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Anthony M. Carbonella IV, D.M.D., Maj, DC, USAF

Tri-Service Orthodontic Residency Program

Air Force Post Graduate Dental School

June 2018

Comparison of Orthodontic Adhesives for Bonding to CAD/CAM

Provisional Crowns

Anthony Martin Carbonella IV

APPROVED:

[redacted]

Larry C. Burton, D.D.S., Supervising Professor

[redacted]

Brian W.B. Penton, D.D.S., M.S.D., Program Director

[redacted]

David P. Lee, D.M.D., M.S., Chairman

6/30/18

Date

APP[redacted]

Jay D. Graver, D.M.D., M.S., Dean, Air Force Postgraduate Dental School

Comparison of Orthodontic Adhesives for Bonding to CAD/CAM Provisional Crowns

A THESIS

Presented to the Faculty of

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By

Anthony Martin Carbonella IV, D.M.D.

San Antonio, TX

June 30, 2018

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DEDICATION

I dedicate this thesis to my family and friends who have been so incredibly supportive during my journey to become an Orthodontist in the United States Air Force. I would not have been able to accomplish any of what I have without you standing behind me every step of the way. I am especially thankful to my wife Angela, who left her family, friends, job, and basically everything she knew to accompany me on my move to Texas for the purposes of military service and to complete the Tri-Service Residency Orthodontics Residency Program (TORP). Your love and dedication has given me the motivation to pursue my professional goals, no matter what barriers lie before me. As always, thank you to my parents who sat with me for countless hours at the kitchen table to instill a healthy work ethic in me at a young age. My three younger brothers also continue to serve as an inspiration to me as they embark on their professional journeys.

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ABSTRACT

Purpose: This study was designed to compare the shear bond strength (SBS) of four commonly-used orthodontic adhesive systems used for bonding metallic brackets to Computer-Aided Design/Computer-Aided Milling (CAD/CAM) Poly Methyl Methacrylate (PMMA) provisional restorations. An Adhesive Remnant Index (ARI) survey was used to reveal patterns in the types and locations of bond failure between the experimental groups.

Methods: A standardized process was used to prepare the surface of PMMA blocks (Ivoclar Vivadent Inc., Amherst, NY) prior to bonding 80 stainless steel orthodontic brackets (3M Unitek Victory Series MBT Versatile+ with 0.022-inch slot, Monrovia, CA). The samples were divided equally amongst four groups, each utilizing a different adhesive bonding system. The first group (Ivoclar) involved adapting a technique recommended by the manufacturer for repairing PMMA provisional restorations and applying it to the bonding process of orthodontic brackets. The remaining three groups utilized orthodontic-specific adhesive bonding systems that are commonly used in orthodontic practices (3M Unitek, Ormco, and Dentsply GAC) to bond brackets to the PMMA substrate. To measure SBS, a single-bladed Instron unit (Model #5943, Norwood, MA) was utilized. All debonded brackets were subsequently examined using a stereo microscope set to 20x magnification to classify the type of bond failure within the Adhesive Remnant Index.

Results: The mean SBS for Group 1 (Ivoclar) was 6.34±0.67 MPa, Group 2 (3M Unitek) was 5.81±1.37 MPa, Group 3 (Ormco) was 6.58±1.22 MPa, and Group 4

(Dentsply GAC) was 5.97±1.28 MPa. No statistically significant differences in SBS were found among the four groups ($p = 0.159$). Although not significantly different according to the statistical analysis, Ormco's orthodontic adhesive bonding system, which includes a universal primer, had the highest SBS. There were statistically significant differences in the failure modes between the groups based on ARI score ($p = 0.016$). Group 1 (Ivoclar) had the highest ARI scores and, which was significantly greater than Groups 3 (Ormco) and Group 4 (Dentsply GAC), but not significantly different from Group 2 (3M Unitek).

Conclusions: Ormco's adhesive provided the highest SBS of all of the groups tested, however this was not statistically higher than the others. Three of the four adhesive bonding systems (Ivoclar, Ormco, and Dentsply GAC) provided SBS within the acceptable range as defined by Reynolds (5.9-7.8 MPa). The other group (3M) provided shear bond strengths so close to the acceptable range that it is safe to conclude that any of the four groups would provide shear bond strengths strong enough to have clinical success when bonding metallic brackets to CAD/CAM-fabricated PMMA provisional restorations. None of the groups produced SBS high enough to cause damage to the surface of the PMMA substrate that would be evident clinically. The primary mode of bond failure for all four of the groups was cohesive in nature, where more than 50% of the adhesive remained on the PMMA surface (ARI = 2).

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I. INTRODUCTION

Due to the advent of adhesive use in dentistry, the days where each tooth had to be banded in order to become incorporated into the orthodontic appliance are long behind us. Angle's E arch, pin and tube, and ribbon arch appliances while revolutionary at the time, were cumbersome for both the patient and the operator, and therefore mastered by only a relatively small number of practitioners. When Angle designed the edgewise appliance in 1928, the practice of orthodontics was fundamentally changed forever. Since then, numerous improvements have been made to the design and materials of the orthodontic appliance in the interest of improved efficiency and effectiveness of treatment. Currently, the vast majority of fixed orthodontic therapy involves bonding brackets to the teeth with various adhesive materials, many of which were originally created for use in restorative dentistry. Adhesives have allowed both the art and science of orthodontics to progress to levels previously thought to be unattainable by our predecessors.

Orthodontists are fortunate in that the requirements for adhesion of brackets to teeth are significantly less than the requirements for when restorative dentists bond their restorations. First of all, brackets typically only need to remain attached to the dentition for the duration of fixed orthodontic therapy, which on average lasts for about 28 months (Beckwith *et al.*, 1999). In the realm of restorative dentistry, a loftier goal has been established in which the practitioner strives to construct a restoration that will last for the lifetime of the tooth in which it is placed. Another advantage orthodontists have when employing adhesive materials is that brackets are typically bonded to external tooth surfaces comprised of enamel. Restorative dentists frequently have to bond restorations to dentin, a process that comes with its own unique set of requirements and challenges (Reynolds, 1979). Nevertheless, in order to facilitate high levels of orthodontic efficiency and effectiveness, a strong and reliable bond between bracket and tooth is necessitated. It has been suggested that an ideal orthodontic adhesive should possess a shear bond strength between 5.9 and 7.8 MPa (Reynolds, 1979; Whitlock *et al*., 1994). Bond strengths should be strong enough to withstand various debonding forces that exist in the oral environment, but also weak enough to facilitate safe and painless removal of the brackets once orthodontic treatment is complete. Proffit states that it is preferable for bond failure to occur at the bracket-adhesive interface to avoid damage to the tooth's surface (Proffit *et al*., 2013).

Halfway through the twentieth century, Buonocore realized that the strength of adhesion to enamel could be increased by first etching the tooth surface with phosphoric acid. This technique drew from an industrial application involving surfaces being prepared with acid prior to being coated with paints or resins (Buonocore, 1955). Ten years later, Newman recognized that acid etching of enamel would be beneficial in the field of orthodontics prior to adhering brackets to teeth (Newman, 1965). In the next decade, Gorelick demonstrated that resin composite materials could act as effective bonding agents for orthodontic brackets (Gorelick, 1977). Since the 1970s, the technique of using acid conditioning prior to bonding brackets to teeth has become a mainstay of fixed orthodontic therapy and has largely replaced the use of orthodontic bands (Minick *et al.*, 2007).

Ever since brackets were first bonded to teeth, research has been conducted in search of the ideal adhesive system. Most studies that investigate the bond strength of orthodontic bracket adhesives to enamel are carried out in vitro, where a mechanical testing machine is used to simulate in vivo bond failures (Akhoundi and Mojtahedzadeh, 2005). Rix *et al*. set out to determine which of three different adhesive types had the highest bond strength for attaching brackets to enamel: composite resin, resin-modified glass ionomer, or polyacid-modified composite resin. By bonding brackets to extracted human premolars, thermocycling the samples in water for 30 days, and then debonding them with a testing machine, he was able to determine that the composite resin adhesive had a significantly higher bond strength compared to the other two materials (Rix *et al.*, 2001).

Although in-vitro studies afford the investigator the ability to impose tight controls on experimental conditions, they are not able to exactly mimic the oral environment that brackets and adhesives are exposed to. Therefore, numerous in-vivo studies on adhesive bond strength have also been conducted. Many of these studies also attempt to answer the question: is there an ideal orthodontic adhesive? Bishara *et al.* set out to determine the effects that a self-etching primer would have on bond strength of orthodontic brackets to enamel and found that its use resulted in a significantly lower, yet clinically acceptable, shear bond strength (Bishara *et al.*, 2001). A few years later Pasquale *et al*. analyzed the rates of bond failure of orthodontic brackets bonded to enamel surfaces with two different adhesive systems for at least 18 months. He compared Transbond Plus Self-

Etching Primer with Transbond XT adhesive (3M Unitek, Monrovia, Calif) and Ideal 1 SEP with Ideal 1 adhesive (Dentsply GAC, Bohemia, NY) and found that the Transbond system had one third the bond failure rate of the Ideal 1 SEP system (Pasquale *et al.*, 2007).

As an increasing number of adults seek orthodontic therapy, orthodontists will frequently be faced with the challenge of having to bond to a variety of surfaces other than enamel (Nattrass and Sandy, 2016). According to Proffit, adults comprise over 25% of patients seeking orthodontic treatment (Proffit *et al.*, 2013). Mathews and Kokich reported that at some orthodontic practices, the proportion of adult patients is more than 40% (Mathews and Kockich, 1997). More often than typical adolescent orthodontic patients, adults will present for orthodontic therapy with provisional restorations already in place, mainly for the purposes of pre-prosthetic orthodontics. This collaboration between the restorative dentist and orthodontist before or during prosthetic rehabilitation can provide many benefits to the patient such as decreased need for endodontic, periodontal, or more complex prosthodontic therapy. Orthodontics can also afford a reduction in the amount of natural tooth structure removal and an increase in the durability of restorations (Spalding and Cohen, 1992).

Not surprisingly, a large number of studies have been conducted on the topic of bonding orthodontic brackets to restorative materials and provisional restorations. One of the first studies to investigate this matter was performed by Newman *et al.* in 1984. They examined whether the use of a silane agent would enhance the bond strength of orthodontic brackets to esthetic restorative materials.

They determined that when a silane was applied, it was possible to achieve the same bond strength of brackets to composite restorative materials as compared to when brackets are bonded to enamel that has been acid-etched. Another finding was that the addition of a silane did enhance the bond strength of brackets to porcelain restorations, but the bond strength may not have been adequate to be effective clinically (Newman et al., 1984). Later Chay et al. studied if bond strengths of orthodontic brackets attached to provisional materials were affected by varying surface treatments and aging of the temporary restorations. They found that bond strength depended on the provisional material being used, the surface treatment implemented, and also on time of attachment. Their final recommendation was that for best clinical effectiveness, brackets should be bonded to provisionals made of bis-acryl composite within 1 week of fabrication of the restoration (Chay et al., 2007). In 2013, Almeida et al. investigated the effect on adhesive resistance after performing various surface treatments to acrylic resin provisional restorations. In the group bonded with Duralay, it was shown that surface abrasion with aluminum particles increased bond strength when compared to roughening with Soflex discs (Almeida et al., 2013).

Although orthodontic adhesive materials have continually improved over the years with bond strengths adequate to withstand the complex force systems utilized during orthodontics, debonding of brackets remains commonplace during the course of treatment. After a debond occurs, valuable information about the adhesive’s properties can be gleaned by studying the site and type of bond failure. In 1984 Artun and Bergland developed the Adhesive Remnant Index (ARI) as a way of classifying bond failures by studying the percentage of adhesive remaining on teeth after debonding of brackets. Since then, their classification system has become one of the main methods of reporting debonding characteristics of orthodontic adhesives. During debracketing studies, it is critical to assign accurate ARI scores, because this information can be used to influence selection of orthodontic adhesives for use in clinical orthodontics.

In 2009, Montasser and Drummond set out to test whether different microscope magnification settings would make a difference in terms of ARI scores assigned to debonded brackets. They bonded brackets to 80 extracted human premolars and utilized a universal testing machine to shear the brackets off. The ARI survey was subsequently carried out, first using the naked eye, then 10X magnification, and finally 20X magnification. Their results revealed significant differences in ARI scores based on the magnification used. Using 20X magnification, a trend was noted in which lower scores decreased and higher scores increased when compared to scoring with the naked eye or 10X magnification (Montasser and Drummond, 2009). After reviewing these findings, it was determined that the microscope setting for the present study would be set to 20X magnification during the ARI survey.

Dentistry has always been and always will be a continuously evolving field, and technological innovations are being put out to market at an ever-increasing pace. The age of digital dentistry is here and perhaps at its center lies computer-aided design and computer-aided manufacturing (CAD/CAM). This technology was first created in the 1950s, but not used commercially until the 1960s. During the 1970s, CAD/CAM revolutionized the design and manufacturing industries, and was later introduced to the field of dentistry during the 1980s in the form of the CEREC (Sirona) and Procera (Nobel Biocare) devices (Klim and Corrales, 2010). Since then, many manufacturers have released their own proprietary systems with varying capabilities. Despite their differences, all CAD/CAM systems have three components in common: a digitization tool/scanner, software to process the collected data, and a production technology to transform the design into a usable product (Beuer *et al.*, 2008). Both dental laboratories and individual practitioners are now able to utilize this technology to scan, design, and mill crowns, as well as other restorations, with a very high degree of precision and accuracy.

Since its introduction to dentistry in the 1980s, the use of CAD/CAM technology has been ever-increasing. This trend has become especially apparent within dental laboratories and an article by Brom-Criscola in 2013 provided numerous compelling statistics:

-55% of laboratories have some form of digital equipment in-house

-the number of crown and bridge and full-service laboratories offering CAD/CAM milled restorations has grown by 14% since 2007

-CAD/CAM milled restorations make up, on average, 41% of the labs' total crown and bridge case load

-37% of dental labs have both a scanner and milling system

-79% of labs say their clients are interested in CAD/CAM milled restorations

-the percentage of labs that plan to purchase digital equipment in the next two years is 60%

Clearly, CAD/CAM in dentistry is here to stay and not only are final restorations being fabricated with it, but also provisional restorations. This technology allows provisional crowns to be milled in only a matter of minutes, and it is reasonable to expect to see more orthodontic patients wearing temporary crowns that were fabricated with this novel and efficient methodology. Currently, there is a paucity of literature investigating the bond strengths of adhesive bonding systems used to attach orthodontic brackets to provisional restorations that were produced using CAD/CAM. It is important to explore this topic because CAD/CAM provisional materials are inherently different from traditional, chairside-constructed temporary restorations.

Conventional provisional restorations are fabricated chairside by mixing of liquid and powder components. After PMMA provisional restorations are allowed to fully set and are polished, typically more than 50% of methacrylate groups in the PMMA material remain unreacted (Phillips, 1991). In contrast, CAD/CAM-fabricated provisional blocks are industrially-produced and offer a consistently high quality when compared to chairside materials because variability in the mixing of components is eliminated. Furthermore, industrially-produced blocks completely avoid the issues of polymerization shrinkage and oxygen inhibited layer (Wanner, 2010).

Orthodontists are frequently called on by restorative dentists to aid in achieving proper tooth alignment during the course of a restorative treatment plan. Proffit defines Adjunctive Orthodontic Treatment as “tooth movement carried out to facilitate other dental procedures necessary to control disease, restore function, and/or enhance appearance" (Proffit *et al.*, 2013). Patients requiring this type of treatment frequently present to the orthodontic office with provisional restorations already in place. As the use of CAD/CAM technology in dentistry becomes more widespread, we can expect to see an increasing percentage of provisional restorations fabricated via this methodology.

One of the most common materials used to construct provisional restorations is poly methyl methacrylate (PMMA). Various PMMA blocks are now available that can be milled using CAD/CAM technology. Due to the fact that these PMMA crowns are milled from industrially-produced blocks, they will be of a different quality compared to chairside fabricated PMMA restorations, and therefore they may have different requirements having orthodontic brackets bonded to their surfaces. The orthodontist should be equipped with the knowledge and the proper materials to be able to effectively bond brackets when faced with this situation. This study was designed to compare the shear bond strength of metallic orthodontic brackets to CAD/CAM-fabricated PMMA provisional restorations using 4 different adhesive bonding systems. Artun and Bergland's Adhesive Remnant Index (ARI) was used to reveal patterns in bond failure.

II. OBJECTIVES

The purpose of this study was to measure the SBS of metallic brackets (3M Victory Series) after being debonded from CAD/CAM-specific PMMA (Telio CAD, Ivoclar) blocks made for provisional crowns using 4 different adhesive bonding systems (Ivoclar, 3M Unitek, Ormco, Dentsply GAC). The Adhesive Remnant Index was used to evaluate the types of bond failure that had occurred.

III. HYPOTHESES

Hypothesis: There is a significant difference in the SBS of metallic brackets to the PMMA CAD/CAM blocks amongst the different adhesive bonding systems.

Null Hypothesis: There is not a significant difference in the SBS of metallic brackets to PMMA CAD/CAM provisional crowns amongst the different adhesive bonding systems.

IV. MATERIALS AND METHODS

A. PMMA Block Preparation

The substrates for bonding in each group were 55mm x 19mm x 15mm, industrially-fabricated, PMMA CAD/CAM blocks (Ivoclar Telio CAD, size B55, shade A3, Ivoclar Vivadent Inc., Amherst, NY) (Figure 1). Each side of each block provided enough surface area to bond and test 4 brackets. Per the manufacturer, no protective coating is added to the external surface of the blocks after the curing process is complete. The blocks arrive to the restorative dental office or dental laboratory with a uniformly polished surface. The experimental protocol was designed to simulate all of the steps a PMMA provisional restoration would go through as if a patient had arrived to the orthodontic clinic with a polished provisional restoration in place, all the way through to bonding of an orthodontic bracket intra-orally.

In order to mimic a clinical technique that has been proven to increase the bond strength of brackets to provisional restorations (Almeida et al, 2013), the polished, future bonding surfaces of the PMMA blocks were micro-abraded using 50 μm aluminum oxide powder and a Sand Storm Professional sand blaster (Vaniman, Fallbrook, CA) (Figure 2). To insure process standardization, each surface was micro-abraded for 10 seconds, at a pressure of 50 PSI, from distance of 1 inch, and at an angle of 45 degrees. To facilitate this, a jig was utilized to hold the Sand Storm's Spray Jet Handle Assembly in the standardized position (Figure 3). For an in-depth description on how the jig was fabricated please see the Appendix. The block was passed underneath the jet of micro-abrasion particles in a linear, back-and-forth pattern to ensure a uniformly abraded surface (Figure 4).

The surfaces were subsequently thoroughly rinsed with water to remove all particulate matter and then completely dried with compressed air. The blocks were then ready for the bonding procedure.

Figure 1: Ivoclar Telio CAD Blocks

Figure 2: Sand Storm Professional Sand Blaster

Figure 3: Air Abrasion Standardization Jig

Figure 4: Pattern of Surface Micro-abrasion

B. Experimental Groups

Four different adhesive bonding system groups were included in the experimental design. Pairings between primer/bonding agents and adhesive resins were determined based on the recommendations of the individual manufacturers (Table 1). Group 1 included Ivoclar's Telio Activator, Heliobond Light-curing Bonding Resin, and Heliosit Orthodontic Resin-based Dental Luting Material for Brackets (Ivoclar Vivadent Inc., Amherst, NY) (Figure 5). This group utilized the products and a bonding technique recommended by the manufacturer of the PMMA blocks. Groups 2-4 utilized adhesive bonding systems commonly found in orthodontic offices. Group 2 included 3M Unitek's Transbond XT Light Cure Adhesive Primer and Transbond XT Light Cure Adhesive Paste (St. Paul, MN) (Figure 6). Group 3 included Ormco's Ortho Solo Universal Bonding Primer/Enhancer and Grengloo Two-Way Color Change Adhesive (Glendora, CA) (Figure 7). Group 4 included Dentsply's NeoBond Primer and NeoBond Bracket Adhesive Paste (Islandia, NY) (Figure 8).

Table 1: Experimental Groups

1	**IVOCLAR**
	-Telio Activator -Heliobond Light-curing Bonding Resin -Heliosit Orthodontic Resin-based Dental Luting Material for Brackets
2	**3M UNITEK**
	-Transbond XT Light Cure Adhesive Primer -Transbond XT Light Cure Adhesive Paste
3	**ORMCO**
	-Ortho Solo Universal Bonding Primer/Enhancer -Grengloo Two-Way Color Change Adhesive
4	**DENTSPLY GAC**
	-NeoBond Primer -NeoBond Bracket Adhesive Paste

Figure 5: **Group 1** - Ivoclar's Telio Activator, Heliobond Light-curing Bonding Resin, and Heliosit Orthodontic Resin-based Dental Luting Material for Brackets

Figure 6: **Group 2** - 3M Unitek's Transbond XT Light Cure Adhesive Primer and Transbond XT Light Cure Adhesive Paste

Figure 7: **Group 3** - Ormco's Ortho Solo Universal Bonding Primer/Enhancer and Grengloo Two-Way Color Change Adhesive

Figure 8: **Group 4** - Dentsply's NeoBond Primer and NeoBond Bracket Adhesive Paste

C. Bracket Bonding Process

The brackets utilized in this study were 3M Unitek's Victory Series metallic brackets with a 0.022-inch slot with the MBT Versatile+ prescription (Monrovia, CA). The bracket for tooth #8 was selected for its relatively flat bracket base design which seated well onto the flat surfaces of the CAD/CAM blocks. Twenty brackets were tested for each adhesive group.

The instructions of each individual manufacturer were followed closely for each adhesive bonding system (Table 2). Four brackets were bonded per side of the previously air abraded PMMA blocks. The materials used to carry out the bonding procedure for Group 1 is shown in Figure 9. The entire bonding technique was carried out for each individual bracket before moving onto the next bracket (Figures 10 and 11). The experimental protocol was the same for the remaining groups, utilizing their respective primer and adhesive components.

Light curing was accomplished with Ultradent's VALO™ L.E.D. Curing Light (South Jordan, UT) from all four sides, each for 5 seconds (Figure 12). In order to standardize the light's intensity, a Demetron L.E.D. Radiometer (KaVo Kerr, Charlotte, NC) was used to ensure the 1,000mW/cm^2 level was reached.

Table 2: Bonding Techniques (Per Each Manufacturer)

1	**IVOCLAR**
	1. Wet bonding area with Telio Activator. Brush onto entire surface for at least 30 seconds using an application brush to ensure even distribution and quick penetration. 2. Subsequently, allow the Activator to react for another 30-60 seconds (total reaction time 1-2 minutes). 3. Apply Heliobond bonding agent, thinly disperse it with blown air. If used in combination with light-curing luting composites, Heliobond does not require separate polymerization. 4. Apply Heliosit Orthodontic to the undersurface of the metal bracket. 5. Firmly seat bracket onto PMMA bonding surface, gently clean away excess bonding material, and light cure from all four sides of the bracket, each for 5 seconds.
2	**3M UNITEK**
	1. Place small amount of Transbond XT Primer in well. Apply thin uniform coat of primer on bonding surface. Since Transbond XT Primer acts as a wetting agent, only a very thin film of primer is necessary. 2. With the syringe, apply a small amount of Transbond XT adhesive paste onto bracket base. Use Sparingly. 3. Firmly seat bracket onto PMMA bonding surface, gently clean away excess bonding material, and light cure from all four sides of the bracket, each for 5 seconds.
3	**ORMCO**
	1. Apply Ortho Solo to bonding surface in a thin, uniform coat. No air dry or cure step is necessary. 2. Extrude small amount of Grengloo adhesive paste onto the base of the bracket pad. 3. Firmly seat bracket onto PMMA bonding surface, gently clean away excess bonding material, and light cure from all four sides of the bracket, each for 5 seconds.
4	**DENTSPLY**
	1. Apply a thin, uniform layer of NeoBond Primer onto the bonding surface. Gently spread the Primer by use of air. Curing the primer is not required. The primed surfaces should have a glossy appearance. 2. Apply a small amount of NeoBond Bracket Adhesive onto all tooth-bearing surfaces of the bracket. 3. Firmly seat bracket onto PMMA bonding surface, gently clean away excess bonding material, and light cure from all four sides of the bracket, each for 5 seconds.

Figure 9: Group 2 Armamentarium for Bonding Brackets

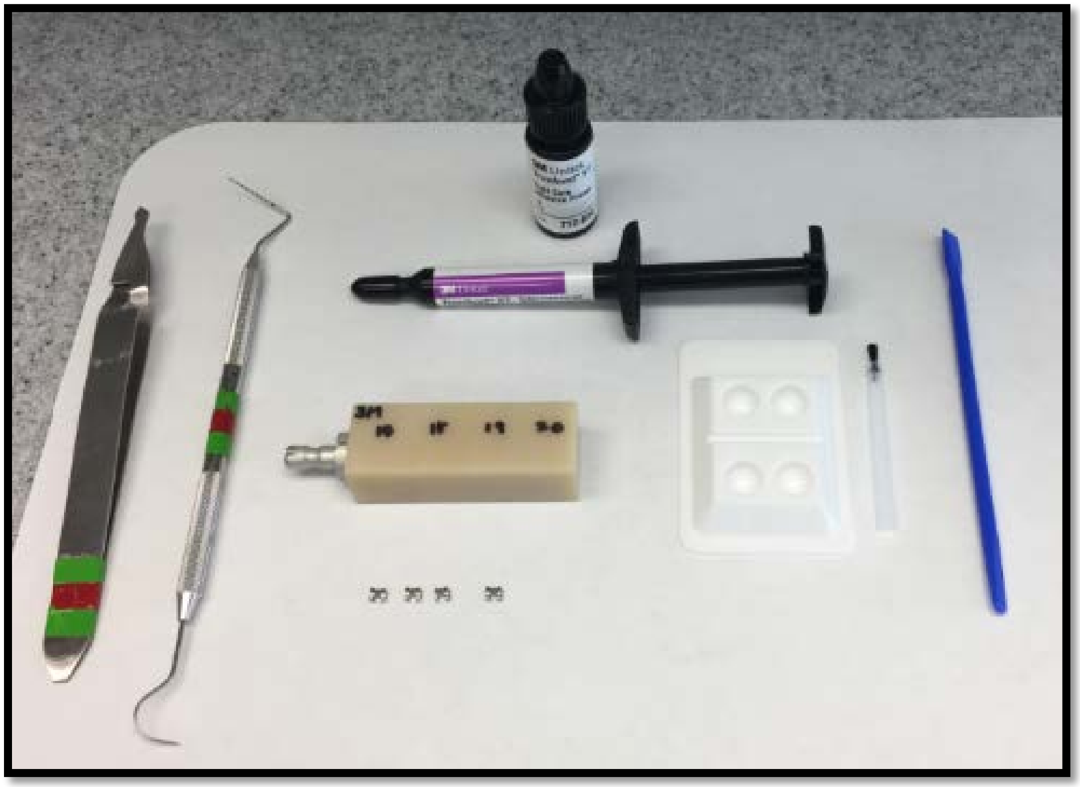


Figure 10: Transbond XT Light Cure Adhesive Primer Applied to PMMA Surface and Transbond XT Light Cure Adhesive Paste Applied to Bracket Base

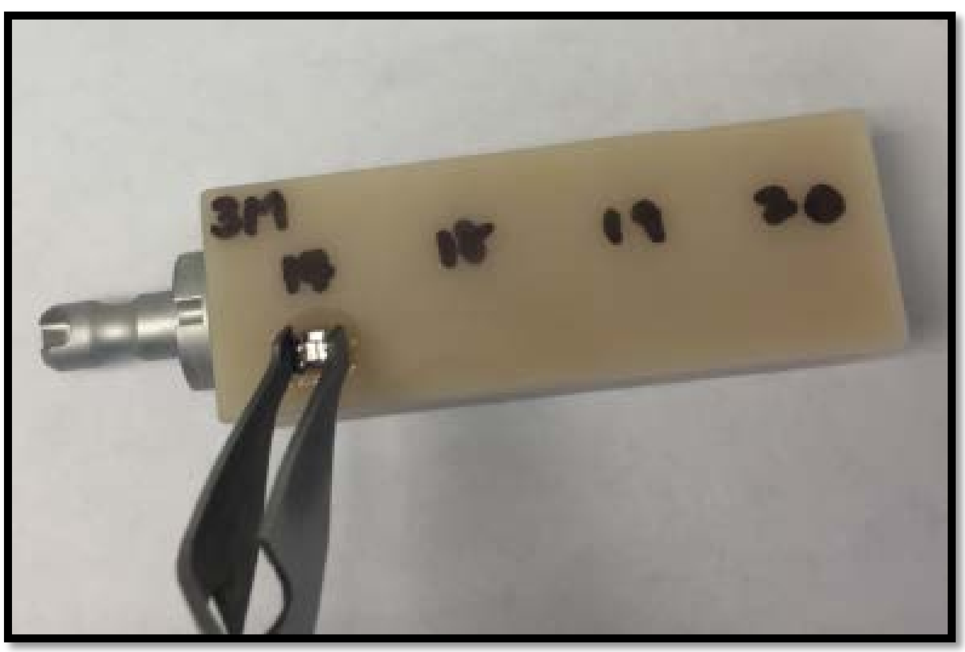


Figure 11: Bracket Placed on PMMA Surface and Excess Adhesive Composite Removed

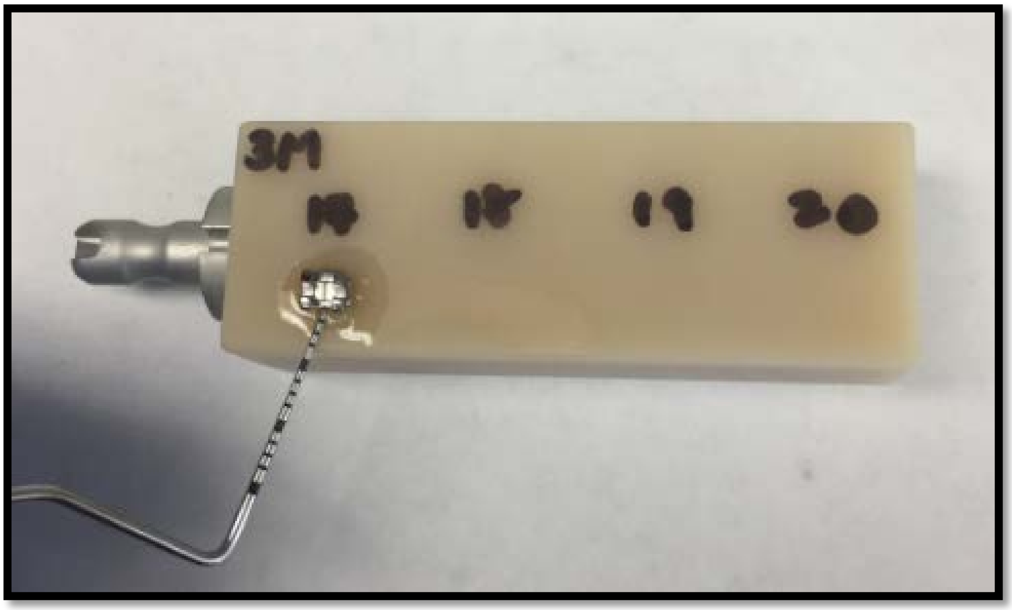


Figure 12: Bracket Light-Cured from All Four Sides for 5 Seconds Each

D. Shear Bond Strength Testing

Once the all of the brackets were bonded according to the specific instructions provided by the individual manufacturers, each PMMA block was mounted on a jig (Ultradent, South Jordan, UT) compatible with the Instron universal testing machine (Instron Model #5943, Norwood, MA) (Figures 13 and 14). The Instron machine's blade was set to deliver a shearing force with a 1mm/min crosshead speed behind the gingival tie wings of each bracket (Figures 15 and 16). The Instron applied increasingly higher levels of force until the brackets were sheared from the face of the PMMA blocks (Figure 17) and the shear bond strength was recorded in Newtons. Utilizing the surface area of the orthodontic bracket base ($10.52mm^2$), Newtons were converted into mega pascals (MPa) using the equation $1N/mm^2=1MPa$. Each bracket was saved in an individually labeled, small plastic bag so that the Adhesive Remnant Index survey could be subsequently carried out.

Figure 13: Instron (Model #5943)

Figure 14: PMMA Block with Bonded Brackets Mounted on Ultradent Jig

Figure 15: Instron Blade Lined Up Flush with Bracket Base

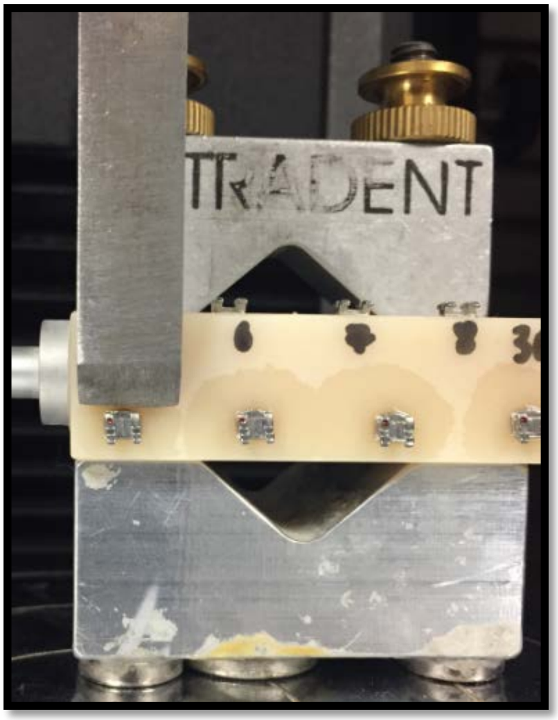


Figure 16: Instron Blade Lined up Flush with Bracket Base

Figure 17: Increasing Force Applied until Bond Failure

E. Adhesive Remnant Index Survey

A Leica Stereo Microscope (Model #S4E, Buffalo Grove, IL) set to 20X magnification was used to identify the adhesive remnants on the bracket bases and PMMA bonding surfaces after bond failure (Figure 18). Artun and Bergland's Adhesive Remnant Index was subsequently used to categorize each bond failure into the categories found in Table 3 (Artun and Bergland, 1984). To prevent bias, another orthodontic resident other than the principle investigator was calibrated, blinded in terms of which group each bracket belonged to, and then used the microscope to assign an ARI score to each bracket.

Similar to the study by Chay *et al.* on the effects of surface treatment and aging on bond strength, when an ARI score of 0 or 1 was assigned, the failure was classified as an "adhesive failure", as it occurred at the adhesive-provisional material interface or within the adhesive itself. When an ARI score of 2 or 3 was assigned, the failure was classified as a "cohesive failure", as it occurred at the adhesive-bracket interface or within the adhesive itself.

Figure 18: Leica S4E Stereo Microscope used for ARI Survey

Table 3: Adhesive Remnant Index Categories

ARI Score	Definition	Type of Failure
0	0 adhesive on PMMA surface (100% on bracket base)	Adhesive Failure
1	<50% adhesive on PMMA surface (>50% on bracket base)	Adhesive Failure
2	>50% adhesive on PMMA surface (<50% on bracket base)	Cohesive
3	100% adhesive on PMMA surface with clear imprint of bracket base (0 adhesive on bracket base)	Cohesive

F. Statistical Management of Data

A power analysis was conducted using the Sampsi Command within the STATA Version 12 statistical software and determined that a sample size of 20 per group was adequate to detect an effect, if there was one, and reasonably reject the null hypothesis in the case it was not true. Four groups with a sample size of 20 per group provided 80% power to detect an effect size of 0.9 standard deviations difference among means when testing with a single factor analysis of variance (ANOVA) at the alpha level of 0.05.

The Instron unit was used to test the SBS of each sample and recorded values in Newtons. In order to convert the Newton values to Megapascals (MPa), the equation $1N/mm^2=1MPa$ was used. In the case of the 3M Unitek Victory Series brackets made for tooth #8, the bracket base surface area was 10.52 mm^2. Once all values were converted to MPa, means and standard deviations were calculated for each group. In order to test for possible significant differences between the mean SBS for each group, a one-way Analysis of Variance (ANOVA) Test was used with significance set to $p<0.05$.

After the single-blinded orthodontic resident determined the ARI score for each bracket, the data was compiled into Table 6. The Kruskal-Wallis and Mann-Whitney U Tests were then used to determine if a significant difference existed between the ARI scores the four groups. Level of significance was initially set to $p<0.05$, but because six different individual comparisons were performed between the groups, a Bonferroni Correction was completed to reduce the chance of false positive results ($\alpha = 0.008$).

V. RESULTS

Once the Instron universal testing machine sheared each bracket from the PMMA surface, the SBS was recorded in Newtons. These values were subsequently converted to MPa. The SBS data for each individual bracket is displayed in Table 4 and the mean SBS and standard deviations for each group are listed in Table 5. Group 3 had the highest average SBS at 6.58 (1.22) MPa. Group 2 had the lowest average SBS at 5.81 (1.37) MPa. The mean SBS values are depicted graphically in Figure 22, which shows a relatively normal distribution of data for each sample group. The one-way ANOVA found no statistically significant difference in SBS values based on type of adhesive used ($p = 0.168$) and thus the collected data failed to reject the null hypothesis (Table 5).

After evaluating SBS, the mode of failure of each bracket was determined using the ARI survey under 20X microscope magnification. ARI scores were recorded for each bracket using the 0-3 scale created by Artun and Bergland. Table 7 and Figure 20 displays the ARI Scores by frequency distribution of failure modes. The Kruskal-Wallis Test was then used and found a significant difference in ARI scores between the adhesive groups ($p = 0.016$). Subsequent significant differences were also found using individual Mann-Whitney U Tests to compare each group post hoc. A Bonferroni Correction was applied because multiple comparisons were completed between groups ($\alpha = 0.008$) (Table 6).

The most common type of adhesive failure mode for all of the groups was cohesive in nature and resulted in more than 50% of the adhesive remaining on the PMMA surface (ARI = 2). Group 1 had the largest amount of failures that occurred between the bracket base and the adhesive, resulting in all of the adhesive being left on the PMMA surface with a clear imprint of the bracket (ARI = 3). Group 3 had the largest amount of adhesive failures resulting in none of the adhesive being left on the PMMA surface (ARI = 0).

Group 1 had the highest overall ARI scores which were significantly greater than Groups 3 and 4, but not significantly different from Group 2 (Table 6). Group 2 was not significantly different from any other group. Groups 3 and 4 had the lowest ARI scores.

Table 4: SBS Values Recorded at Bond Failure

	Group 1: IVOCLAR		Group 2: 3M UNITEK		Group 3: ORMCO		Group 4: DENTSPLY GAC	
#	N	MPa	N	MPa	N	MPa	N	MPa
1	77.55	7.37	51.67	4.91	64.22	6.10	77.05	7.32
2	74.60	7.09	73.13	6.95	53.02	5.03	44.90	4.26
3	63.47	6.03	56.17	5.33	59.71	5.67	59.35	5.64
4	58.00	5.51	53.90	5.12	58.52	5.56	62.25	5.91
5	62.65	5.95	52.92	5.03	62.08	5.90	53.34	5.07
6	72.94	6.93	67.07	6.37	74.12	7.04	76.29	7.25
7	67.57	6.42	49.39	4.69	85.82	8.15	66.75	6.34
8	72.84	6.92	84.45	8.02	57.56	5.47	47.87	4.55
9	53.31	5.06	60.36	5.73	77.61	7.37	81.94	7.78
10	69.45	6.60	94.79	9.01	61.65	5.86	52.92	5.03
11	68.77	6.53	66.47	6.31	88.65	8.42	58.49	5.55
12	63.75	6.05	56.30	5.35	53.02	5.03	92.65	8.80
13	51.85	4.92	63.68	6.05	70.75	6.72	63.87	6.07
14	65.90	6.26	52.83	5.02	74.35	7.06	53.48	5.08
15	65.36	6.21	56.24	5.34	55.32	5.25	84.78	8.05
16	68.86	6.54	57.69	5.48	60.55	5.75	59.82	5.68
17	70.59	6.71	49.10	4.66	81.34	7.73	52.74	5.01
18	67.97	6.46	52.85	5.02	88.92	8.45	48.07	4.56
19	60.89	5.78	36.67	3.48	65.98	6.27	52.80	5.01
20	77.72	7.38	88.48	8.41	93.10	8.84	68.47	6.50

Table 5: SBS by Mean, Standard Deviation, and Statistical Difference

Group #	MPa (Standard Deviation)*
3	6.58 (1.22) a
1	6.34 (0.67) a
4	5.97 (1.28) a
2	5.81 (1.37) a
**Groups with the same lower case letter are not significantly different (p>0.05)*	

Figure 19: Shear Bond Strength Box Plot

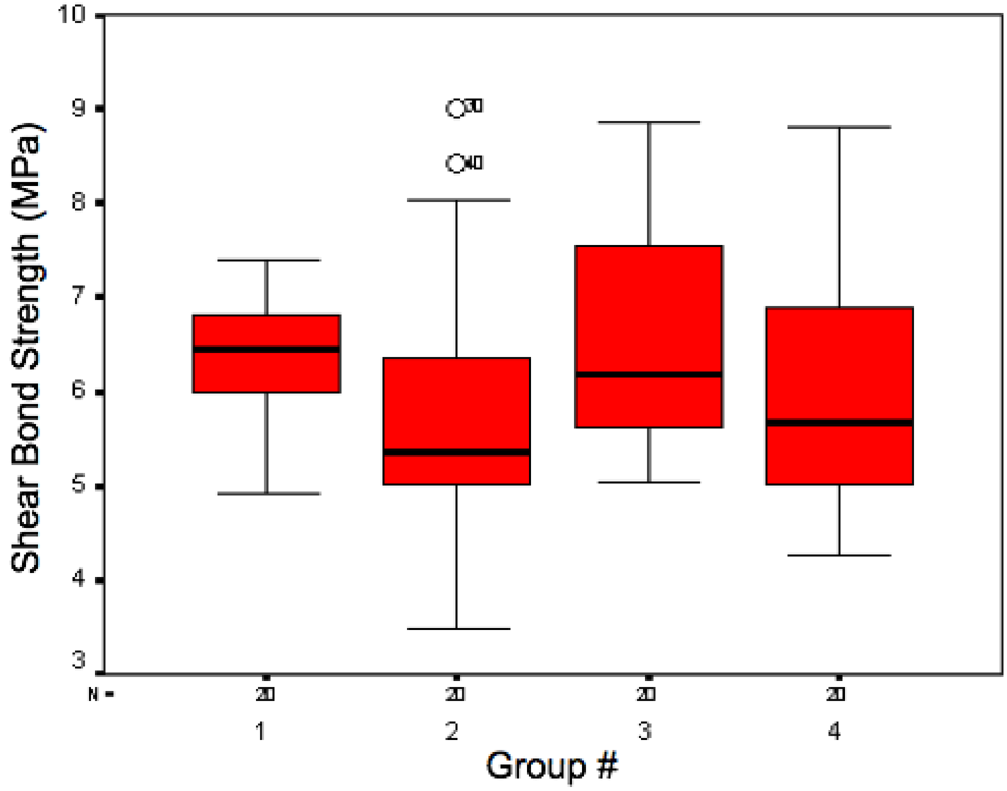


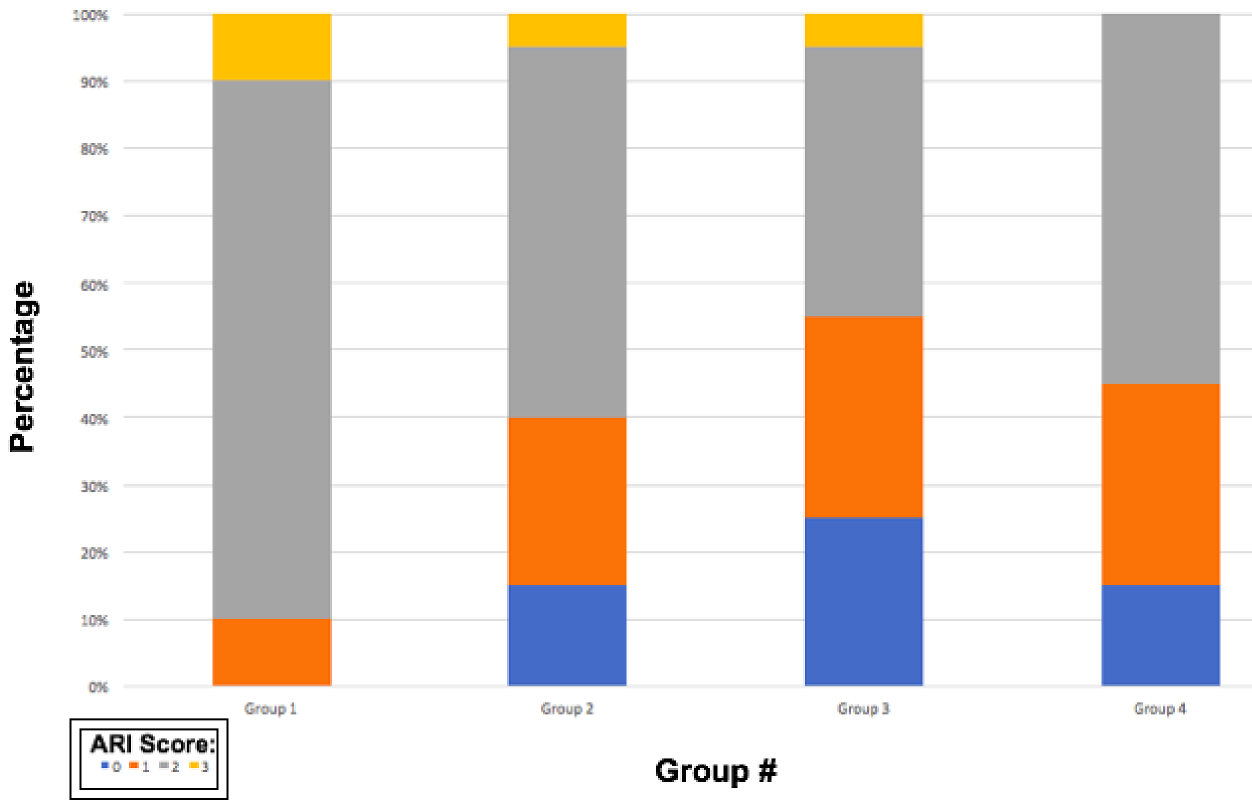
Table 6: ARI Scores by Mean Rank and Statistical Difference

Group #	Mean Rank
1	52.75 a
2	39.50 ab
3	33.13 b
4	36.63 b
**Groups with the same lower case letter are not significantly different (p>0.05)*	

Table 7: ARI Scores by Frequency Distribution of Failure Modes

	ARI Scores			
Group #	**0**	**1**	**2**	**3**
1	0	2	16	2
2	3	5	11	1
3	5	6	8	1
4	3	6	11	0

Figure 20: Graph of ARI Scores by Frequency Distribution of Failure Modes



VI. DISCUSSION

This study investigated if there were any significant differences in SBS or failure mode of orthodontic adhesive systems used to bond metallic brackets to CAD/CAM-fabricated PMMA provisional restorations. Four groups were created, each including a different adhesive bonding system. These groups shared some similar characteristics in that they all included commonly used adhesive systems produced by reputable manufacturers, all of which were designed for the purpose of bonding metallic orthodontic brackets. In addition, they all included a liquid primer and a resin composite adhesive paste and required relatively similar steps in their bonding processes.

The four groups also differed in various ways. For instance, Group 1 (Ivoclar), which also happened to be the manufacturer of the PMMA blocks, was different from the others in that it involved a preliminary step in the bonding process prior to application of the liquid primer. Ivoclar's recommendation was to first treat the PMMA surface with a product they call the Activator, which is a monomer that contains methyl methacrylate, ethylene glycol methacrylate, and triethylene glycol dimethacrylate. According to the documentation provided with the product, this step is designed to "activate" the surface of the restoration so that it can then be adjusted, relined, or customized. For the purposes of this study, the Activator was used on the PMMA surface in preparation for having an orthodontic bracket bonded to its surface.

Another difference was found within Group 3 (Ormco) in that it utilized a universal primer. Universal primers typically have 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) included in their formulation. This functional monomer is designed to enhance the adhesive's performance by increasing monomer penetration and resin diffusion and is considered one of the best materials available for chemical bonding (Turp et al., 2013). The other three groups did not advertise themselves as universal adhesives, nor did they provide details of their chemical formulation within their included documentation, therefore it can be assumed that they do not utilize any additional functional monomers such as 10-MDP.

Group 3 (Ormco) had the highest mean SBS (6.58 MPa) of the four groups, and this may be due to the fact that this group included a universal primer which contained the 10-MDP functional monomer. It was also noted during the bonding process, that the primer used within this bonding system, Ortho Solo, was less viscous, and this may have provided better wettability of the PMMA surface, possibly contributing to higher SBS. Group 1 (Ivoclar) had the second highest mean SBS (6.34 MPa) and this may be due to the fact that this group included a preliminary step of activation of the PMMA surface. It is important to note however, that the SBS values for all of the groups were not statistically significantly different from each other. More than likely this would translate into performance differences that would not be clinically significant.

The one-way ANOVA found no statistically significant difference in SBS values based on type of adhesive used ($p = 0.168$) and thus the collected data failed to reject the null hypothesis. All four groups had mean SBS either within (Ivoclar, Ormco, and Dentsply GAC), or very close to being within (3M), the acceptable range (5.9-7.8 MPa) for clinically acceptable bond strengths as determined by Reynolds (Reynolds, 1979). More than likely, any of the four adhesive bonding systems tested in this study would be able to provide adequate clinical SBS in bonding a metallic bracket to a PMMA provisional restoration that was fabricated using CAD/CAM technology.

In terms of ARI scores, the most common type of adhesive failure mode for all of the groups was cohesive in nature and resulted in more than 50% of the adhesive remaining on the PMMA surface (ARI = 2). The fact that more than 50% of the adhesive remained on the bonding surface points to the fact that all four adhesives were able to form an adequately strong bond to the PMMA substrate. Both PMMA and orthodontic adhesives are composites of resin and filler materials, so it was expected that the strongest bonds formed would be between the adhesive and the substrate's bonding surface, and this was supported by the findings of the ARI survey.

During the ARI survey, the secondary investigator who was responsible for assigning the scores to each debonded surface under 20X magnification pointed out two findings worth mentioning. The first interesting finding is that when viewed at this magnification, it was possible to see that overall, the bond failures occurred with two distinct patterns. Groups 2, 3, and 4 (3M, Ormco, and Dentsply GAC) mainly failed with a line clearly demarcating the area where adhesive remained on the PMMA surface, and the area where adhesive sheared from the PMMA surface (Figure 21). Group 1 (Ivoclar), however, failed differently in that small, circular areas of adhesive remained on the PMMA surface instead of failing in a pattern similar to Groups 2, 3, and 4. A potential explanation for this may be that Group 1 was different from the others in that it included an extra preliminary step in the bonding process that involved activation of the PMMA surface.

The second interesting finding pointed out by the secondary investigator was that overall, none of the groups caused damage to the PMMA surface that was visible to the naked eye. This is an important finding and should help clinical orthodontists feel comfortable that if they are using any of these adhesive bonding systems to attach brackets to PMMA provisional crowns, they should not expect gross damage to the surface if a debond were to occur. On a microscopic level however, when viewed under 20X power, it became apparent that the failure pattern of Group 3 was slightly different in that it did cause micro-damage to the PMMA surface. Small amounts of PMMA were actually pulled from the bonding surface when the adhesive failed at the adhesive/substrate interface (an “adhesive” failure). This could be attributed to the slightly higher SBS that Group 3 was able to achieve (6.58 MPa) as compared to the other groups. Overall, because this damage was only microscopically apparent, the clinician should not be worried about debonding of brackets causing clinically relevant damage to the surface of PMMA restorations.

There were various weaknesses that can be identified within the design of this study and it is important to point them out so that future investigators can learn from them and improve future study designs. The first limitation worth noting is that some of the experimental protocols were not as tightly controlled as they could have been. The temperature and humidity of the room, and ambient light are examples. In addition, the amounts of the various primer and adhesive paste components were not measured prior to carrying out the bonding protocol. In 1998, Hotta *et al*. studied if varying the ratio of primer to adhesive would have an effect on the polymerization of bonding agents. By measuring the degree of conversion and tensile strength of their samples, they were able to determine that a higher amount of primer caused a lower degree of conversion and poorer mechanical properties compared to mixtures with lower amounts of primer (Hotta *et al*., 1998). Within the present study, it was possible that differing ratios of liquid primer to adhesive paste were used from sample to sample. This could have caused varying degrees of polymerization during light curing, which could have subsequently affected the structural properties of the cured adhesives and their SBS values. In potential future studies, it is recommended that tight controls are placed on the amounts of liquid primer and adhesive paste.

Another variable that was not standardized or tightly controlled during this study was the amount of force used to seat each bracket on the PMMA surface. This could have resulted in varying thicknesses of cured adhesive between the bracket bases and substrate surfaces. Recently it has been shown that shear bond strength required to debond orthodontic brackets tends to increase with a decrease in the thickness of adhesive up to a point, and then decreases (Jain *et al*., 2013). It was also determined that the force required for removal of brackets can be reduced by decreasing the thickness of orthodontic adhesive between teeth and brackets (Hama *et al*., 2014). Within the current study, the instructions for the manufacturers were followed, and each bracket was “firmly” seated onto the PMMA bonding surface, but an exact seating force level was not measured or ensured. Brackets seated with a heavier force would result in a thinner layer of adhesive, and according to Jain and Hama, these brackets would have affected the force levels required to cause a bond failure. Perhaps by ensuring tighter controls on these variables, more accurate data could have been obtained and reported.

The Instron universal testing machine itself introduced a possible confounding variable as well (Figures 23 and 24). The crosshead blade is the portion of the machine that actually comes into contact with the bracket to apply shearing force and eventually debond the bracket. Ideally, the crosshead blade should be set to travel down along PMMA block, flush with the bonding surface to deliver the shearing force to the bracket base. However, during pilot testing for this study, it was determined that if the crosshead blade was set in this way it would first come into contact with the small amount of residual, cured bonding agent around the bracket. The crosshead blade would begin to apply a shearing force to the cured bonding agent and then tend to slip over the bonding agent, causing an abrupt drop in recorded force application. This abrupt slip motion was interpreted by the Instron as a debond and force application was immediately halted.

To mitigate this issue, instead of setting the crosshead blade to travel down flush with the face of the PMMA surface, a small amount of space was allowed between the crosshead and the bonding surface. Once the blade reached the bracket, it would not come into the contact with the cured adhesive or the bracket base, but instead would contact behind the gingival tie wings on the slot base

(Figure 23). When set perfectly, the Instron's blade would apply a pure shearing force to the bracket until bond failure and debond. A potential for error was created by the thickness of the blade's slanted tip. Because of this thickness, it was possible for the slanted surface of the blade to contact the gingival tie wings themselves before the tip of the blade could come into contact with the slot base. If applied in this way, instead of a linear shearing force, the slanted surface applies a torqueing force, which this study wasn't designed to evaluate. This could have been avoided, and can be avoided in future studies, by either ordering a blade with a slimmer tip, or by filing down the existing crosshead tip to make it slimmer. Due to the fact that orthodontic adhesives have to resist many different types of debonding forces in the harsh oral environment (including both shearing and torqueing), the data collected during this study and their interpretation are still very valuable to the clinician.

Another weakness identified was that the primary investigator was not blinded to which adhesive bonding system was being used when carrying out the bonding protocol, which could have introduced bias. However, bias was avoided since the determination of which group would best serve orthodontists in this potential clinical scenario was solely based on the objective, numerical data collected instead of subjective preference. This weakness could have been avoided had the bottles and syringes containing the bonding materials been stripped of all identifying labels.

The final weakness identified was that it was not possible to completely blind the investigator who conducted the ARI survey due to the fact that Ormco's

Grengloo adhesive paste cures to a light green color. Again, since objective, numerical data was relied upon for determining which system would best serve orthodontists clinically, potential bias was avoided. This weakness could have been completely avoided if during the ARI survey, high resolution photographs of the bonding surface were obtained through the microscope and then digitally modified to appear in only black and white. These photographs could then have been presented to the investigator responsible for carrying out the ARI survey.

This study follows in a lineage of similarly designed studies that also set out to determine what the best adhesive system would be for bonding orthodontic brackets to a specific substrate. In 2016, Segall investigated how various orthodontic bonding systems affected SBS between metallic brackets bonded to a zirconia substrate designed for CAD/CAM use. He reported SBS values ranging from 8.26 to 12.47 MPa, which were somewhat higher than those found in this study (Segall, 2016). In 2017, Domm carried out a study that utilized a similar design with ceramic brackets and CAD/CAM zirconia blocks. She reported SBS values ranging from 16.7 to 35.2 MPa, which were vastly greater than those reported in the currently study (Domm, 2017). It is known that ceramic brackets are capable of routinely achieving much higher SBS values as compared to metallic brackets. Since more and more adults are seeking orthodontic treatment and esthetic orthodontic appliances are in high demand, a potential future study that would benefit the body of orthodontic scientific knowledge would be to test various adhesive bonding systems and how they affect SBS values between

PMMA blocks designed for use with CAD/CAM technology and more esthetic ceramic brackets.

It is important to remember that this was strictly an in vitro study and that assumptions had to be made when making recommendations for clinical orthodontics. Future studies could be further improved by either incorporating design features that attempt to mimic the oral environment (i.e. thermocycling) or by carrying out a longitudinal in vivo study. An in vivo study would be particularly illustrative in terms of evaluating potential damage the debonding process could have on a polished PMMA provisional restoration. It would also be valuable to compare how treating the PMMA blocks with various surface treatments (i.e. air abrasion vs. disc roughening vs. diamond bur roughening) would affect SBS values. This information would be very useful to an orthodontist faced with the clinical scenario of having to bond an orthodontic bracket to a provisional restoration that was milled from a solid PMMA block.

In conclusion, this study assumed that since PMMA blocks made for use with CAD/CAM were industrially-fabricated, that they would possess different characteristics when it comes to bonding orthodontic brackets to their surfaces when compared to traditional PMMA provisional restorations fabricated with liquid and powder mixtures in a chairside manner. It would be particularly revealing to directly compare traditional, chairside-fabricated PMMA restorations to CAD-CAM-fabricated PMMA restorations, and see if there truly are differences in SBS when bonding orthodontic brackets to them. With this information, orthodontists may be able to better communicate with their restorative dentist counterparts when collaborating on interdisciplinary cases.

Figure 21: Pattern of Adhesive Failure for Groups 2, 3, and 4.

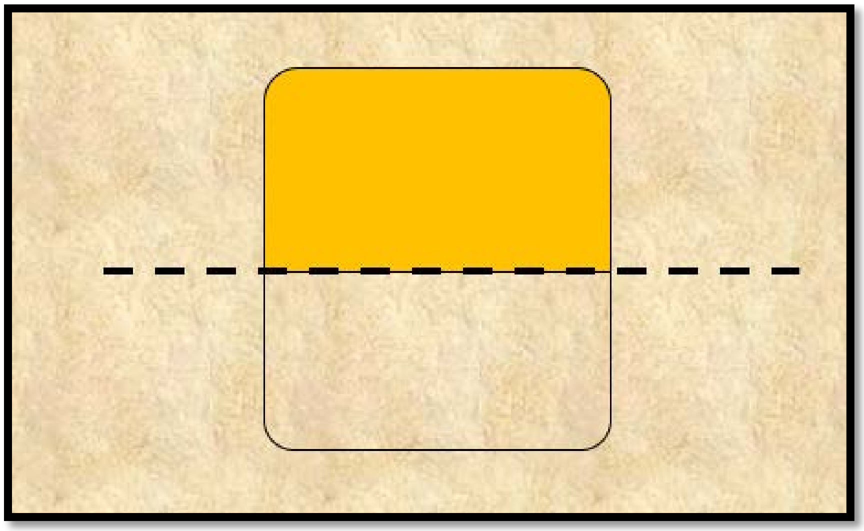


Figure 22: Pattern of Adhesive Failure for Group 1.

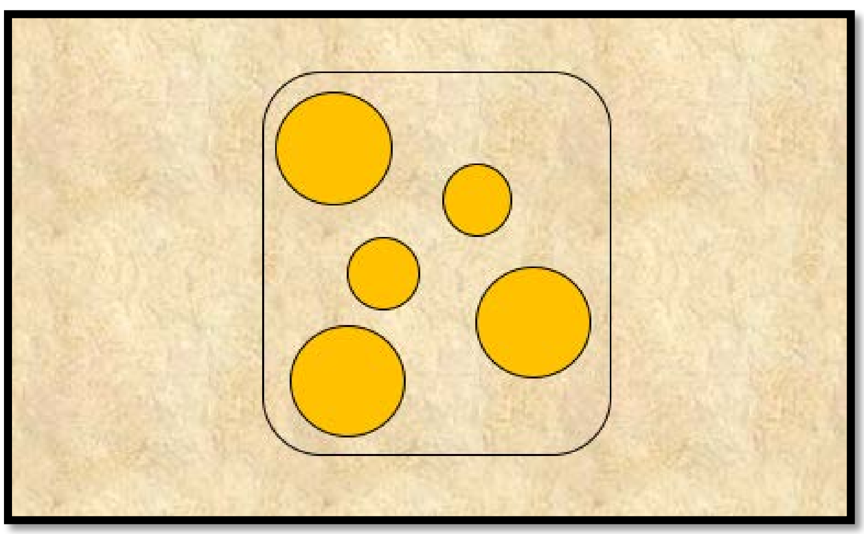


Figure 23: Correct Force Application: Instron Crosshead Applying Shearing Force

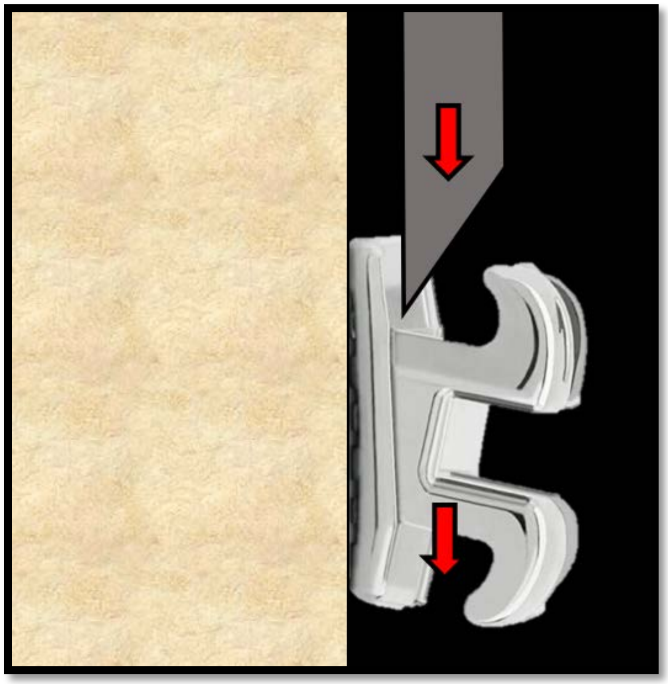
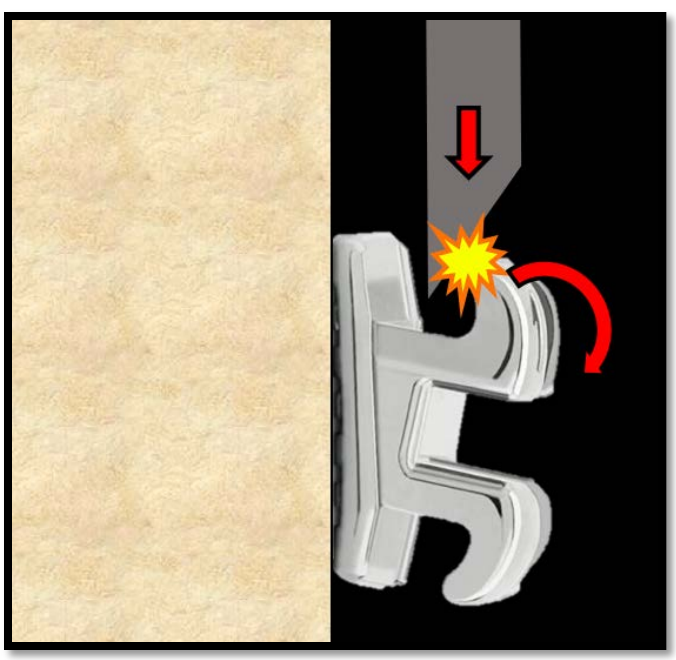


Figure 24: Incorrect Force Application: Instron Crosshead Applying Torqueing Force



VII. CONCLUSIONS

1. There were no statistically significant differences in SBS values based on type of adhesive used ($p = 0.168$) and thus the collected data failed to reject the null hypothesis.
2. Three groups (Ivoclar, Ormco, and Dentsply GAC) had SBS within the clinically acceptable range as defined by Reynolds (5.9-7.8 MPa) (Reynolds, 1979), however these SBS were not statistically significantly different when compared to the other group. The other group (3M) had SBS very close to, but not within the clinically acceptable range, however its SBS were so close that it can be assumed that it would also be able to provide clinically acceptable SBS with adequate performance.
3. None of the groups produced SBS high enough to cause damage to the surface of the PMMA substrate that would be evident clinically.
4. There were statistically significant differences in ARI scores based on the type of adhesive used ($p = 0.016$).
5. The primary mode of bond failure for all four of the groups was cohesive in nature, where more than 50% of the adhesive remained on the PMMA surface (ARI = 2).
6. Taking the limitations of this study into account, it can be concluded that any of these four, commonly-used orthodontic adhesive bonding systems could be utilized in a clinical setting to bond metallic brackets to PMMA provisional restorations that have been fabricated using CAD/CAM technology.

VIII. REFERENCES

Akhoundi MS, Mojtahedzadeh F. Problems in Standardization of Orthodontic Shear Bond Strength Tests; A Brief Review. J Dent, Tehran Univ of Med Sci. 2005 Mar;2(1):36-40.

Artun J, Bergland S. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. Am J Orthod. 1984 Apr;85(4):333-340.

Beckwith FR, Ackerman RJ, Cobb CM, Tira DE. An evaluation of factors affecting duration of orthodontic treatment. Am J Orthod Dentofacial Orthop. 1999 Apr;115(4):439-447.

Beuer F, Schweiger J, Edelhoff D. Digital Dentistry: an overview of recent developments for CAD/CAM generated restorations. Br Dent J. 2008 May;204(9):505-511.

Bishara SE, VonWald L, Laffoon JF, Warren JJ. Effect of a self-etch primer/adhesive on the shear bond strength of orthodontic brackets. Am J Orthod. 2001 June;119(6):621-624.

Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. J Dent Res. 1955 Dec;34(6):849-853.

Domm GM. Shear bond strength of ceramic brackets to zirconia conditioned with various primer-adhesive systems. Bethesda (MD): Uniformed Services University of the Health Sciences; 2017.

Gorelick L. Bonding metal brackets with a self-polymerizing sealant-composite: a 12-month assessment. Am J Orthod. 1977 May;71(5):542-553.

Hama T, Namura Y, Nishio Y, Yoneyama T, Shimizu N. Effect of orthodontic adhesive thickness on force required by debonding pliers. J Oral Sci. 2014 Sep;56(3):185-190.

Hotta M, Kondoh K, Kamemizu H. Effects of primers on bonding agent polymerization. J Oral Rehabil. 1998 Oct;25(10):792-799.

Jain M, Shetty S, Mogra S, Shetty VS, Dhakar N. Determination of optimum adhesive thickness using varying degrees of force application with light-cured adhesive and its effect on the shear bond strength of orthodontic brackets: an in vitro study. Orthodontics (Chic). 2013;14(1):e40-49.

Klim J, Corrales EB. Innovation in dentistry: CAD/CAM restorative procedures. Dental Academy of Continuing Education. 2010.

Minick GT, Oesterle LJ, Newman SM, Shellhart WC. Bracket bond strengths of new adhesive systems. Am J Orthod Dentofacial Orthop. 2009 Jun;135(6):771-776.

Montasser MA, Drummond JL. Reliability of the adhesive remnant index score system with different magnifications. Angle Orthod. 2009 Jul;79(4):773-776.

Nattrass C, Sandy JR. Adult orthodontics--a review. Br J Orthod. 1995 Nov;22(4):331-337.

Newman GV. Epoxy adhesives for orthodontic attachments: progress report. Am J Orthod. 1965 Dec;51(12):901-912.

Pasquale A, Weinstein M, Borislow AJ, Braitman LE. In-vivo prospective comparison of bond failure rates of 2 self-etching primer/adhesive systems. Am J Orthod Dentofacial Orthop. 2007 Nov;132(5):671-674.

Phillips RW. Restorative resins: repair of composites. In: Dyson J, editor. Skinner's science of dental materials. Philadelphia: W. B. Saunders; 1991. p. 235.

Proffit WR, Fields HW, Sarver DM. Contemporary Orthodontics. 5th ed. St. Louis: Mosby;2013.

Reynolds IR. A review of direct orthodontic bonding. Br J Orthod. 1979;2:171-178.

Rix D, Foley TF, Mamadras A. Comparison of bond strength of three adhesives: Composite resin, hybrid GIC, and glass-filled GIC. Am J Orthod Dentofacial Orthop. 2001 Jan;119(1):36-42.

Segall MD. Shear bond strength of metal brackets to zirconia conditioned with various primer-adhesive systems. Bethesda (MD): Uniformed Services University of the Health Sciences; 2016.

Spalding PM, Cohen BD. Orthodontic Adjunctive Treatment in Fixed Prosthodontics. Dent Clin N Amer. 1992 Jul;36(3):607-629.

Turp V, Sen D, Tuncelli B, Ozcan M. Adhesion of 10-MDP containing resin cements to dentin with and without the etch-and-rinse technique. J Adv Prosthodont. 2013 Aug;5(3):226-233.

Wanner D. Scientific Documentation Telio CAD. Ivoclar Vivadent AG. 2010.

Whitlock BO 3rd, Eick JD, Ackerman RJ Jr, Glaros AG, Chappell RP. Shear strength of ceramic brackets bonded to porcelain. Am J Orthod Dentofacial Orthop. 1994 Oct;106(4):358-364.

IX. APPENDIX: Fabrication of Air Abrasion Jig

In order to standardize the air abrasion process of the PMMA blocks, a jig was fabricated to hold the tip of the Sand Storm's Spray Jet Handle Assembly (Vaniman, Fallbrook, CA) at a constant height (1 inch) and angulation (45 degrees) in relation to the bonding surface. This appendix is designed to lay out the steps taken to fabricate this device using materials and equipment commonly found in a dental laboratory.

The first step is to fabricate the stone base. Whip Mix White Orthodontic Stone (Whip Mix, Louisville, KY) was combined in a 100g powder to 28mL water ratio and vacuum mixed in a Whip Mix VPM2 Vacuum Mixer at 350 RPM for 20 seconds (Figure 25). This will provide you with 5-7 minutes of working time and will have an overall setting time of 10 minutes. During this time, the wet stone mixture should be poured into a 5oz Solo Cold Cup (Neenah, WI) and vibrated into place utilizing a Whip Mix Heavy Duty Vibrating Table (Figure 25).

After the 10-minute setting time, the cup-shaped base is ready to be trimmed and the cup can be torn away from the set stone (Figure 27). A Wehmer Pro-Trim Model Trimmer (Lombard, IL) can be used to first flatten the top and bottom of the base (Figure 28). Next, the model trimmer is set to 45 degrees to cut a slanted edge into the top surface of the base (Figures 29 and 30).

Once the base has been cut to its final form, retentive grooves will then be cut into the top and slanted surface of the base using an NSK Ultimate XL Straight Handpiece (Hoffman Estates, IL) (Figures 31 and 32). DENTSPLY/Caulk Reprosil Polyvinyl Siloxane (Milford, DE) is then mixed in equal proportions to form the portion of the jig that will hold the Spray Jet Handle. The Reprosil mass is first pressed into the retentive grooves, then the Spray Jet Handle is laid across the mass on the slanted portion of the base so that the Reprosil can be formed around the Handle to almost completely encircle it (Figures 33 and 34). Once fully set, the Air Abrasion Jig is ready for use (Figure 35).

Figure 25: Whip Mix VPM2 Vacuum Mixer

Figure 26: Stone Mixture Poured into Cold Cup

Figure 27: Cup-Shaped Base Ready for Trimming

Figure 28: Wehmer Pro-Trim Model Trimmer used to Flatten Base

Figure 29: Model Trimmer set to 45-Degrees

Figure 30: 45-Degree Cut Made

Figure 31: Retentive Groove Position Marked

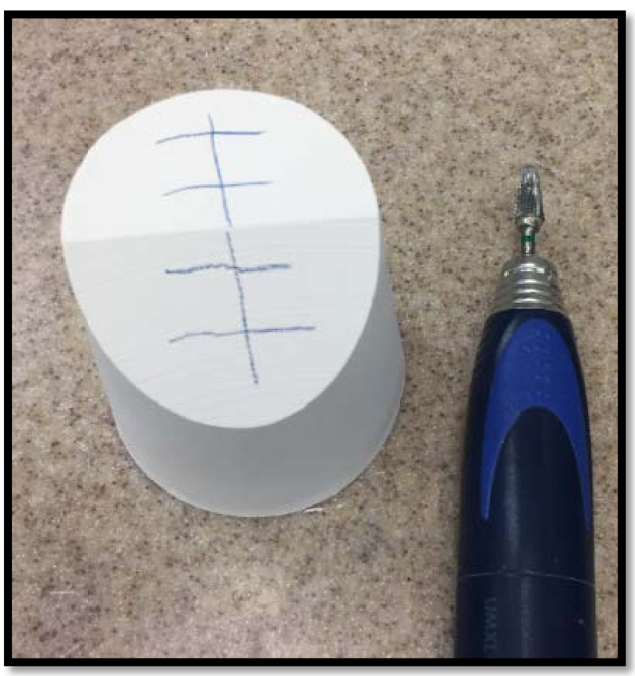


Figure 32: Retentive Grooves Cut

Figure 33: Reprosil Formed

Figure 34: Spray Jet Assembly in Position

Figure 35: Abrasion Jig in Use