9-11-2015

SEM Assessment of the Enamel Surface After Debonding of Ceramic Brackets

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ANUJA KOTHARI, D.D.S.

A Thesis Presented to the Faculty of the College of Dental Medicine of

Nova Southeastern University in Partial Fulfillment of the Requirements for the

Degree of

MASTER OF SCIENCE IN DENTISTRY

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December 2015

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TITLE OF SUBMISSION: SEM Assessment of the Enamel Surface After

Debonding of Ceramic Brackets

DATE SUBMITED: September 11, 2015

I certify that I am the sole author of this thesis, and that any assistance I received in its preparation has been fully acknowledged and disclosed in the thesis. I have cited any sources from which I used ideas, data, or words, and labeled as quotations any directly quoted phrases or passages, as well as providing proper documentation and citations. This thesis was prepared by me, specifically for the M.Sc.D. degree and for this assignment.

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DEDICATION

To my family for their endless love and support.

Acknowledgements

I would like to acknowledge the following individuals:

Dr. Sergio Real for serving as my mentor for this thesis and throughout the Orthodontics program. Thank you for your patience and guidance throughout this journey.

Dr. Cristina Garcia-Godoy for serving on my committee. I appreciate all of your assistance and insight during this project.

Dr. Marissa Cooper for serving on my committee. Thank you for all of your contributions during this process.

Mr. Jim Rothrock for all of your help and insight in the research lab.

Dr. Patrick Hardigan for your guidance and expertise in Statistics.

Artur Zielinski of Vistar Machine Shop for your creativity and patience in fabricating the Instron jig.

Chris Hansen for your interest and time in completing this study.

Abstract

SEM ASSESSMENT OF THE ENAMEL SURFACE AFTER DEBONDING OF CERAMIC BRACKETS

DEGREE DATE: DECEMBER 11, 2015

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Objective: This study was conducted to compare the shear bond strengths, patterns of bond failure and enamel surfaces after debonding two ceramic brackets (ClearVu and Radiance Plus) and one standard metal bracket (Mini Uni-Twin). **Background:** Ceramic brackets are an esthetic alternative to metal brackets. The mean shear bond strength of ceramic brackets is significantly greater than for metal brackets. Excessive bond strength can result in pain upon debonding, damage to the bracket or permanent damage to the enamel including flaking, cracks or tooth fracture. Numerous studies have evaluated techniques to reduce the risk of enamel damage when debonding ceramic brackets, including the use of debonding pliers. Debonding pliers produce a concentrated stress within the adhesive, resulting in cohesive failures within the resin or adhesive failures outside the resin. **Methods:** A total of 75 caries-free extracted human premolar teeth were randomly divided into 3 groups: ClearVu ceramic bracket

(TP Orthodontics, LaPorte, IN), Radiance Plus ceramic bracket (American Orthodontics, Sheboygan, WI) and Mini Uni-Twin metal bracket (3M Unitek, Monrovia, CA). The Instron Universal Testing Machine Model 8841 with a customized jig with a bracket removing plier was used to debond the brackets. The teeth were microscopically evaluated to determine the location of bond failure. Selected teeth were evaluated with the scanning electron microscope to evaluate for enamel cracks and tear-outs. **Results:** A one-way ANOVA was created and no significant differences in shear bond strength were discovered between the three groups. Using a chi-square test of independence it was determined that the brackets all possessed a different ARI score. After examining the standardized residuals, we found that Radiance Plus Ceramic bracket and ClearVu Ceramic bracket were both likely to have favorable bond failure patterns, compared to the Mini Uni-Twin Metal bracket. Radiance Plus was most likely to debond at the bracket-adhesive surface, with a majority or all of the adhesive on the tooth after debond. Teeth with unfavorable bond failure patterns (ARI score of 0 or 1) were evaluated with the scanning electron microscope. 11% of the total teeth in the study had enamel damage, including cracks and tear-outs. 62.5% of these teeth were from the ClearVu ceramic bracket group. **Conclusions:** Our results show that both Radiance Plus ceramic bracket and ClearVu ceramic brackets are comparable to the gold standard metal bracket used in this study, the Mini Uni-Twin, in terms of shear bond strength. Radiance Plus ceramic bracket had the most favorable bond failure pattern, but shattered more during debonding. ClearVu ceramic bracket had the most enamel damage when

evaluated with the scanning electron microscope. American Orthodontics' Radiance Plus Ceramic bracket is the recommended bracket of those studied.

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Chapter 1: Introduction

1.1 Orthodontics

Orthodontic treatment has long been considered an "enhancement technology", a medical or dental intervention aimed at producing results that are "better than well" or "beyond normal"[1]. Older adults are the fastest-growing group seeking orthodontic treatment in order to improve their smiles[1]. In addition to being more concerned about their teeth and smiles, they are equally concerned about the esthetics of the appliances that will be used during orthodontic treatment. Many adults and teenagers seek orthodontic care after seeing advertisements for "invisible" orthodontic appliances such as Invisalign™ or lingual braces. A 2009 survey concluded that patients find lingual braces and clear aligner therapy more attractive than any fixed appliance; ceramic brackets were rated more esthetic than metal or self-ligating brackets[2]. When a patient does not qualify for clear aligner therapy due to the complexity of the orthodontic movements needed, they often end up with ceramic brackets. The ideal orthodontic appliance should be esthetically pleasing to the patient, while providing the technical performance needed by the clinician.

1.2 Metal and Plastic Brackets

Until the 1950s, fixed orthodontic appliances consisted of bulky metal bands cemented to each individual tooth. Buonocore's work on phosphoric acid etching allowed for a significant increase in bond strength and allowed bonding of smaller metal brackets to enamel[3].

In the 1970s, plastic brackets were introduced as an esthetic alternative to metal brackets. These polycarbonate resin brackets stained easily and were a disappointment to patients[4]. High-hopes from clinicians were also crushed due to poor dimensional stability and friction between the slot and the archwires. Thermoplastic materials such as polycarbonate must resist permanent deformation or creep, which occurs when a constant load is sustained over a long period of time. Dobrin *et al* found a constant physiologic stress of 2000 gm.-mm distorted these brackets, thus preventing these brackets from properly transmitting torque and enduring longer treatment times[5]. A study by Keldner *et al* found that reinforcement of a polycarbonate bracket with a metal slot strengthened the matrix and provided a clinician with the ability to torque teeth as with metal brackets, but these brackets did not satisfy the esthetic requirements of many patients[6].

1.3 Ceramic Brackets

Ceramic brackets debuted in 1986 and overcame many of the esthetic limitations of metallic and plastic brackets that were concerns for patients. For the clinician, the use of ceramic brackets came with many problems.

1.3.1 Ceramic bracket composition

Ceramic brackets are composed of aluminum oxide. There are two types of ceramic brackets, monocrystalline and polycrystalline, that are distinct due to their manufacturing process[7]. Monocrystalline brackets are milled from a single crystal of sapphire after heating and cooling of the molten mass[8]. Production of polycrystalline brackets is relatively simpler, thus these brackets are more readily available[8]. Manufacturing of polycrystalline brackets is done by a sintering process using special binders to thermally fuse the particles prior to machining[4]. Machining or milling induces structural imperfections such as propagation lines which can compromise the integrity of the bracket. Bracket produced by injection-molding have less structural irregularities and create less friction than other ceramic brackets[9].

1.3.2 Esthetics

For a layperson, the major difference between monocrystalline and polycrystalline brackets is optical clarity. Monocrystalline brackets are more transparent than translucent polycrystalline brackets, but both are able to resist staining and discoloration[8].

1.3.3 Friction

Similar to plastic brackets, ceramic brackets displayed higher frictional resistance compared to stainless steel brackets due to increased surface roughness of ceramic brackets[10,11]. Friction can decrease the efficiency of tooth movement by limiting movement of a tooth along an archwire. Similar to the evolution of plastic brackets, metal-lined ceramic brackets improved resistance to sliding compared to earlier generations of ceramic brackets[12].

1.3.4 Fracture toughness

The low fracture toughness of aluminum oxide causes breakage of ceramic brackets easily[13]. Fracture of the tie wings during treatment can increase chairtime due to difficulty in securing the archwire into the slot of the bracket. Johnson *et al* found the ability to resist fracture depends on the bracket configuration, type of material, bulk of material and the surface texture[14]. Some clinicians prefer to reposition brackets rather than make compensating bends in the archwire to detail tooth positions towards the end of treatment. Ceramic brackets are difficult to “recycle” because they are more likely to fracture at debonding, unlike metal brackets that temporarily distort but can be rebonded.

1.3.5 Hardness

Ceramic is the third hardest material known to man[8]. Ceramic brackets are nine times harder than stainless steel brackets and can damage teeth opposing ceramic brackets[8]. Viazis *et al* found that ceramic brackets caused significantly greater enamel abrasion compared to stainless steel brackets in an artificial oral environment[15]. Studies such as this encouraged clinicians to avoid contact of opposing teeth with ceramic brackets by using ceramic brackets selectively, such as only on maxillary teeth.

1.3.6 Shear Bond Strength

Obtaining the ideal bond strength is a challenge for clinicians. A minimum of 5.9 to 7.8 MPa (60 to 80 kg/cm^2) is necessary for adequate clinical bonding[16]. An inadequate bond will result in debonded brackets, more emergency appointments, increased treatment time and dissatisfied patients. An excessive bond could result in pain upon debonding, damage to the bracket and worst of all, permanent enamel damage including enamel flaking, enamel cracks and tooth fracture[17]. Joseph *et al* compared mean shear bond strength between metal brackets and ceramic brackets and found the shear bond strength of ceramic brackets (24-28 MPa) are significantly greater than that of stainless steel brackets (17 MPa)[18].

1.3.7 Adhesive Remnant Index

In 1984, Artun and Bergland developed the Adhesive Remnant Index (ARI) to quantitatively express where bond failure occurs during bracket removal[19,20]. A score of 0 indicates bond failure at the adhesive/enamel surface since no adhesive remains on the previously bonded tooth. If less than 50% or more than 50% of the adhesive remains on the tooth, this indicates a score of 1 or 2, respectively. A score of 3 is given when 100% of the adhesive remains on the tooth, indicating bond failure at the bracket-adhesive interface. The increased risk of enamel damage is related to the site of bond failure for ceramic brackets, which occurs primarily at the enamel/adhesive interface; the failure site for metal brackets is generally at the bracket/adhesive interface[21].

1.4 Debonding

Numerous studies have evaluated techniques to reduce the risk of enamel damage when debonding ceramic brackets. The three main categories of debonding techniques that have been published to reduce enamel damage are ultrasonic, electrothermal and conventional/mechanical.

1.4.1 Ultrasonic debonding

Specially designed ultrasonic tips can be applied at the bracket-adhesive interface, but this method is time-consuming, involves expensive instruments and requires water spray to prevent heating of the pulp[22]. Bishara *et al* found a decreased incidence of enamel damage and bracket failure with this method[22]. An added benefit of this technique is efficiency since the same instrument can be used to remove residual adhesive after debonding[22].

1.4.2 Electrothermal debonding

The electrothermal technique involves heating the bracket to deform the adhesive and allow bond failure[22,23]. This method was found to be quick, effective and safe, eliminating bracket and enamel fracture[22]. There is some speculation in the literature that heating may result in pulp damage leading to pulpal necrosis, but the heating temperature was found to be too low and the duration too short for damage[24]. Disadvantages of this technique are the risks of dropping a heated bracket in the patient's mouth and the large size of the handpiece, which may be difficult to manipulate intra-orally, especially in the posterior regions[22].

1.4.3 Other debonding techniques

CO_2, YAG and Diode lasers have been used for debonding ceramic brackets, but the high cost of the instrument is a major limitation for their use[25,26]. Peppermint oil derivatives have been tested as method to "soften to resin matrix", but showed no significant effect on the surface microhardness of the adhesives[27].

1.4.4 Conventional/mechanical debonding

Debonding pliers work by producing a concentrated stress within the adhesive, which results in cohesive failures within the resin or adhesive failures outside the resin[22]. Many manufacturers have developed special instruments or pliers for debonding their own ceramic brackets. The method that will be used in this study for debonding the brackets is different than the method used in most other studies involving debonding brackets using the Instron machine. Most studies use the Instron Universal Testing machine as a method to evaluate and compare shear bond strengths of various brackets using a unilateral force to debond brackets[28-32]. Clinically, a bilateral force is applied when debonding brackets. Similarly, many studies use a debonding instrument recommended by the manufacturer to debond brackets[32-37]. A customized jig and debonding plier will be mounted on the Instron testing machine to apply a bilateral compressive force based on previous studies by Bishara *et al* and Habibi *et al*[38,39]. This unique method will more closely emulate a clinical situation.

Habibi *et al*[39] compared 2 ceramic brackets and 1 metal bracket. They found the mean bond strength for the metal brackets was significant higher than that of the ceramic brackets. There was no significant difference between the mean bond strength for the 2 ceramic brackets. They also found no significant difference in the number or length of enamel cracks among the 3 groups.

Bishara *et al*[38] compared 3 ceramic brackets and found all bond strengths to be within a clinically acceptable range with no significant difference between the groups. ARI scores suggested a cohesive type of bond failure with 82% of teeth experiencing no increase in enamel cracks after debonding.

1.5 Importance of Study

Aggressive marketing in the field of orthodontics is evident at meetings, conferences and in the literature. Orthodontists everywhere are looking for the “latest and greatest” in products including appliances, brackets, wires and the like. Although product testing is conducted by the manufacturers of these brackets, practitioners should be cautious of the results of these studies as they may be biased. To date, there have been no studies reported in the orthodontic literature utilizing the ceramic brackets we intend to use. Corporations are marketing these brackets as their newest brackets and the practitioners are purchasing them without unbiased research to support their use. This project is unique since no other published study has tested this latest generation of ceramic brackets. This study will examine the effects on enamel when debonding these brackets, a grave concern with ceramic brackets. The bond strength and debonding characteristics of these ceramic brackets has not yet been reported in the literature. Through this study, we will be able to make recommendations on the use of these new brackets. Also, this study will include a standard metal bracket to serve as a control group.

1.6 Purpose, Specific Aims and Hypotheses

1.6.1 Purpose

This study will use the scanning electron microscope to evaluate the effects on enamel when debonding these ceramic brackets. Through this study, we will be able to make recommendations on the use of these new brackets.

1.6.2 Specific Aims

1. To compare the shear bond strength of the two new ceramic brackets and one metal bracket after debonding using bilateral compressive force

delivered by a debonding plier mounted on the Instron Universal Testing machine;

2. To determine the location of bond failure using the Adhesive Remnant Index (ARI) after shear bond testing;
3. To evaluate the enamel surface using an index that evaluates enamel cracks and tear-outs after debonding using a scanning electron microscope.

1.6.3 Hypotheses

H_o: There is no difference in the shear bond strengths of the brackets after debonding using bilateral compressive force delivered by a debonding plier mounted on the Instron Universal Testing machine.

H_o: There is no difference in the location of bond failure using the Adhesive Remnant Index (ARI) after shear bond testing.

H_o: There is no difference in the amount of enamel cracks and/or tear-outs after debonding the tested brackets.

Chapter 2: Materials and Methods

2.1 Study

Based on a power analysis, seventy-five extracted human maxillary and mandibular premolars were included in this *in-vitro* study.

2.1.1 Institutional Review Board Approval

IRB approval to conduct research using extracted human teeth was granted at Nova Southeastern University (No. Exempt 2014-35).

2.1.2 Ethical Issues

No potential ethical issues could be identified as part of this research study. All data collection complied with IRB and HIPAA regulations and all data was de-identified to ensure confidentiality.

2.1.3 Grant

This study was awarded a grant by the Health Professions Division at Nova Southeastern University (#335581).

2.2 Sample Size Estimate

In this interventional in-vitro study, 75 caries-free human premolar teeth were used. This sample size was based on the work of Habibi *et al*[39], Liu *et al*[29] and Theodorakopoulou *et al*[32]. Our power estimate also indicates an adequate number of teeth (alpha = 0.05, power=80%, standardized effect size of 0.50).

2.3 Sample Preparation

75 Maxillary and mandibular first and second human premolar teeth were used. These teeth were used since they are most commonly extracted for orthodontic treatment. The teeth were stored in an aqueous solution of thymol (0.1% wt/vol) to inhibit bacterial growth until they were used for the study[38]. Teeth with large restorations or caries were excluded as their enamel strength may be compromised. The teeth were examined using the Olympus SZX7 Zoom Stereomicroscope (Olympus, Center Valley, PA) at 8x magnification to check for any pre-existing cracks in the enamel prior to being included in this study. Teeth with pre-existing cracks were excluded from this study. The teeth were randomly assigned to one of three groups (n=25) (Figure 1).

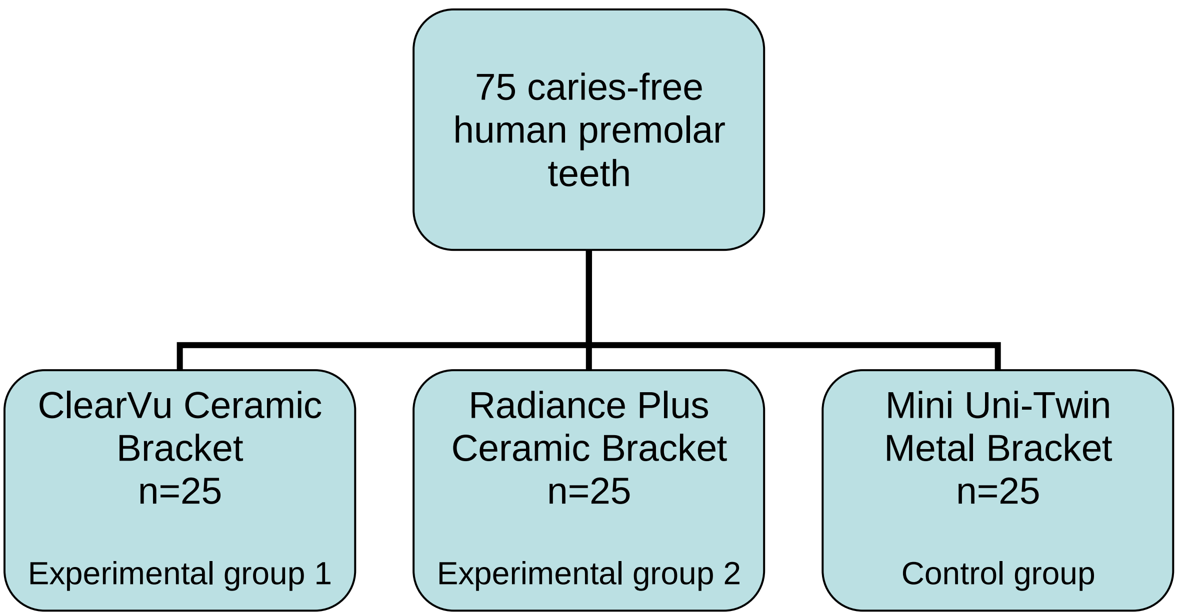

Figure 1. Flow chart of the division of the total sample into treatment groups by random assortment.

Two of the newest ceramic brackets (ClearVu and Radiance Plus) in the market and one standard metal bracket (Mini Uni-Twin) were used in this study (Figure 2, 3, 4). The metal bracket served as the gold-standard or control against which to compare the ceramic brackets. There was a chance that the collected extracted teeth will include more upper first premolars than any other type of premolar, since they are commonly extracted in patients with a Class II crowding malocclusion. For this reason, upper first premolar brackets were used for all three experimental groups. The brackets had a .022 x .028-in slot and Roth prescription based on a 2008 study reporting that these types of brackets are most commonly used by practitioners[40]. Average surface area for each bracket type was obtained from the manufacturers.

Figure 2: ClearVu ceramic bracket (TP Orthodontics, LaPorte, IN) – experimental group 1

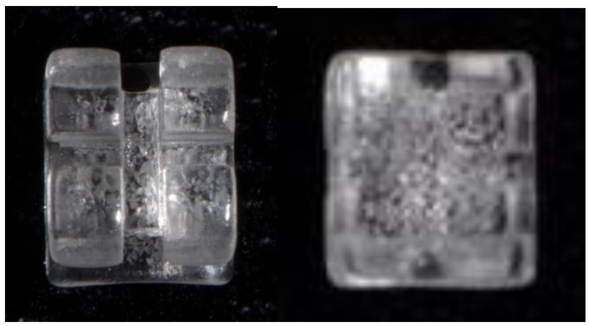

Figure 3: Radiance Plus ceramic bracket (American Orthodontics, Sheboygan, WI) – experimental group 2

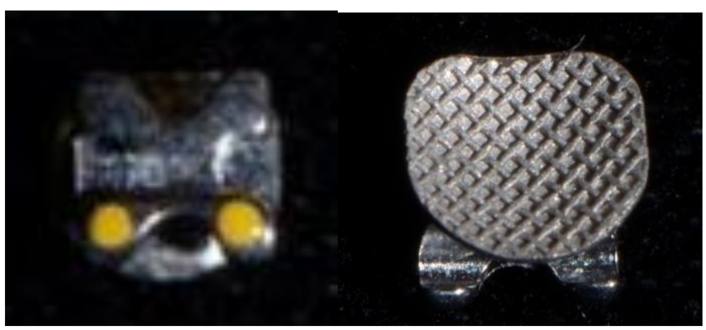

Figure 4: Mini Uni-Twin metal bracket (3M Unitek, Monrovia, CA) – control group

Each tooth was hand-scaled prior to receiving a 10-second prophylaxis with a rubber cup and pumice[39]. The teeth were rinsed thoroughly with water and dried with air. The buccal surface of each tooth was conditioned with 37% phosphoric acid (Transbond Etching Gel, 3M Unitek, Monrovia, CA) for 30 seconds[32,36,38,41]. The etch was rinsed off and the enamel surface was washed for 20 seconds with air and water and dried until the etched enamel had a white, frosty appearance[30,38]. 5 teeth were prepared at a time to ensure that each sample was prepared appropriately.

Transbond XT Primer (3M Unitek, Monrovia, CA) was rubbed on the tooth surface for 5 seconds with an applicator tip followed by a gentle air burst[32,41]. Transbond PLUS Color Change Adhesive (3M Unitek, Monrovia, CA) adhesive resin was applied to the bracket base. Each bracket was pressed firmly against the center of the facial surface of the crown using a stainless steel Bracket Height Gauge (Orthopli, Philadelphia, PA) and all excess resin was removed prior to curing. Many manufacturers' debonding instructions specify the removal of excess adhesive prior to debonding to minimize enamel damage. Color change adhesive was used to minimize the amount of excess adhesive. VALO Ortho light-emitting diode curing light (Opal Orthodontics, South Jordan, UT) was used according to manufacturer's instructions to cure the adhesive. The Demetron L.E.D. Radiometer (Kerr, Middleton, WI) was used to ensure the curing light was performing at the required energy level described by the manufacturer's (1200 mW/cm^2 for standard power mode). The curing light was checked with the Demetron L.E.D. Radiometer after bonding groups of 15 teeth.

The bonding sequence is illustrated in Figure 5. After an initial polymerization of 15 minutes at room temperature, specimens were stored in distilled water for 24 hours at 37°C to allow hardening of the adhesives[31,37,42,43].

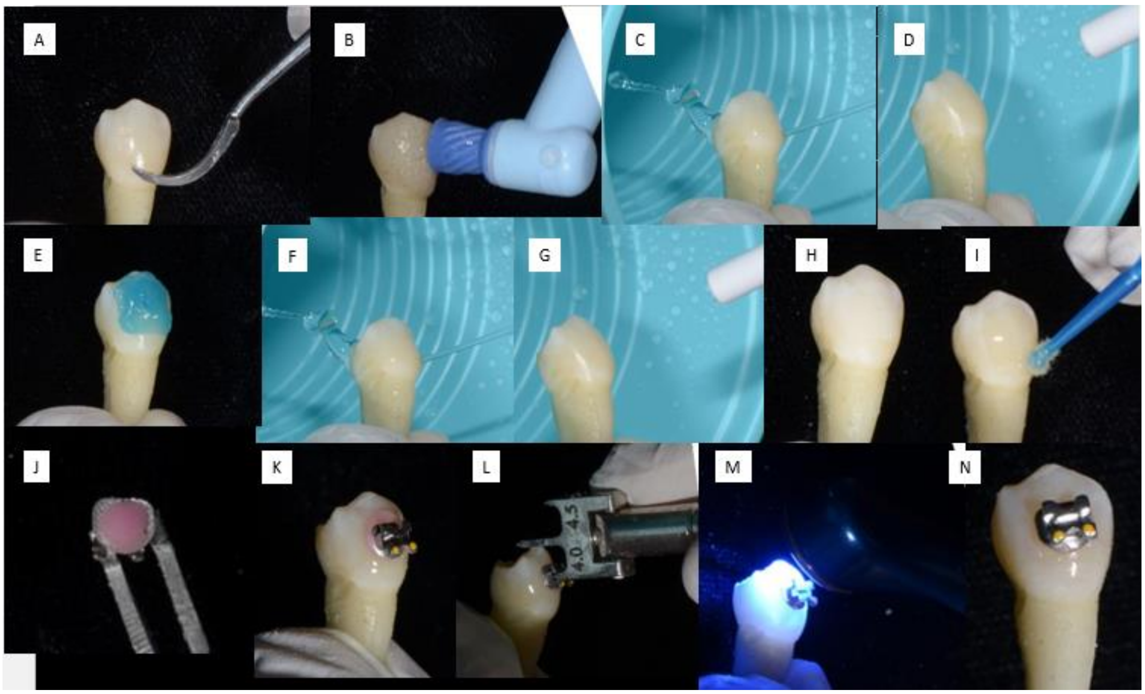

Figure 5: Sample preparation

2.4 Debonding

The Instron Universal Testing Machine Model 8841 (Instron, Norwood, MA) was used to measure debonding strength. A customized jig was fabricated to hold the Straight Bracket Removing Plier (Hu-Friedy, Chicago, IL) (Figure 6).

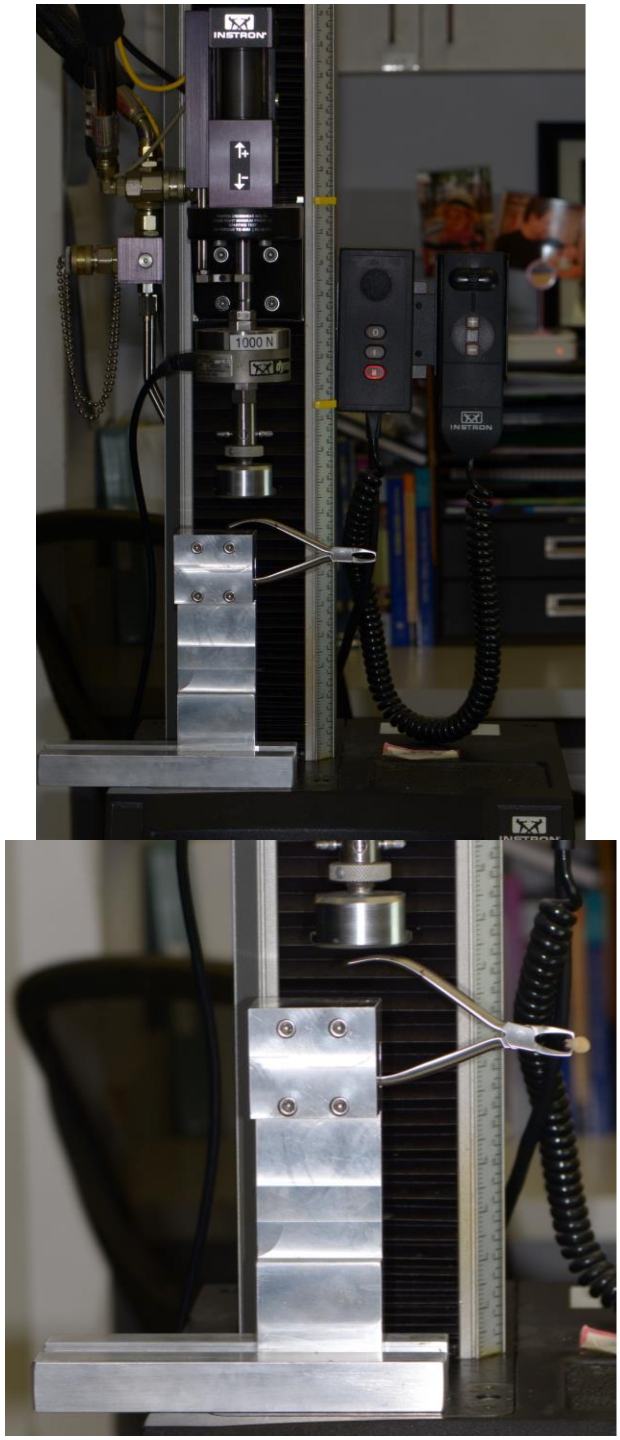

Figure 6. Customized jig and Straight Bracket Removing Plier mounted on the Instron Universal Testing Machine Model 8841.

Sample teeth and bonded brackets were placed between the blades of the pliers in a mesiodistal direction at the bracket-adhesive interface (Figure 7).

Figure 7. Samples placed in the Straight Bracket Removing Plier in a mesiodistal direction.

Since the teeth were not mounted when placed in the Instron Universal testing machine, a padded covering surrounded the tooth and bracket as to not further damage the tooth after bond failure occurred. The brackets were shear tested to failure using a crosshead speed of 5 mm/min and a load cell of 1 kiloNewton[32,44].

2.4.1 Actual force versus measured force

In accordance with Bishara et al[38], the debonding force recorded on the Instron machine is not equal to the actual debonding force applied at the bracket-adhesive interface due to the force being applied at a predetermined distance on the plier beaks. These forces are directly proportional and were calculated using the following formula:

$$\boxed{\text{Measured force (in Newtons)} * (a/b) = \text{Actual force (in Newtons)}}$$

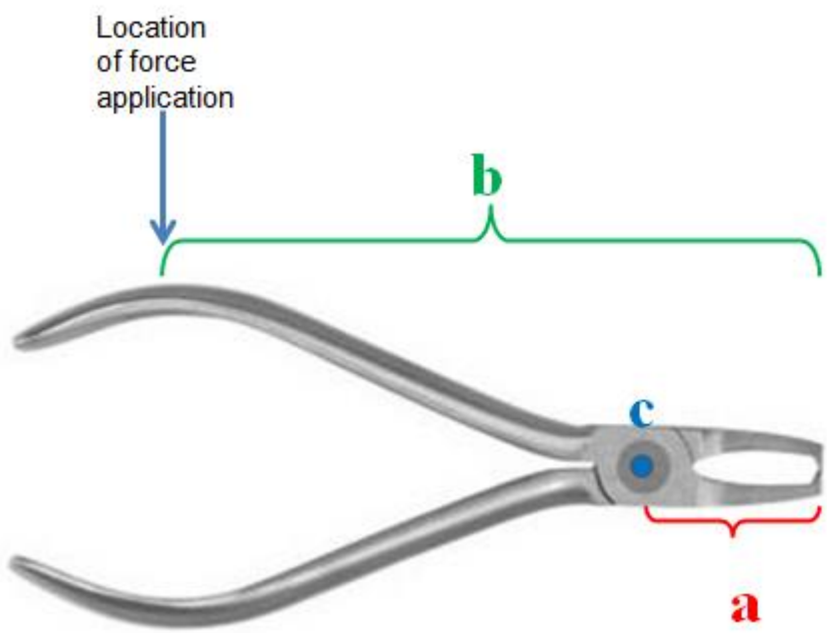

Figure 8. Diagram of a/b measurement for actual force vs. measured force

a = distance from where the measured force is applied to the fulcrum of the pliers

b = distance from where the actual force is applied to the fulcrum of the plier

c = fulcrum

A ratio of (a/b) was calculated for each experimental group (Figure 8).

The failure producing force was recorded to Newtons (N) and was converted to force per unit area (MPa) by dividing the actual force values by the mean surface area of the type of brackets[32]. The mean surface area was obtained from the manufacturers.

2.4.2 Variables evaluated

The following three variables were evaluated:

1. Shear bond strength (SBS): calculated based on the following formula[32]

$$\boxed{\text{Bond strength (MPa)} = \text{Actual Force (N)} / \text{Area of the bracket base (mm}^2\text{)}}$$

2. Adhesive remnant index (ARI) – The debonded enamel surface of each tooth was evaluated with the Olympus SZX7 Zoom Stereomicroscope (Olympus, Center Valley, PA) at 8x magnification. Some sample images were captured with Olympus MicroSuite Basic imaging software (Olympus, Melville, NY and Soft Imaging System Corp., Lakewood, CO). The ARI is of clinical importance to represent the mode of bond failure[29]. The greater the incidence of failure at the enamel-adhesive interface, the greater the stresses applied to the enamel surface[19]

The ARI[20,45] scores were graded according to the following criteria:

ARI Score	Criteria
0	No adhesive remaining on tooth surface
1	<50% adhesive remaining on the tooth surface
2	>50% adhesive remaining on the tooth surface
3	All adhesive remaining on the tooth surface

Table 1. ARI criteria

3. <u>Enamel damage</u>

Teeth with an ARI score of 0 or 1 based on the above criteria were further evaluated using the FEI Quanta 200 scanning electron microscope (FEI, Hillsboro, OR). Previous studies by Bishara *et al*[38] suggest that adhesive remnants do not need to be removed after debonding, as cracks can still be seeing through the adhesive with a proper light source. Prior to SEM imaging, the specimens were placed in the Cressington 108 Auto Sputter Coater (Watford, England, UK) and sputter coated in a layer of gold. Their enamel surfaces were scored based on criteria by Kitahara-Ceia *et al*[36].

Enamel Damage Score	Criteria
0	Enamel surface free from cracks or tear-outs
1	Enamel surface with cracks
2	Enamel surface with tear-outs
3	Enamel surface with cracks and tear-outs

Table 2. Enamel damage criteria

2.5 Data Storage

The de-identified data was entered and stored on excel spreadsheets on a password protected computer.

2.6 Statistical analysis

Statistical analysis of the data was then carried out. A one-way ANOVA was created to assess if there were differences between the average shear bond strengths of the three groups. A chi-square test of independence was used to determine if there was a significant association between groups and ARI scores. Descriptive statistics were used to evaluate the enamel damage data.

Chapter 3: Results

3.1 Shear Bond Strength

A one-way ANOVA was created and no significant differences between the groups were discovered [$F(2, 72) = 0.60$, $p = 0.551$]. Figure 9 illustrates the mean shear bond strengths of these groups.

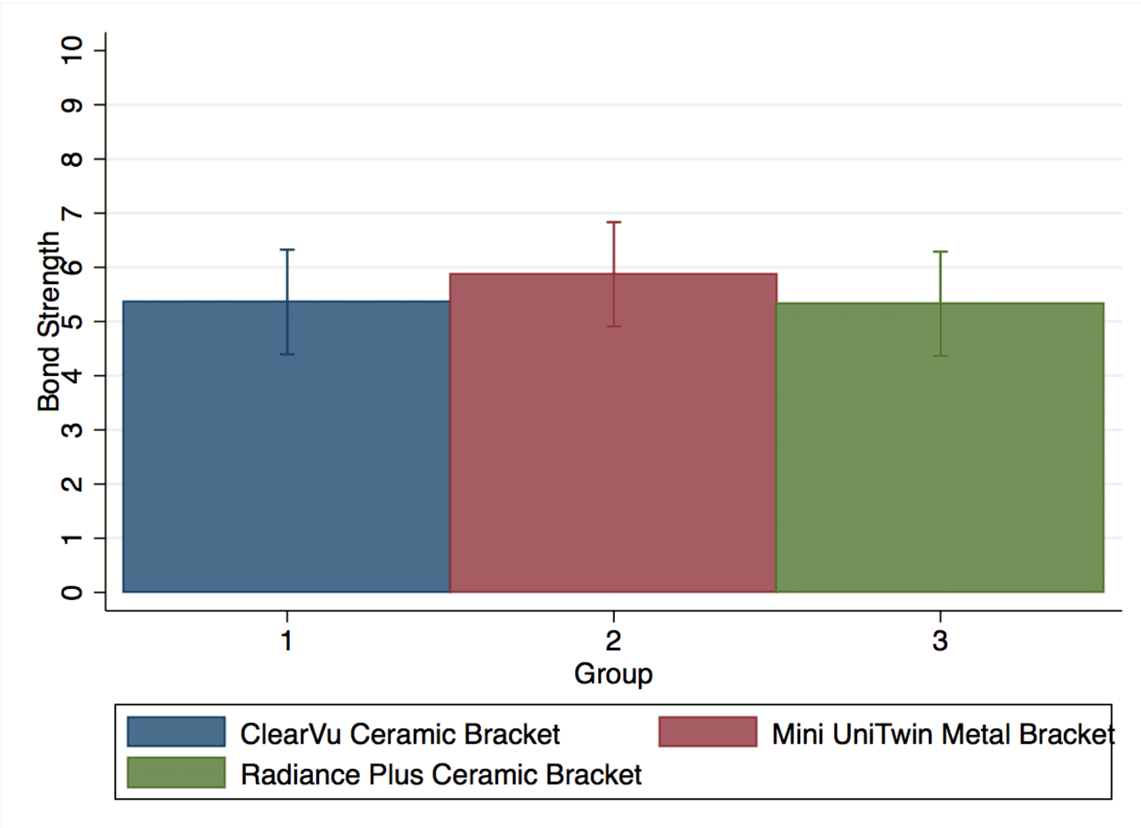

Figure 9. Shear bond strength with 95% confidence intervals

	N	M	SD	Min	Max
ClearVu Ceramic Bracket	25	5.36	1.67	2.05	8.63
Radiance Plus Ceramic Bracket	25	5.32	2.41	2.63	10.37
Mini Uni-Twin Metal Bracket	25	5.87	1.74	2.18	9.16

Table 3. Descriptive Statistics for shear bond strength

3.2 ARI Score

Using a chi-square test of independence it was determined that the brackets all possessed a different ARI score, $c^2(6, N = 75) = 34.64, p = 0.000$. After examining the standardized residuals, we found:

ClearVu Ceramic Bracket is more likely to score a 2

Radiance Plus Ceramic Bracket is more likely to score a 3

Mini Uni-Twin Metal Bracket is more likely to score a 1

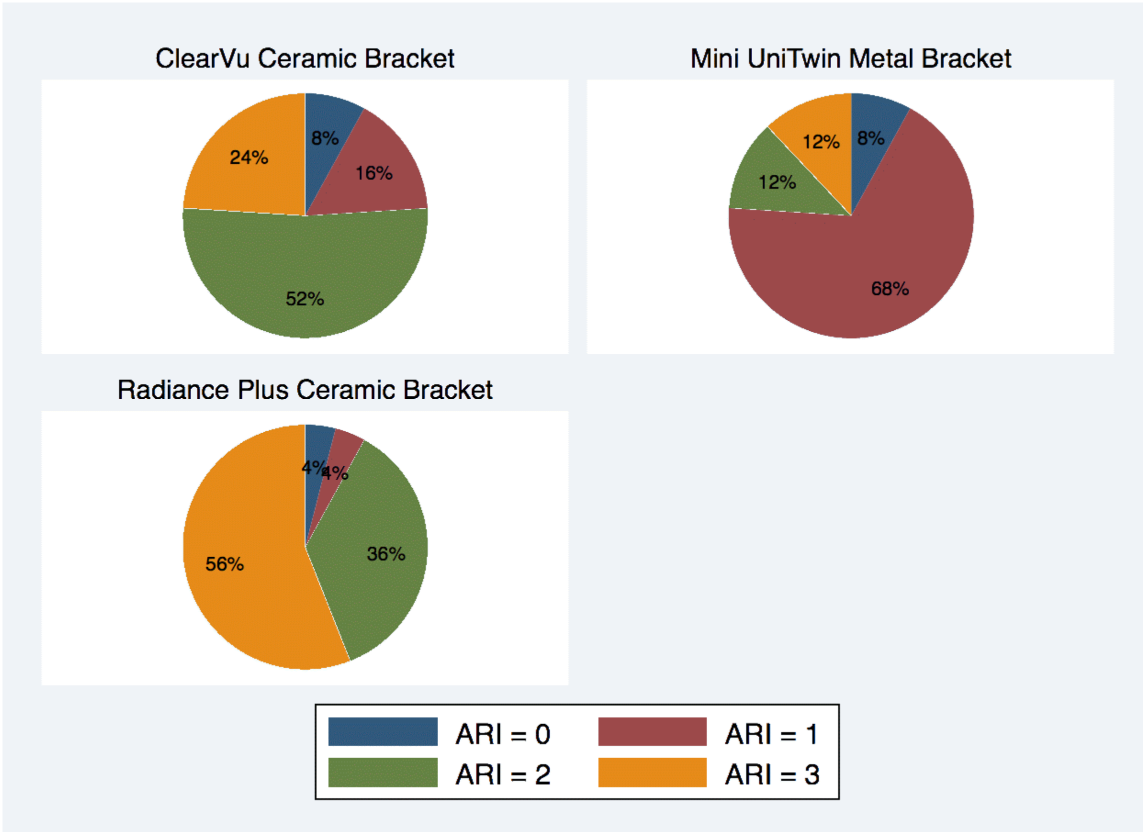

Figure 10. ARI score by treatment group

ARI Score	ClearVu Ceramic bracket	Radiance Plus Ceramic bracket	Mini Uni-Twin Metal Bracket
0	2 (8%)	1 (4%)	2 (8%)
1	4 (16%)	1 (4%)	**17 (68%)**
2	**13 (52%)**	9 (36%)	3 (12%)
3	6 (24%)	**14 (56%)**	3 (12%)

Table 4. ARI score by treatment group

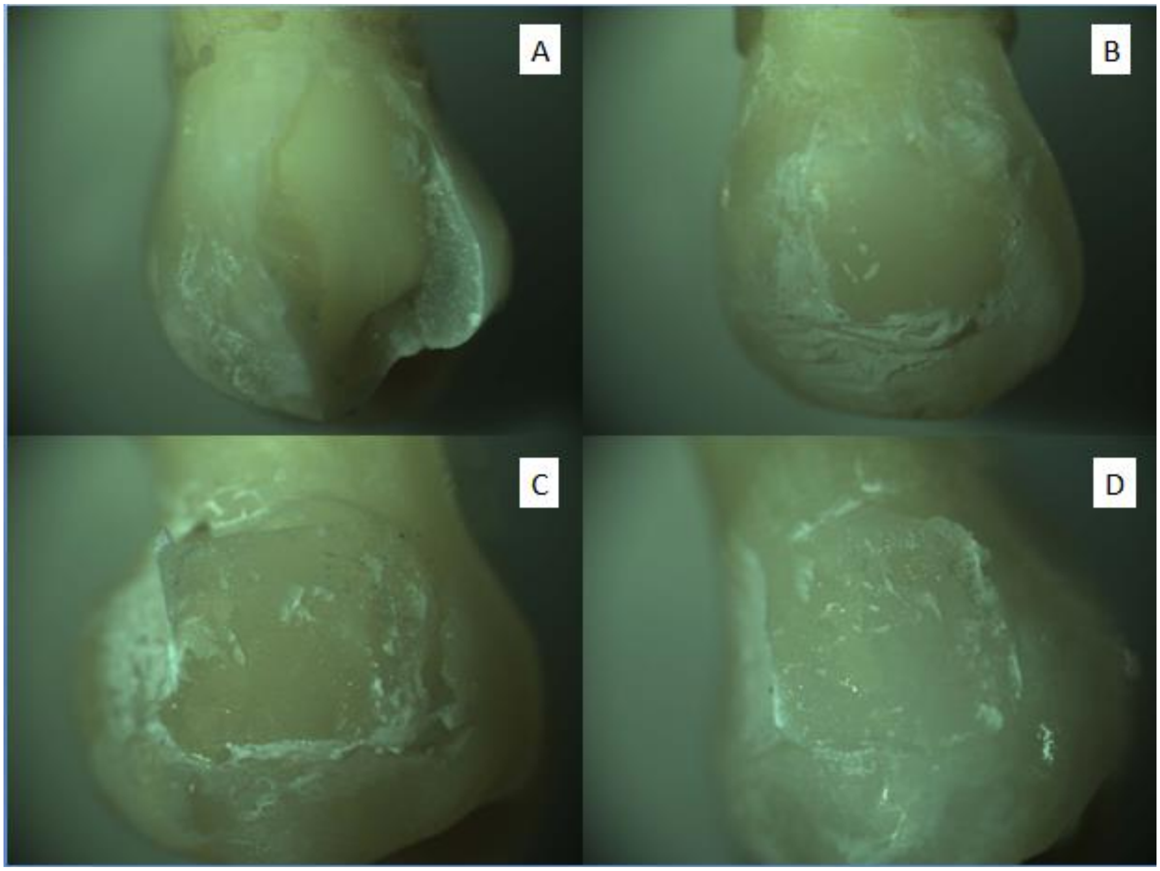

Figure 11. Typical representation of ARI scores of ClearVu Ceramic brackets (A=O, B=1, C=2, D=3) under 8x magnification with Olympus SZX7 Zoom Stereomicroscope (Olympus, Center Valley, PA).

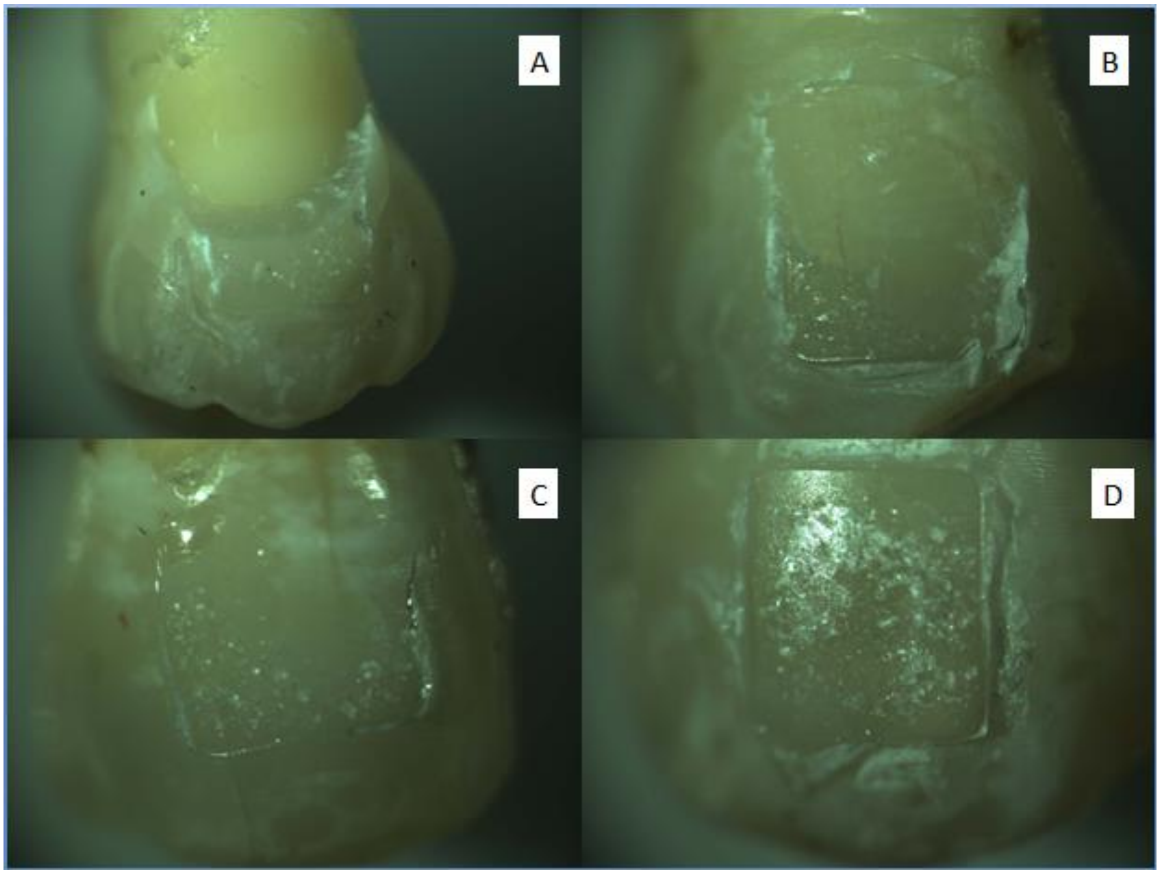

Figure 12. Typical representation of ARI scores of Radiance Plus Ceramic brackets (A=O, B=1, C=2, D=3) under 8x magnification with Olympus SZX7 Zoom Stereomicroscope (Olympus, Center Valley, PA).

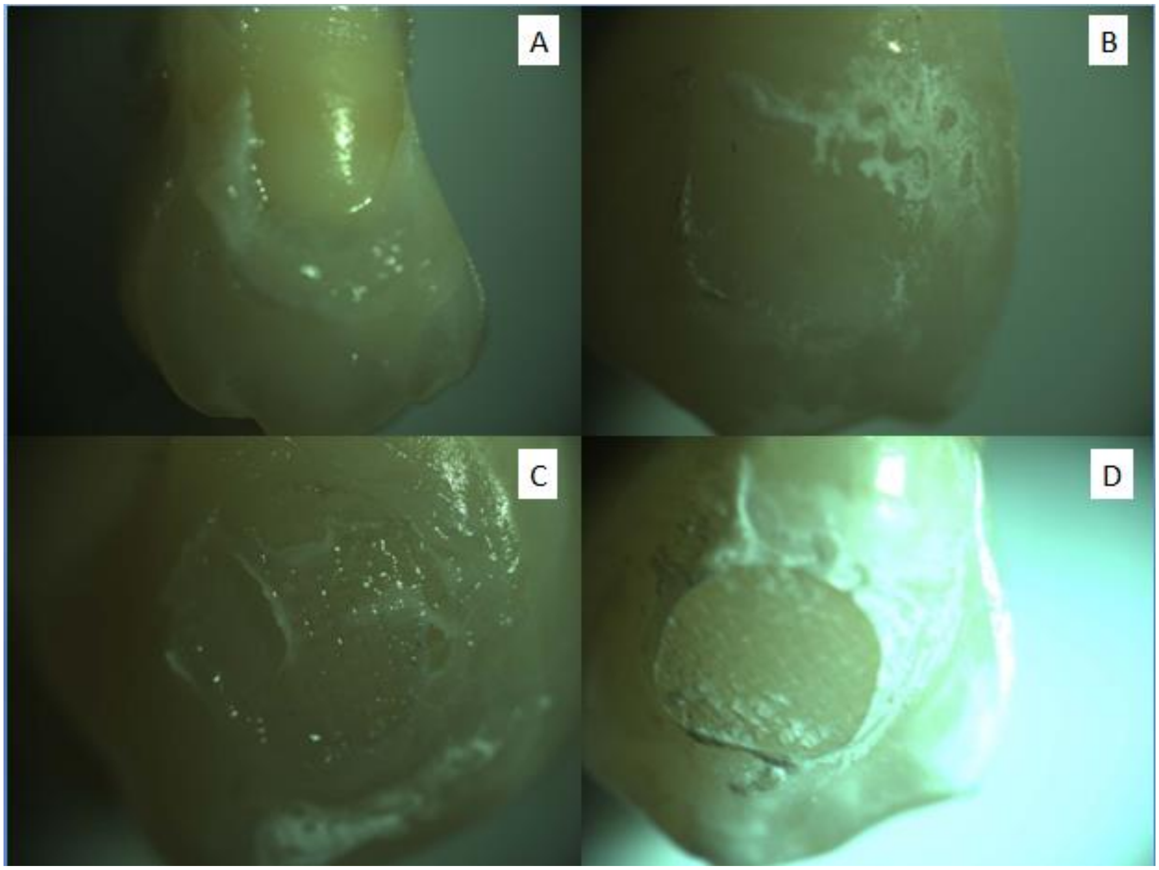

Figure 13. Typical representation of ARI scores of Mini Uni-Twin Metal brackets (A=O, B=1, C=2, D=3) under 8x magnification with Olympus SZX7 Zoom Stereomicroscope (Olympus, Center Valley, PA).

3.3 Enamel damage

Descriptive statistics were used to analyze the enamel damage scores. Table 5 shows the occurrence of each score per bracket.

Enamel damage score	ClearVu Ceramic Bracket	Radiance Plus Ceramic Bracket	Mini Uni-Twin Metal Bracket
0	1 (16%)	1 (50%)	
1	2 (33%)		
2	1 (16%)		2 (100%)
3	2 (33%)	1 (50%)	

Table 5. Enamel damage score by treatment group

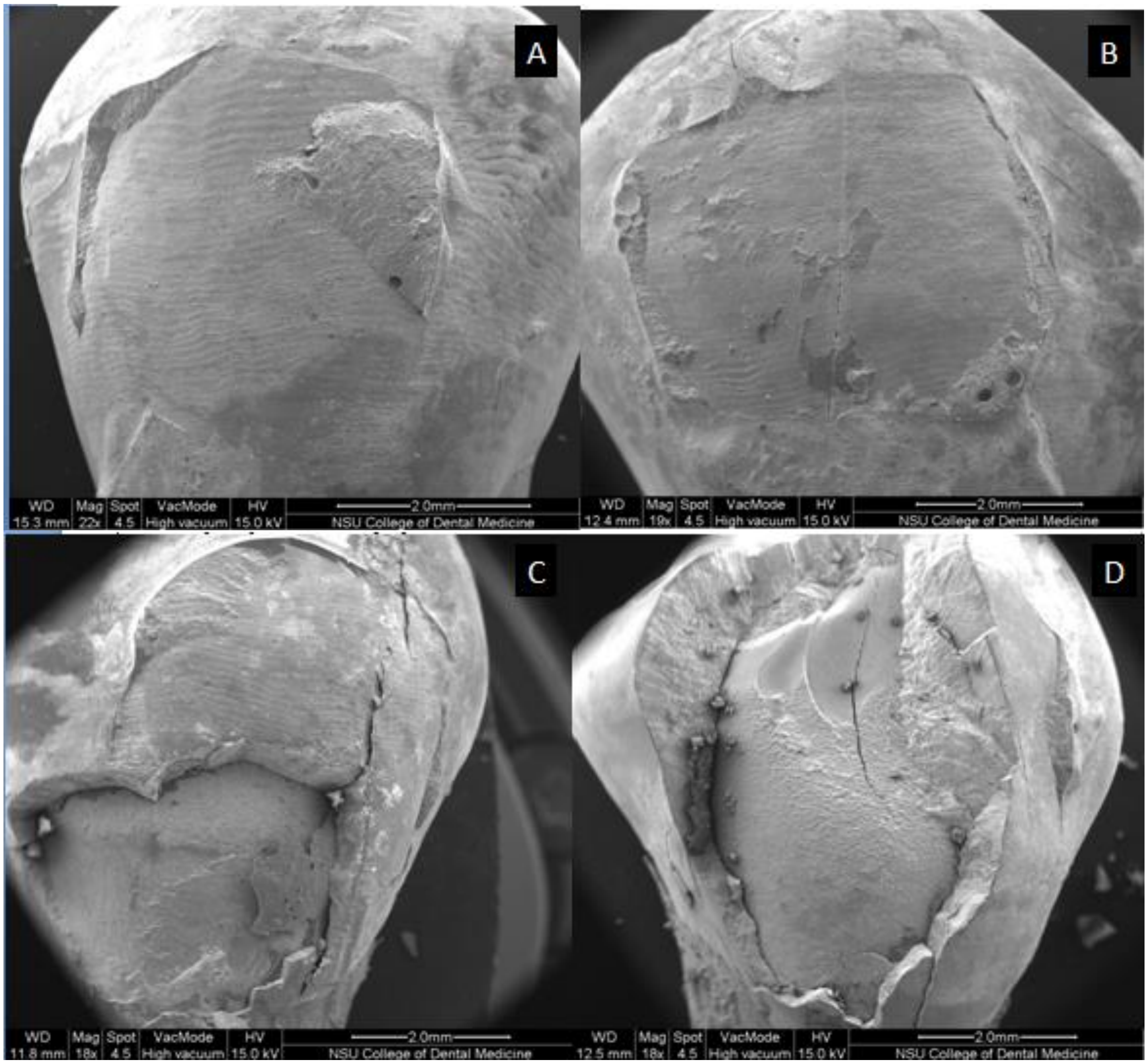

Figure 14. Typical representation of enamel damage of ClearVu Ceramic brackets (A=O, B=1, C=2, D=3) under 18x-22x magnification with FEI Quanta 200 scanning electron microscope (FEI, Hillsboro, OR).

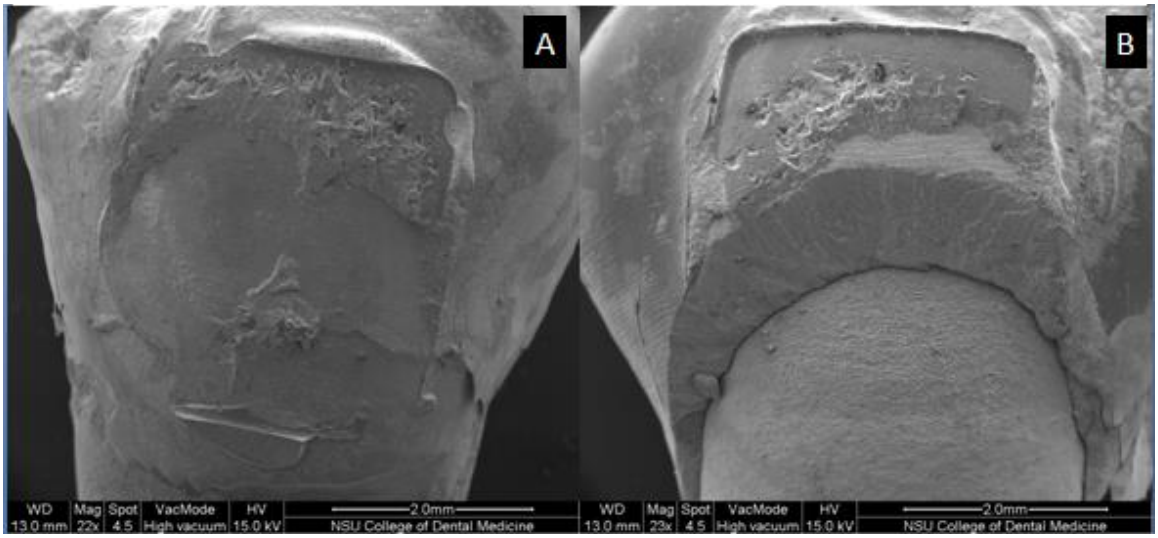

Figure 15. Typical representation of enamel damage of Radiance Plus Ceramic brackets (A=O, B=3) under 22x-23x magnification with FEI Quanta 200 scanning electron microscope (FEI, Hillsboro, OR).

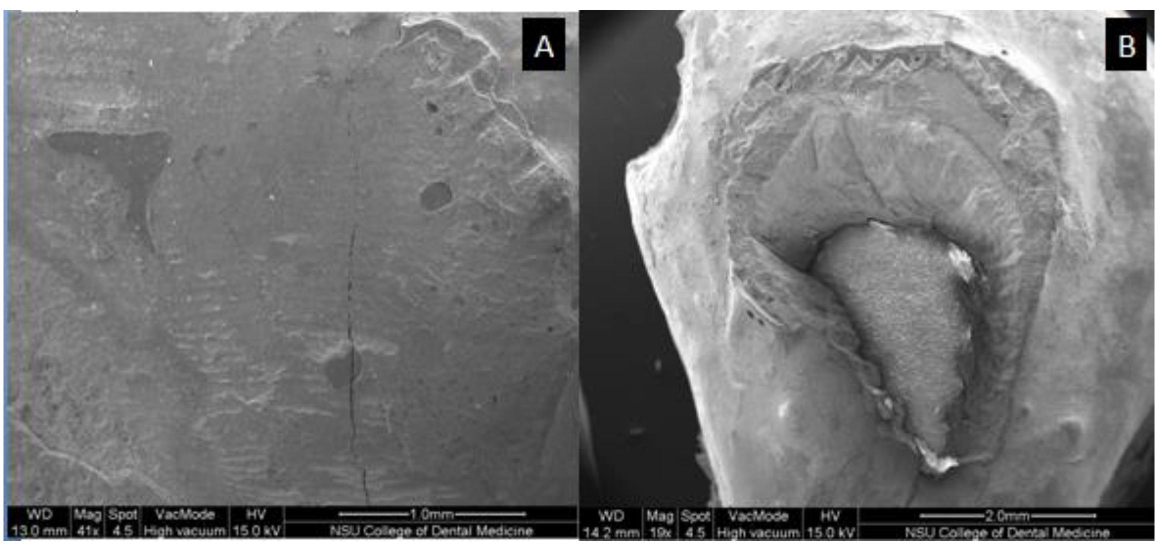

Figure 16. Typical representation of enamel damage of Mini Uni-Twin Metal brackets (A=O, B=2) under 19x-41x magnification with FEI Quanta 200 scanning electron microscope (FEI, Hillsboro, OR).

Chapter 4: Discussion

The purpose of this in vitro study was to compare the shear bond strength, pattern of bond failure and enamel surface after debonding two ceramic brackets (ClearVu and Radiance Plus) and one standard metal bracket (Mini Uni-Twin).

A customized jig was fabricated to hold Straight Bracket Removing Plier and brackets were debonded using on the Instron Universal Testing Machine Model 8841. ClearVu ceramic bracket and Radiance Plus ceramic brackets are two of the newest ceramic brackets on the market. Both brackets were tested against the gold-standard, a metal bracket (Mini Uni-Twin).

This study tested one monocrystalline ceramic bracket (Radiance Plus) and one polycrystalline ceramic bracket (ClearVu). Theodorakopoulou *et al* tested the debonding characteristics of a monocrystalline ceramic bracket versus a polycrystalline ceramic bracket. Their study also found no statistically significant difference in shear bond strength and ARI scores.[32] Monocrystalline brackets are produced by milling whereas polycrystalline brackets are produced from machining. Both processes can create structural imperfections in the brackets that are compromise the integrity of the bracket.

Obtaining the ideal bond strength is a challenge for clinicians. A minimum of 5.9 to 7.8 MPa is necessary for adequate clinical bonding[16]. Joseph *et al* compared mean shear bond strength between metal brackets and ceramic brackets and showed the shear bond strength of ceramic brackets (24-28 MPa) are significantly greater than that of stainless steel brackets (17 MPa)[18]. Habibi *et al* also used a bilateral compressive force using debonding pliers mounted on a universal testing machine. They compared two polycrystalline ceramic brackets and one metal bracket and found the mean bond strength for the metal brackets was significantly higher than that of the ceramic brackets[39]. Bishara *et al* studied three different ceramic brackets with a set up similar to the study of Habibi *et al*. Bishara *et al* found no significant differences between the three bracket types[38]. In our study, there was no statistically significant difference in shear bond strength between the metal bracket groups and the two ceramic bracket groups. The mean shear bond strength for the ClearVu ceramic bracket group was 5.36 MPa ± 1.67. Radiance Plus ceramic bracket group had a mean shear bond strength of 5.32 MPa ± 2.41. The metal bracket group (Mini Uni-Twin) had a mean shear bond strength of 5.87 MPa ± 1.74. All groups had mean shear bond strength that are clinically adequate.

While shear bond strength is important in determining if there is a risk of enamel damage, the location of bond failure is also important. The location of bond failure was evaluated using the Olympus SZX7 Zoom Stereomicroscope (Olympus, Center Valley, PA) under 8x magnification. Odegaard *et al* found that the increased risk of enamel damage is related to the site of bond failure for ceramic brackets, which occurs primarily at the enamel/adhesive interface; the failure site for metal brackets was mainly at the bracket/adhesive interface[21]. Based on the ARI scores in our study, a majority of ceramic brackets had bond failure at the bracket-adhesive interface. This disagrees with the findings of Odegaard *et al*. The majority of the Radiance Plus ceramic bracket had an ARI score of 3, indicating that all adhesive remained on the tooth surface when debonded. This coincides with the finding that more of the Radiance Plus brackets shattered upon debonding. The ARI score for the majority of the ClearVu ceramic bracket group was 2, indicating that more than 50% of the adhesive remained on the tooth. Only 3 samples of 50 in the ceramic bracket groups had ARI scores of 0, indicating bond failure at the adhesive-enamel interface. Shockingly, our study found the largest majority of the metal bracket group had an ARI score of 1, indicating less than 50% of the adhesive remaining on the tooth surface at debond. This is likely due to the bilateral compressive force that forced the brackets to collapse at the slot in order to debond. On the other hand, the ceramic brackets could shatter when force was applied.

Sample teeth with an ARI score of 0 (indicating no adhesive remaining on the tooth surface) or 1 (less than 50% adhesive remaining on the tooth surface) were further evaluated using the FEI Quanta 200 scanning electron microscope (FEI, Hillsboro, OR) using an enamel surface criteria developed by Kitahara-Ceia *et al*[36]. Although 68% of the samples in the Mini Uni-Twin metal bracket group had ARI scores of 1, only 2 randomly selected samples were evaluated under the SEM since the primary focus of this study was to evaluate the ceramic bracket samples. Of the two samples that were studied with ARI scores of 1, both were free from cracks or tear-outs and had an enamel surface score of 0. Both Mini Uni-Twin samples with ARI scores of 0 had tear-outs in the enamel surface when evaluated with the SEM. Six ClearVu ceramic bracket samples were evaluated under the SEM. 83% of these samples had some enamel damage, including cracks, tear-outs or both. Two Radiance Plus samples were evaluated with the

SEM, revealing severe enamel damage on 1 sample and no damage on the second sample. All three studied groups had very few teeth with severe enamel damage. Clinically, enamel damage of this magnitude could require endodontic treatment and a full-coverage restoration. A study by Habibi *et al* found no statistically significant difference in the number and length of cracks between the metal and two ceramic groups[39].

ARI scores of 1, 2 and 3 are safest since it implies that bond failure occurred between the bracket and adhesive interface. Whether it is while the clinician is repositioning brackets or at the end of treatment, all adhesive remaining on the enamel surface must be removed. A study by Mahdavie *et al* found that most clinicians use a high speed handpiece with a 12-, 20- or 30-fluted carbide bur or a white stone[46]. After evaluating post-debonding SEM images, they found the 12-fluted bur produced visible gouges on the enamel surface, while the 20-fluted and 30-fluted burs resulted in finer scratches. The white-stone bur produced irregular surfaces with a complete loss of the original enamel topography and extensive grooves. Adhesive that remains on the enamel surface after debonding can ultimately lead to enamel damage when the clinician removes adhesive.

The debonding plier jig mounted on the Instron Universal Testing Machine produced a bilateral compressive force to debond the brackets. While this is an improvement from the standard unilateral force that many use in debonding studies, neither fully emulates debonding in a clinical setting. Clinically, an orthodontist would apply a bilateral compressive force as well as a torquing action to debond a bracket. This difference in debonding could have been responsible for the severe enamel damage on some of the samples since the bracket had to be compressed until bond failure occurred.

Manufacturer's of both brackets claim their bracket bases are novel and allow for easy debonding. Brochures distributed by American Orthodontics state, "A patented Quad Matte™ base gives Radiance Plus its' amazing bond strength. This technology delivers a strong bond in the center of the bracket, and a smooth perimeter to make the debonding process predictable and simple." TP Orthodontics states, "One design feature that sets ClearVu Cosmetic Brackets apart is the patented polymer base. The mesh design closely replicates a metal base, while the polymer material provides a protective barrier between the ceramic bracket and the enamel. Since the base flexes upon debonding, the bracket removes cleanly without the need to fracture the bracket or rely on special tools."

Low fracture toughness of aluminum oxide is a problem for clinicians. In our study, more of the Radiance Plus brackets shattered upon debonding than the ClearVu brackets, but many of the ClearVu brackets had broken hooks upon debonding. Clinically, proper eye protection should be used for the clinician and the patient to avoid any incidents. In general, ceramic brackets are more expensive than metal brackets, but this added cost is usually passed on to the patient. For a clinician who prefers to reposition brackets mid-treatment, their overhead expense would likely increase due to their inability to reuse these ceramic brackets if they shatter during debonding. Metal brackets are usually able to be reused when repositioning.

4.1 Limitations, Implications and Future Studies

The limitations in our study include the in vitro nature of the study and the non-blind manner in which the study was conducted. In vitro studies can only simulate intra-oral conditions but are unable to fully reproduce these conditions. Orthodontic brackets can be present in the mouth for years and are subject to complex chemical, physical and thermal challenges that cannot all be accurately reproduced in vitro. The study was completed in a non-blind methodology that may have introduced confounding variables that affected the results. Theodorakopoulou *et al* stated that extracted teeth stored in distilled water are much drier than vital teeth and are more susceptible to enamel damage[32]. Ideally, the sample teeth should be stored in saliva.

Orthodontists everywhere are looking for the “latest and greatest” in products including appliances, brackets, wires and the like. Although product testing is conducted by the manufacturers of these brackets, practitioners should be cautious of the results of these studies as they may be biased. To date, there have been no studies reported in the orthodontic literature utilizing these ceramic brackets. A 2008 study reported that 83% of orthodontists use ceramic brackets in their practice[40]. Corporations are marketing these brackets as their newest brackets and the practitioners are purchasing them without unbiased research to support their use.

This study examined the effects on enamel when debonding these brackets, a grave concern with ceramic brackets. The findings of our study indicate that the Radiance Plus ceramic bracket and the ClearVu ceramic bracket are acceptable alternatives to metal brackets in terms of their shear bond strength, ARI scores and ultimately, enamel damage. The majority of the samples in the ceramic bracket groups had ARI scores of 2 or 3, while the majority of the Mini Uni-Twin metal brackets had an ARI score of 1.

Future studies may include using the torsion attachment of the Universal Testing Machine to apply a bilateral compressive force and torsion to debond ceramic brackets to emulate clinical debonding.

Chapter 5: Conclusions

Our results show that both Radiance Plus ceramic bracket and ClearVu ceramic brackets are comparable to the gold standard metal bracket used in this study, the Mini Uni-Twin. All three groups had clinically acceptable shear bond strengths with no statistically significant difference between the groups. Radiance Plus ceramic bracket had the most favorable bond failure pattern, but shattered more during debonding. ClearVu ceramic bracket had the most enamel damage when evaluated with the scanning electron microscope. American Orthodontics' Radiance Plus Ceramic bracket is the recommended bracket of those studied.

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ClearVu Ceramic Bracket

Sample	Measured force (N)	a/b	Actual force (N)	Bracket base (mm2)	Bond strength (MPa)	ARI	SEM
1	128.64	0.717	92.23	15.27	6.04	0	3
2	180.14	0.717	129.16	15.27	8.46	2	
3	46.17	0.717	33.10	15.27	2.17	0	3
4	118.76	0.717	85.15	15.27	5.58	2	
5	124.18	0.717	89.04	15.27	5.83	2	
6	183.74	0.717	131.74	15.27	8.63	2	
7	121.12	0.717	86.84	15.27	5.69	2	
8	96.31	0.717	69.05	15.27	4.52	3	
9	141.06	0.717	101.14	15.27	6.62	2	
10	94.39	0.717	67.68	15.27	4.43	3	
11	126.67	0.717	90.82	15.27	5.95	2	
12	80.59	0.717	57.78	15.27	3.78	1	1
13	133.79	0.717	95.93	15.27	6.28	3	
14	146.27	0.717	104.88	15.27	6.87	2	
15	102.22	0.717	73.29	15.27	4.80	3	
16	63.05	0.717	45.21	15.27	2.96	1	0
17	115.92	0.717	83.11	15.27	5.44	2	
18	43.73	0.717	31.35	15.27	2.05	1	2
19	97.8	0.717	70.12	15.27	4.59	1	1
20	109.97	0.717	78.85	15.27	5.16	2	
21	109.67	0.717	78.63	15.27	5.15	2	
22	129.04	0.717	92.52	15.27	6.06	3	
23	168.13	0.717	120.55	15.27	7.89	3	
24	82.33	0.717	59.03	15.27	3.87	2	
25	110.46	0.717	79.20	15.27	5.19	2	

Radiance Plus Ceramic Bracket

Sample	Measured force (N)	a/b	Actual force (N)	Bracket base (mm2)	Bond strength (MPa)	ARI	SEM
1	70.03	0.719	50.35	13.32	3.78	3	
2	69.92	0.719	50.27	13.32	3.77	2	
3	96.3	0.719	69.24	13.32	5.20	2	
4	63.3	0.719	45.51	13.32	3.42	1	0
5	179.86	0.719	129.32	13.32	9.71	3	
6	168.26	0.719	120.98	13.32	9.08	3	
7	79.09	0.719	56.87	13.32	4.27	2	
8	54.96	0.719	39.52	13.32	2.97	3	
9	164.18	0.719	118.05	13.32	8.86	3	
10	160.9	0.719	115.69	13.32	8.69	2	
11	76.57	0.719	55.05	13.32	4.13	3	
12	142.91	0.719	102.75	13.32	7.71	2	
13	61.68	0.719	44.35	13.32	3.33	3	
14	90.64	0.719	65.17	13.32	4.89	3	
15	112.69	0.719	81.02	13.32	6.08	3	
16	60.96	0.719	43.83	13.32	3.29	3	
17	70.93	0.719	51.00	13.32	3.83	2	
18	80.12	0.719	57.61	13.32	4.32	2	
19	82.04	0.719	58.99	13.32	4.43	3	
20	71.73	0.719	51.57	13.32	3.87	3	
21	192.15	0.719	138.16	13.32	10.37	3	
22	61.22	0.719	44.02	13.32	3.30	0	3
23	67.27	0.719	48.37	13.32	3.63	3	
24	139.8	0.719	100.52	13.32	7.55	2	
25	48.69	0.719	35.01	13.32	2.63	2	

Mini Uni-Twin Metal Bracket

Sample	Measured force (N)	a/b	Actual force (N)	Bracket base (mm2)	Bond strength (MPa)	ARI	SEM
1	90.82	0.7087	64.36	9.61	6.70	3	
2	88.86	0.7087	62.98	9.61	6.55	1	
3	43.87	0.7087	31.09	9.61	3.24	1	
4	52.96	0.7087	37.53	9.61	3.91	2	
5	68.61	0.7087	48.62	9.61	5.06	1	
6	104.14	0.7087	73.80	9.61	7.68	3	
7	39.2	0.7087	27.78	9.61	2.89	1	
8	71.51	0.7087	50.68	9.61	5.27	1	
9	56.15	0.7087	39.79	9.61	4.14	1	0*
10	101.78	0.7087	72.13	9.61	7.51	1	
11	29.62	0.7087	20.99	9.61	2.18	1	
12	102.43	0.7087	72.59	9.61	7.55	1	
13	97.25	0.7087	68.92	9.61	7.17	1	
14	87.71	0.7087	62.16	9.61	6.47	1	
15	114.42	0.7087	81.09	9.61	8.44	1	
16	76.09	0.7087	53.92	9.61	5.61	1	
17	77.89	0.7087	55.20	9.61	5.74	1	0*
18	58.98	0.7087	41.80	9.61	4.35	3	
19	74.76	0.7087	52.98	9.61	5.51	1	
20	100.39	0.7087	71.15	9.61	7.40	1	
21	82.77	0.7087	58.66	9.61	6.10	0	2
22	75.13	0.7087	53.24	9.61	5.54	0	2
23	78.56	0.7087	55.68	9.61	5.79	2	
24	124.23	0.7087	88.04	9.61	9.16	2	
25	91.75	0.7087	65.02	9.61	6.77	1	