the second. A two-way analysis of variance (ANOVA) was used to determine if there were significant differences in bond strength between the three different adhesives (GG, TB, LB), for each of the time intervals (15 sec, 30 sec, 1 min, 3 min), prior to light curing and to see if there was any interaction between these independent variables. A Tukey's honestly significant difference (HSD) test evaluated differences in the levels within each independent variable. All statistical analyses were performed using SPSS Base 16.0 statistical package (SPSS, Inc Chicago, IL).

RESULTS

The results of the univariate ANOVA showed no statistically significant difference (F=3.07, p=0.083), in shear bond strength between the sixty (60) bicuspids tested in the first run compared to rebonding and testing the same sixty (60) teeth again (Table I).

The results of the 2-way ANOVA showed a statistically significant difference (F=5.78, p=0.004), in the shear bond strength of the adhesives tested (Table II). There was a statistically significant difference between the shear bond strength of Grengloo and Transbond, with Transbond having the stronger bond. There was no statistically significant difference in shear bond strength between Grengloo and Light Bond or between Transbond and Light Bond (Table II, Figure 5).

There was a significant difference (F=8.50, p=0.0005), between the shear bond strength of the adhesives after being cured at different times (Table II). There was a statistically significant difference in shear bond strength between the 30 second curing group and the remaining three groups, with the 30 second group having the strongest bond. There was no statistically significant difference in shear bond strength between the 15 sec, 1 min, and 3 min curing groups (Table III, Figure 6).

There was no significant interaction (F=0.77, p=0.593), between the types of adhesive and the times prior to curing (Table III, Figure 7).

DISCUSSION

The advancement in dental adhesive materials throughout the twentieth century has led to the practice of direct bonding in lieu of banding in orthodontics. From the double-mix two paste systems, to the current single step, self cure composites, orthodontists are still concerned about the material properties of the adhesives and their longevity in the oral environment. Without adequate bond strength between the bracket base and the enamel surface, adhesive failures are more prevalent. While specific protocols are recommended by the manufacturers of the orthodontic adhesives, these protocols may be modified in clinical practice. These different protocols, office lighting conditions, and material properties can result in variations in shear bond strength.

One important discovery found in the initial trial was the fact that the high intensity operatory lighting (20,000 lux), provided too much visible light for all three adhesives in the three minute group. All three adhesives auto polymerized prior to any manipulation. As a result, it was decided to run the current trial only under standard operatory lighting conditions, (10,000 lux).

Shear Bond Strength Difference Using Same Sample Again

Research has shown that enamel is affected when the adhesive is removed from the enamel surface. The average enamel loss found from removing orthodontic adhesive with carbide burs averaged only 7.4 µm (Van Waes 1996). Since only a very minute amount of enamel is removed during the debonding procedure, it was hypothesized that the same 60 specimens could be reused in the present study. The univariate analysis confirmed this hypothesis by comparing the mean shear bond strengths of the first sixty teeth, compared to using the same sixty teeth again. There was no statistical significant difference, (F=3.066, p=0.083). The research hypothesis of the current study supported the data validity and therefore allowed the principal investigator to use the same sixty bicuspids for a second trial.

Comparison of Present Study to Previous Studies

A study by Murfitt in 2006, found no statistically significant differences for bond failure rate with respect to age of patient, operator, tooth location, or the number of manipulations of the bracket. Prior to the present study, the degree of bracket movement prior to curing, and the effect of delayed manipulation under controlled lighting conditions has never been studied. In most United States orthodontic residency programs, residents place the brackets, wait for a faculty member to evaluate bracket position, and manipulate the bracket to a more ideal position if necessary. In private practice dental auxiliaries often place the brackets, and the orthodontist later evaluates placement and manipulate the bracket to a better position if necessary.

This study demonstrated that all three adhesives achieved clinically acceptable shear bond strengths of 6-8 MPa, even after manipulation. These results confirm the effect of proper handling according to the manufacturer's procedural recommendations. Transbond's shear bond strength (9.64 MPa), exceeded the clinically acceptable average and was significantly greater than that of Grengloo (7.18 MPa). Even though all clinical parameters were controlled as strictly as possible, this value could have resulted from numerous factors such as inconsistency of the Grengloo adhesive, operator error when applying the adhesive to the base of the bracket and the enamel condition of the teeth to which Grengloo was applied. Another factor which may have influenced the results, is the use of the LED light for this current project. Ormco actually recommends using the

CoolBeam™ LED light for curing Grengloo. This light differs in comparison with the 3m Unitek, Ortholux™, with regard to its power output and light activation range. The use of the CoolBeam™ LED light may have interacted more effectively with the photoinitiator in Grengloo to polymerize and ultimately lead to increased bond strength.

All three adhesives used have a similar chemical makeup. Light cured resin adhesives typically have three major components: an organic matrix and monomer, filler material, and a photoinitiator. Each adhesive uses different quantities, which may have an effect on the properties that result after light curing. Another factor which may have led to a difference in bond strength was the use of the Transbond self-etching primer. The materials in the self-etching primer, may be more compatible to the composition of the Transbond XT adhesive, leading to higher bond strength.

The most interesting result of the present study was that there was significantly stronger bond strength for all three adhesives when the bracket was rotated and cured, 30 seconds after placement. This was followed in descending order, by the 15 second group, the 3 minute group and finally 1 minute group. Even though the remaining three time groups were not in the original order that we projected, there was no statistically significant difference between the 15 seconds, 1 minute and 3 minute groups. The initial hypothesis was that the strongest bond strength would occur in the group moved after the least delay (15 seconds), since the earliest signs of polymerization did not begin to occur until after 22 seconds in a previous study by Martin (2008). Martin found that the three adhesives used in his study had initial polymerization times ranging from 22-90 seconds under 10,000lux. The author of the present study believed that the peak bond strength would occur at the 15 second mark and continually decrease, with the lowest shear bond strength occurring at the 3 minute mark. The question to why the results in this current study demonstrated significantly different bond strength for the 30 second group is unknown; however, a few factors may be considered.

Factors affecting the bond strength at the 30 second interval could have been due to the following: the time oxygen was involved in the system, amount of water in the interface, additional etching still occurring, and the compatibility of the adhesives with the Transbond self-etching primer. Oxygen acts as an inhibitor and causes the excited state of radicals, which are formed during the polymerization, to be suppressed (Brantley 2001). Therefore, the more time the adhesives are exposed to oxygen, the more capability for the polymerization process to be altered and not form a strong bond.

The composition of the Transbond self etching primer could also have an effect because it's normal amount of water is from 15-25% (3M Unitek 2010). 3M Unitek recommends applying a gentle air burst for two seconds after the primer is applied. This step ensures the primer is thinned and the water component evaporates (2010). All teeth in this current study had the two second air burst, however, additional water could have been left on the enamel surface which could have affected the bond strength. Additional water may have evaporated between the 15 second and 30 second time group, leading to higher mean bond strength. As previously mentioned, the chemical composition of the adhesives used could be more molecularly compatible at the 30 second time group. The combination of the Transbond XT and Transbond self etching primer may have provided the ideal conditions for the best bond strength after waiting 30 seconds.

Another possibility leading to the highest strength after waiting thirty seconds, is that additional etching may still be occurring. Normally, there are three mechanisms which stop the etching process. These include formation of a complex between hydroxyapatite and calcium, the air burst removing excess solvent, and after light curing occurs (Cinader 2010). There is a possibility that the etching process had not fully been neutralized and additional etching was occurring, allowing for increased penetration of the primer and resin. This could have led to increased bond strength in the 30 second time group.

Paul Gange, founder and owner of Reliance Orthodontic Products Inc., (Personal Communication, 2010) would have hypothesized that there would have been no clinically significant difference in shear bond strength for any of the four time intervals. Gange stated that the major factor that would affect the bond strength would be due to the catalyst, which is in the composite adhesive, which typically begins to evaporate after the 3 minute mark. Gange also described a Reliance Orthodontic Inc. internal product study where shear bond strength was tested after manipulation of brackets. In this unpublished study, Gange bonded two different groups. In one group, brackets were placed and turned approximately 5-10° clockwise and then cured. In the second group, brackets were placed and manipulated first clockwise and then counterclockwise 10°. Ultimately, there was no significant difference in the bond strengths between these two groups according to Gange.

Hypothesis versus Results

Our first research hypothesis stated that there will be a significant difference in shear bond strength between the following three orthodontic adhesives: Transbond XT, Grengloo, and Light-Bond. This was confirmed with Transbond XT having statistically significant stronger bond strength than Grengloo. The mean bond strength, 9.64 MPa bond strength of Transbond XT, is approximately 34% greater than the 7.18 MPa bond strength of Grengloo. Even though these values are close to or within the 6-8 MPa range of clinical acceptability, this difference was significant statistically. A “clinically acceptable” 6-8 MPa range was determined in the review article by Reynolds (1975) (Finnema 2010). “Because it has never actually been tested whether 6 to 8 MPa is sufficient in-vitro bond strength for clinical use, the use of this reference value has been criticized” (Finnema 2010). The question is whether this difference is clinically relevant. Therefore, Finnema suggested that interpretation of bond strength data should be limited to relative effectiveness of the adhesives used in a particular study (2010). Unfortunately no references have been determined for in-vivo bond strength acceptability. Also no reference has been determined on the low and high ends of the spectrum. Studies have not shown when the bond strength could be too high and would negatively affect the enamel upon debonding, or how low bond strength can be prior to bond failure.

The second research hypothesis stated that adjustments to bracket position beyond 15 seconds after initial bracket placement will decrease the shear bond strength of orthodontic brackets to clinically unacceptable levels. This hypothesis was not confirmed. All shear bond strengths measured within the four different time intervals produced clinically acceptable values. The shear bond strength was strongest at the 30 second time interval. The remaining time intervals showed decreased shear bond strength. The bond strength occurring at the 30 second time interval was statistically greater than the remaining three time groups. Since the results from (Martin 2008) showed that the initial polymerization occurred with Grengloo at 22 seconds, the belief was that the 15 second group would ultimately provide the strongest bond strength because manipulation ceased prior to any polymerization that should occur under the conditions tested in this study. In general, as time progressed, and the brackets were manipulated, the shear bond strength did decrease relative to the 30 second time interval. This is the result of many factors including working time, oxygen inhibition, chemical composition of adhesive and primer, and manipulation after polymerization had already taken place.

Surprisingly, waiting 3 minutes then turning the bracket and curing, did not result in the lowest bond strength. The shear bond strength at 1 minute, 7.18 MPa, was the lowest measured, versus the 3 minute group with mean shear bond strength of 7.44 MPa. One possibility to explain this result could be that the bracket did not have any manipulation prior to the 3 minute mark. Manipulation during the one minute mark could have a more detrimental effect on the bond strength versus waiting to manipulate and break chemical bonds occurring at the 3 minute mark. The movement at the one minute mark, could affect the strength more because of the rate of the reaction. Timing could possibly be more critical near the one minute mark compared to three minutes. Therefore the study shows different bond strengths at various times throughout the reaction, however, this may not be clinically important because of values obtained are within normal limits.

The third research hypothesis stated that there will be a significant interaction between working time and type of orthodontic adhesive on the effect of shear bond strength. There was no statistically significant interaction between the type of orthodontic adhesive and the time prior to curing the bracket after manipulation. These findings show that there is no direct correlation between one adhesive and a certain time interval. All the adhesives have similar chemical composition to allow them to be used as orthodontic bonding agents. The key factor is the process of polymerization and how the changes occur and at what specific times they occur.

This study used clearly stated parameters to measure the dependent variable, shear bond strength. The amount of light, light curing source and time of curing were constant in this study. This was performed to eliminate any possible bias in the current study. Even though many orthodontic practices may bond under different lighting conditions depending upon the type of operatory light, location of the chair, and time of the day, this protocol maintained stable conditions to effectively measure the shear bond strength of the three adhesives.

When comparing the shear bond strength values of the current study with past research, it is apparent that the strength values are lower in the current investigation. In the meta-analysis on bond testing by Finnema, bond strength values ranged from 3.5-27.8 MPa (2010). Previous studies showed in vitro bond strengths of orthodontic adhesives as high as 23.23 MPa (Jonke 2008). Other studies found mean shear bond strength of 12.27 MPa for Transbond XT and 14.93 MPa for Light Bond (Vicente 2004). The values found by Vicente were statistically significant. In the study by Vicente et. al, the number of teeth measured for each adhesive was 25. In the present investigation, the sample size derived through a power analysis was found to be 120 specimens, with 40 teeth for each adhesive. The current study had an increased minimum number of samples because two dependent variables were analyzed compared to one dependent variable in the Vicente study. Factors that could have accounted for the lower bond strength in this study are the following: storage media, time from extraction to mounting, environmental conditions such as humidity and temperature, and finally adhesive placement to the bracket base by the principal investigator. These bicuspids were bonded initially and then debonded. One adhesive at a time was tested. Twenty specimens of Grengloo were tested first, followed by twenty specimens of Light Bond and finally twenty specimens of Transbond XT. Each curing time group of the individual adhesive was bonded and then debonded until testing with the adhesive was finished. The fifteen second group was first, followed by the 30 second, 1 minute and 3 minute groups. The original adhesive was removed with a multi-fluted carbide bur and the exact protocol was repeated to end up with a total of 120 specimens.

Clinical Suggestions

The proper understanding for handling orthodontic materials by clinical staff and orthodontists is critical for proper success when bonding orthodontic brackets. Every material used in orthodontics is tested prior to coming to market, and the specific storage instructions, handling recommendations, and usage protocol are available from the respective manufacturers. More importantly, clinical users of the light activated orthodontic adhesives must be aware of the clinical lighting conditions. This study used a light value of 10,000 lux. Normally, ambient light in the dental operatory is approximately 1,200 lux (Martin, 2008). Many orthodontists are aware that the reduced amount of light will produce a longer working time with adhesives, and practitioners commonly turn operatory lights away from the mouth when performing a bonding procedure (Dlugokinski et al., 1998). However, each light activated adhesive still has its own specific limitations.

The results of this study suggest that each of the adhesives tested has adequate shear bond strength under the in-vitro conditions tested. The results suggest that curing within 30 seconds after bracket placement will lead to the highest bond strength. Practitioners should strive for minimal bracket manipulation after as short a time as possible prior to curing the adhesive. Product knowledge, delegation of clinical responsibilities, and time management are critical when attempting to attain proper shear bond strength.

Research Limitations

Key factors such as saliva control and avoiding other possible contaminates that could be encountered intra-orally must be accounted for to draw concrete conclusions. Another limitation is the protocol followed. The current investigation utilized a one-step etch/prime system (Transbond Plus® self-etching primer) for all adhesives tested. This combined etch and primer is recommended specifically for use with the Transbond XT adhesive. Ormco, the producer of Grengloo, recommends a separate acid etch and use of Ortho Solo as a priming agent. Finally, Reliance Orthodontic Products, Inc., the makers of Light Bond, also recommend a separate etch and priming sequence. Finally, the storage time of the bicuspids which were collected over approximately a four month period, could have affected the enamel surface of the teeth.

Future Research

Future studies could include an analysis of similar light activated resin adhesives under longer time periods. Longer time periods may have resulted in clinically unacceptable results. Another possibility would include the same adhesives, but use the protocols recommended for each adhesive, (i.e. using a two step etch and the appropriate priming agent with Grengloo and Light Bond). A final possibility would be to conduct an adhesive remnant index (ARI) calculation to see whether more adhesive is remaining on the bracket base or tooth after all brackets are removed.

CONCLUSIONS

The purpose of this study was to determine whether shear bond strength was reduced by bracket manipulation subsequent to initial placement under controlled lighting conditions. A secondary purpose was to determine whether waiting different time periods prior to curing ultimately affected bond strength as well.

The results of the testing showed that there was a statistically significant difference in shear bond strength between Transbond XT and Grengloo. There was no statistical difference between Transbond XT and Light Bond or Grengloo and Light Bond. Even though a statistical difference was found, the mean bond strengths of all three adhesives were within the range of 6-8 MPa, which is the recommended normal value (Reynolds 1975). These differences may not be clinically important.

The results of the elapsed time between bracket placement and light curing, also showed a significant difference. After bracket placement, manipulation and curing after 30 seconds, the shear bond strength was the strongest. The remaining three time groups resulted in lower bond strengths, with the group 1 minute curing after manipulation having the lowest bond strength. While the three remaining groups (15 seconds, 1 minute, and 3 minutes) had lower bond strengths, all groups had bond strength within the recommended guidelines.

Another important finding with this current study showed that the 20,000 lux lighting condition proved to be too much visible light for all three adhesives when waiting three minutes. In the trial run, under 20,000 lux, each adhesive was cured prior to manipulating the bracket and light curing with the LED. Therefore careful bonding conditions must be observed in an office that uses high intensity operatory lights.

The results of this study cannot be directly compared to in vivo conditions; however, the results do show an interesting pattern. In vivo conditions have many different variables that cannot be controlled such as saliva, temperature, bacteria, and blood. All values fall within the normal limits for bond strength. The statistical differences may not equate into clinical importance. The time prior to curing results suggest, that each adhesive does have a limited working time. Under our controlled parameters, curing at 30 seconds provided the highest bond strength.

Orthodontists and auxiliary staff must know the composition of the clinical materials, proper protocols, and limitations of all products used in the office.

Table I. Mean Shear Bond Strength for Data Validity

Variable	Shear Bond Strength Mean (MPa)	SD	F	p
First Half; (60) Bicuspids	7.74a	3.8	3.07	0.083
Second Half; same (60) Bicuspids	8.96a	3.8		

Table II. Results for Shear Bond Strength of Orthodontic Adhesives

Variable		Shear Bond Strength Mean (MPa)	SD	F	p
Adhesive Type					
	Transbond	9.64a*	3.7	5.78	0.004
	Light Bond	8.19ab	4.0		
	Grengloo	7.18b	3.4		
Time Prior to Curing					
	30 seconds	10.93a*	4.2	8.52	0.000 5
	15 seconds	7.67b	2.9		
	3 minutes	7.44b	3.3		
	1 minute	7.18b	3.5		
Adhesive Type * Time Prior to Curing				0.77	0.593

*Different letters indicate a significant difference (P≤0.05) in shear bond strength between groups.

Table III. Mean Shear Bond Strength for Adhesive and Time Prior to Curing

	Shear Bond Strength	
Adhesive Type * Time Prior to Curing	Mean (MPa)	SD
Transbond		
15 seconds	8.8a*	4.3
30 seconds	12.14b	3.9
1 minute	7.98a	2.7
3 minutes	9.64a	2.6
Light Bond		
15 seconds	6.83a*	1.7
30 seconds	10.97b	5.1
1 minute	8.33a	3.7
3 minutes	6.5a	3.4
Grengloo		
15 seconds	7.3a*	1.8
30 seconds	9.78b	3.6
1 minute	5.01a	3.5
3 minutes	6.04a	2.9

*Different letters indicate a significant difference ($P \leq 0.05$) in shear bond strength between groups.

Figure 1 – Adhesives Tested: Transbond XT, Light Bond, and Grengloo including Transbond Plus self-etching primer.

Figure 2 – Lux meter: Sinometer LX1010B used to ensure constant lighting conditions during bonding procedure. Measurement shown in lux x100.

Figure 3 – Instron Machine used to mount, debond each bracket, and calculate shear bond strength.

Figure 4 – Tooth sample in place prior to testing. Shearing blade was used to break the enamel/adhesive bond.

Figure 5 – Mean Shear Bond Strength of all Adhesives Used in the Present Study. Transbond showed the highest bond strength. (F=5.7, P=0.004)

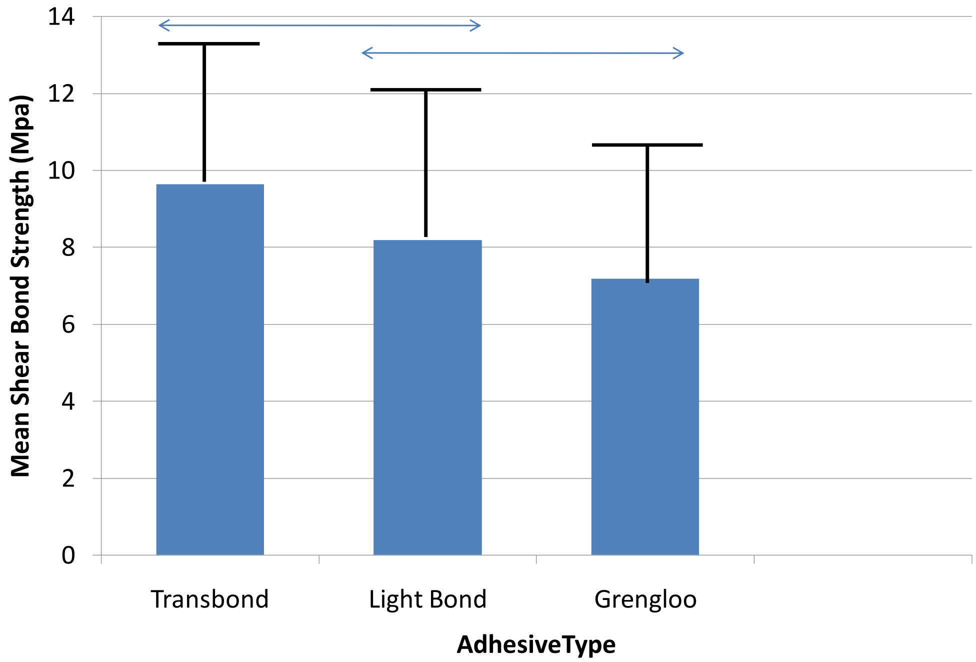


Figure 6 – Mean Bond Strength of all adhesives after waiting a specific amount of time, manipulation, and curing. Thirty second wait period exhibited the highest bond strength. (F=8.5, P=0.0005)

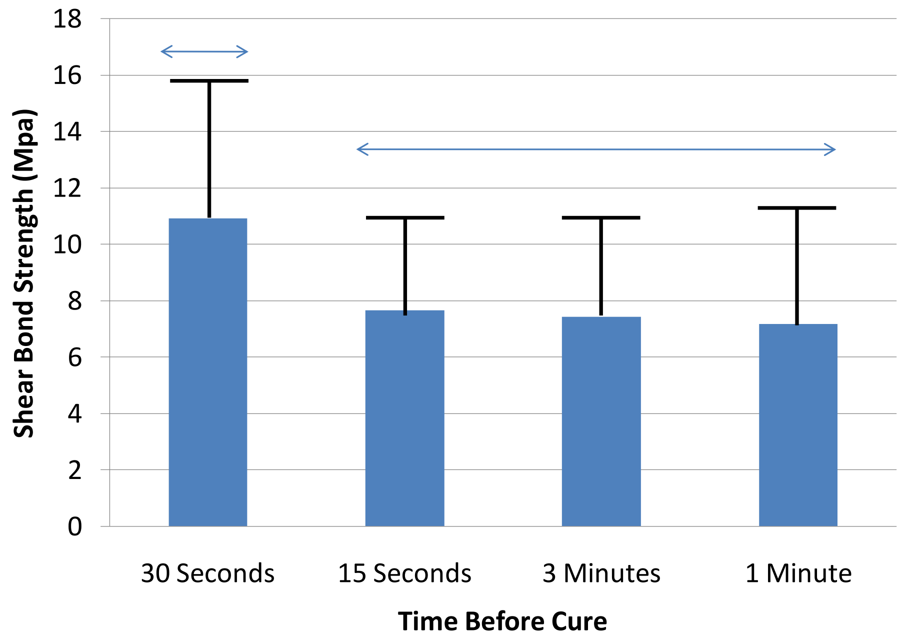
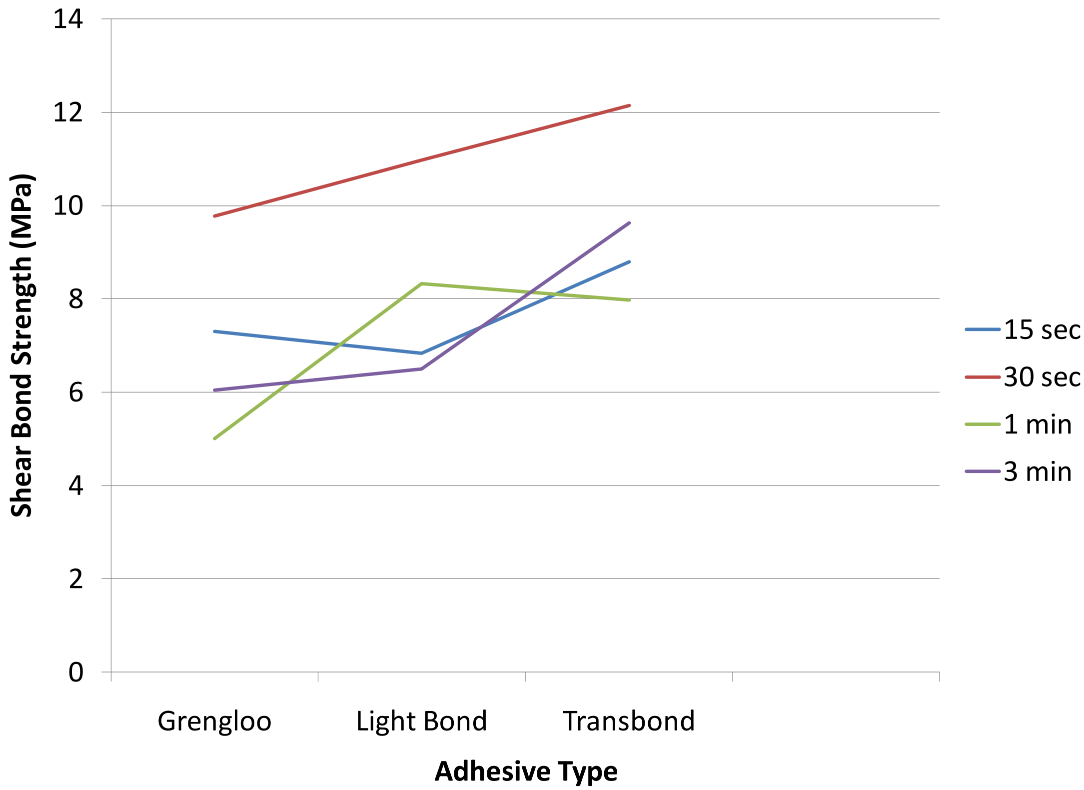


Figure 7 – Interaction Plot showing no significant interaction between the type of adhesive and time period prior to curing. (F=0.78, P=0.59)



Appendix--Results from Test Trial

It was the original intent of this study to utilize both standard (10,000 lux) and high intensity (20,000 lux) operatory lighting conditions during the testing procedures. During a preliminary trial, five brackets were bonded with each of the three adhesives using the protocol outlined in the methods and materials section. Therfore, there were a total of fifteen brackets bonded under 10,000 lux lighting conditions, and fifteen brackets bonded under 20,000 lux. When bonding under 20,000 lux, three of the five brackets bonded with Grengloo had polymerized at the three minute point due to exposure to the operatory light alone, prior to exposure to the dental curing light, and thus, rotation of the bracket was not possible. For both Transbond XT and Light Bond, two brackets for each adhesive polymerized due to exposure to the operatory light alone prior to the three minute waiting interval. Due to these findings, a decision was made to conduct further tests utilizing 10,000 lux lighting conditions only.

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