2019

Effect of Shear Bond Strength with Novel APC™ Flash-Free Brackets and Different Bonding Protocol: An In Vitro Study

Carl Bernstein

West Virginia University, cabernstein@mix.wvu.edu

Follow this and additional works at: <https://researchrepository.wvu.edu/etd>

Part of the [Dental Materials Commons](#), and the [Orthodontics and Orthodontology Commons](#)

Recommended Citation

Bernstein, Carl, "Effect of Shear Bond Strength with Novel APC™ Flash-Free Brackets and Different Bonding Protocol: An In Vitro Study" (2019). *Graduate Theses, Dissertations, and Problem Reports*. 3913. <https://researchrepository.wvu.edu/etd/3913>

This Thesis is protected by copyright and/or related rights. It has been brought to you by the The Research Repository @ WVU with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you must obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/ or on the work itself. This Thesis has been accepted for inclusion in WVU Graduate Theses, Dissertations, and Problem Reports collection by an authorized administrator of The Research Repository @ WVU. For more information, please contact researchrepository@mail.wvu.edu.

Effect of Shear Bond Strength with Novel APC™ Flash-Free Brackets and Different Bonding Protocol: An In Vitro Study

Carl Bernstein, D.D.S.

Thesis submitted
to the School of Dentistry
at West Virginia University
in partial fulfillment of the requirements for the degree of

**Master of Science in
Orthodontics**

Chris Martin, D.D.S., M.S.

Peter Ngan, D.M.D.

Elizabeth Kao, D.M.D.

Department of Orthodontics

Morgantown, West Virginia

2019

Keywords: shear bond strength, flash-free, ARI, self-etch, sealant, ceramic bracket, metal bracket, adhesive

Copyright 2019 Carl Bernstein D.D.S.

ABSTRACT

EFFECT OF SHEAR BOND STRENGTH WITH NOVEL APC™ FLASH-FREE BRACKETS AND DIFFERENT BONDING PROTOCOL: AN IN VITRO STUDY

Carl Bernstein, D.D.S.

Background and Objectives: In today's time, there is an increasingly crowded field of competition vying over a small subset of the population. Now, more than ever it is imperative to compete with efficiency and esthetics. Each step for orthodontic bonding procedures increases the chance for error to occur. However, orthodontic bracket, etchant, sealant, and adhesive material has the ability to improve bond strength and final outcome for the patient and provider. The aim of this study was to determine effective bonding protocols for Advanced Clarity APC™ Flash-Free Brackets and to determine if adhesive remains on enamel or orthodontic bracket after debond.

Experiment Design and Methods: A sample of 105 extracted human premolars were randomly divided to seven groups. Group 1 (control) stainless-steel APC™ II Adhesive Coated bracket bonded with phosphoric acid etch, Transbond™ MIP, Group 2 ceramic APC™ Flash-Free adhesive bracket with phosphoric acid etch and Transbond™ MIP, Group 3 ceramic APC™ Flash-Free adhesive bracket bonded with Transbond™ plus, Group 4 ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Transbond™ plus, Group 5 ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Group 6 ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Pro Seal L.E.D., and Group 7 ceramic APC™ Flash-Free adhesive bracket bonded with Transbond™ Plus, Pro Seal L.E.D.. Orthodontic brackets were bonded to the facial surface of the premolar and placed in a thermocycler for 24 hours with baths of 5°C and 55°C. After 24 hours of thermocycling, the bracket was debonded with an Instron machine calculating shear bond strength (SBS). The bracket and tooth interface was looked under 10x magnification to determine the adhesive remnant index (ARI) and the nature of debond failure.

Results: To compare the difference in SBS and ARI scores between groups, we utilized one-way ANOVA followed by Tukey honestly significant difference (HSD) test. All statistical tests were two-sided and p-value of less than 0.05 was considered statistically significant. There was a significant difference in mean SBS between different groups (p-value <0.001). Group 1 had a significantly greater SBS than all other groups except group 5. Group 7 had less SBS than all other groups. Comparing of ARI scores revealed a significant difference from Group 7.

Conclusion: All groups except group 7 have clinically acceptable SBS to withstand occlusal forces during orthodontic treatment. APC™ Flash-Free adhesive has an inconsistent adhesive remnant index, however, there is a tendency for adhesive to remain on enamel after bracket debond.

DEDICATION

To Mom, You are the reason I went to dental school. The life you provided me included your love for me and your success in the dental field. I wanted to be like you, my hero. I am lucky to have the most supportive and caring mom.

To Dad, You were always there to support me and lift my spirits when I was down. Your never-ending encouragement made me know I chose the right path in life. We also got to enjoy some concerts together, always a fun time.

To Roger, I could always count on you telling me how it was and being unnecessarily stern. It is what makes you who you are and I wouldn't want it any other way. Because of you, I found golf, which kept me busy when I was alone.

To Jordan, I am so glad you found me and didn't think I was too crazy for you. You see the best in me and always supporting of me. And crazy Daisy keeps me nimble on my toes.

To Jared, Always there to speak with when I had no one else to speak to. I couldn't have asked for a better brother, even if we do get in our fair share of arguments.

To Rosie, My BFS, best friend sister, was always there to listen to me complain when things weren't going well. You helped me stay sane when it didn't seem possible.

To Shira, You are the best sister, a more amazing mother and someone I look up to. You have always been a role model to me.

To Matt, Always there to play games and waste time when the stress was starting to build up. I am lucky to have a friend for all but one year of my life.

To Adam, When I needed a laugh I could always talk to you and hear the most ridiculous things. Thank you for always bringing laughter to my life.

ACKNOWLEDGMENTS

Dr. Peter Ngan, Thank you for being on my research committee.

Dr. Elizabeth Kao, My research would have been lost without you. You were able to set me up with everything I needed and taught me how to write a thesis.

Dr. Chris Martin, Without you this program would have fallen apart. You were hard on me but you saw my potential from the first day. I am forever indebted for the knowledge you bestowed on me.

Vince Kish, You are the man. I could have never completed this thesis without your assistance and guidance. I will always believe you are a genius and a magician with those hands. I cannot say thank you enough times.

Jun Xiang, You were able to analyze my data way quicker than I ever expected. I cannot express how thankful I was to have you part of this research.

Marina Gonchar, You were the person who taught me the most in my orthodontic residency. I would not be the orthodontist I am today if it wasn't for you. M, thank you for always being there and being one of my best friends.

Niki Chahin, I have no idea what I would have done if I didn't have you as a co-resident. You were always there to listen to my complaints and put me in my place. I know that we will remain friends for forever.

MacKenzie Boyles, Thank you for being such a great big for me. Being able to sit next to you in the clinic for two years was a remarkable experience for me. I was able to bounce so many ideas off of you, which made me a better clinician.

Sarah, Joanna, Stephanie, Dustin, and Minh, Thank you for making this program enjoyable and a great experience. You all had an impact on me, even if you don't think so. You all believe in me so much. Means the world to me.

Michele, Karen, and Marsha, You all made each day passable. I would not have been able to make it through this program without your support. You three mean more to me than you can imagine.

TABLE OF CONTENTS

Table of Contents

<i>DEDICATION</i>	<i>iii</i>
<i>ACKNOWLEDGMENTS</i>	<i>iv</i>
<i>LIST OF FIGURES</i>	<i>vii</i>
<i>LIST OF TABLES</i>	<i>viii</i>
<i>CHAPTER 1: INTRODUCTION</i>	<i>1</i>
BACKGROUND	1
STATEMENT OF THE PROBLEM	2
SIGNIFICANCE OF THE PROBLEM	3
NULL HYPOTHESIS	3
DEFINITION OF TERMS	6
ASSUMPTIONS	7
LIMITATIONS	8
DELIMITATIONS	8
<i>CHAPTER 2: REVIEW OF THE LITERATURE</i>	<i>9</i>
HISTORY	9
DECALCIFICATION	14
PREVENTION OF DECALCIFICATION	15
SEALANTS	15
SELF-ETCHING PRIMERS	16
BOND STRENGTH	17
IN VITRO LITERATURE REVIEW	19
ARI RESULTS	21
IN VITRO	24
PREPARING TEETH FOR MOUNTING	25
THERMOCYCLING	31
BOND STRENGTH	35
ADHESIVE REMNANT INDEX (ARI)	37
NULL HYPOTHESIS	39

CLINICAL IMPLICATIONS.....	46
RECOMMENDATIONS	47
<i>CHAPTER 5: SUMMARY AND CONCLUSION.....</i>	48
SUMMARY	49
CONCLUSIONS.....	50
<i>REFERENCES.....</i>	51
<i>APPENDIX.....</i>	56
DATA RESULTS.....	56

LIST OF FIGURES

<i>Figure 1:</i> Epoxy resin for tooth mounting.....	26
<i>Figure 2:</i> Stainless-steel rings with wax base.....	26
<i>Figure 4:</i> Mounted tooth with bracket bonded parallel to facial surface.....	27
<i>Figure 4:</i> Thermocycle bath with samples.....	31
<i>Figure 5:</i> Sample ready for testing with Instron Mechanical testing machine.....	32
<i>Figure 6:</i> Optical microscope.....	34
<i>Figure 7:</i> Boxplot of mean shear bond strength for different degrees of ARI.....	36
<i>Figure 8:</i> Boxplot of shear bonding strength for different degrees of ARI.....	38

LIST OF TABLES

<i>Table 1:</i> Groups included in samples.....	31
<i>Table 2:</i> Modified ARI scoring.....	33
<i>Table 3</i> Comparison of mean shear bond (SBS).....	35
<i>Table 4:</i> Significant results of multiple comparisons of mean shear bond strength.....	36
<i>Table 5:</i> Comparison of mean ARI score by group.....	36
<i>Table 6:</i> Significant results of multiple comparisons in SBS between different groups.....	37
<i>Table 7:</i> Comparison of mean shear bond strength between different ARI scores.....	38
<i>Table 8:</i> Significant results of multiple comparisons in shear bonding strength between different degrees of ARI.....	38

CHAPTER 1: INTRODUCTION

BACKGROUND

The most common method of bonding to teeth is with stainless-steel brackets and a conventional three-step system, i.e., phosphoric acid etch, primer, and adhesive resin. The clinician has to uniformly apply adhesive to the base of the bracket, place the bracket on the facial surface of tooth enamel, remove excess adhesive, and light cure the bracket to the tooth. This process includes extra time to the clinician and excess adhesive material around the orthodontic bracket. Attempts to minimize time and the amount of flash have led to the creation of different bonding systems and techniques. The company 3M (Monrovia, CA) developed Flash-Free adhesive (APC™ Flash-Free Adhesive Coated Appliance System, 3M Unitek) as an attempt to eliminate the need for flash removal. Each bracket is individually packaged with an optimal amount of adhesive precoated on the bracket, allowing for placement by the clinician and no removal of flash. Self-etch primer was introduced to reduce the number of steps during bonding. Self-etch primer is considered a two-step system because the etchant and primer are included in one. Flash-Free adhesive and self-etch primer has become popular, yet, there is a scarcity of literature on the shear bond strength of this specific procedure compared with stainless-steel brackets and phosphoric acid etch, primer, adhesive protocols. Lee and Kanavakis¹ studied ceramic brackets with a self-etch primer. They compared shear bond strength of Flash-Free adhesive ceramic brackets to precoated ceramic brackets to manual paste adhesive brackets¹. It was determined that ceramic Flash-Free adhesive had greater shear bond strength than ceramic precoated adhesive and ceramic manual pasted adhesive¹. Research by Foersch et al² studied ceramic Flash-Free adhesive brackets compared to ceramic precoated adhesive

brackets bonded with phosphoric acid etch and primer on bonding time and excess flash. They found that chair time WAS reduced with Flash-Free adhesive, significantly less flash around the bracket post-bonding, and less adhesive remaining on the tooth after debonding.²

The purpose of this study was to determine if a stainless-steel precoated adhesive bracket bonded with phosphoric acid etch and primer have a significant difference in shear bond strength with ceramic Flash-Free adhesive brackets. Additionally, this study was trying to determine the bond strength of ceramic Flash-Free adhesive brackets with different bonding protocols have significant differences in shear bond strength; Flash-Free adhesive with self-etch primer, Flash-Free adhesive with self-etch primer followed by a sealant, Flash-Free adhesive with phosphoric acid etch, primer, and sealant. After orthodontic brackets are debonded, a modified adhesive remnant index will be read for the tooth and bracket. The modified-ARI index identifies remaining adhesive left on the bracket and adhesive failure.

STATEMENT OF THE PROBLEM

Do ceramic brackets with APCTM Flash-Free adhesive, phosphoric acid etch, and primer have the same in-vitro shear bond strength as stainless-steel brackets with APCTM II Adhesive, phosphoric acid etch, and primer.

Is there an effect to shear bond strength of ceramic brackets with APCTM Flash-Free adhesive using different bonding protocols?

Is there an effect on shear bond strength when a sealant is applied to the tooth following application of a primer?

What are the characteristics of enamel-adhesive-bracket failure?

SIGNIFICANCE OF THE PROBLEM

Orthodontist's routinely use composite resin in bonding orthodontic brackets to tooth enamel; however, this is a multi-step procedure that requires isolation of the tooth and acid-etching of enamel. Self-etching primers, such as Transbond Plus (Monrovia, CA), will have higher shear bond strengths in a contaminated environment when compared to moisture insensitive primers³, such as Transbond MIP. Additionally, sealant materials, such as Pro Seal L.E.D. (Reliance Orthodontic Products Inc., Itasca, IL), has been shown to more effective in the prevention of decalcification (white spot lesions), in comparison to brushing alone⁴.

NULL HYPOTHESIS

1. There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch and TransbondTM MIP, Ortholux LED Curing Light; in vitro
2. There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with TransbondTM plus, Ortholux LED Curing Light; in vitro
3. There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, TransbondTM plus, Ortholux LED Curing Light; in vitro

4. There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light; in vitro
5. There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with TransbondTM Plus, Pro Seal L.E.D., Ortholux LED Curing Light; in vitro
6. There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Pro Seal L.E.D., Ortholux LED Curing Light; in vitro
7. There was no significant difference in shear bond strength of ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch and TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with TransbondTM plus, Ortholux LED Curing Light; in vitro
8. There was no significant difference in shear bond strength of ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, TransbondTM plus, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light
9. There was no significant difference in shear bond strength of ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light

compared with ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light; in vitro

10. There was no significant difference in shear bond strength of ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light
11. There was no significant difference in shear bond strength of ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Transbond Plus, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light
12. There was no significant difference in shear bond strength of ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Transbond Plus, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light
13. There was no significant difference in shear bond strength of ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light
14. There was no significant difference in shear bond strength of ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free bracket bonded with phosphoric acid etch, Assure Plus, Pro Seal L.E.D., Ortholux LED Curing Light

15. There was no significant difference in adhesive remnant index score for ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Transbond MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light
16. There was no significant difference in adhesive remnant index score for ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, TransbondTM plus, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light
17. There was no significant difference in adhesive remnant index score for ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light

DEFINITION OF TERMS

1. Composite resin: An adhesive that consists of a polymer base resin and inorganic filler material. Coupling agents are often used to chemically bond these constituents together.
2. TransbondTM Plus Self Etching Primer: An all in one bonding solution which allows you to etch, prime and bond to enamel in one simple and cost-effective step.
3. Enamel: the normally visible part of the tooth, covering the crown, a very hard, white to off-white, highly mineralized substance that acts as a barrier to protect the tooth but can become susceptible to degradation, especially by acids from food and drink

4. Phosphoric Acid: the use of an acidic substance to prepare the tooth's natural enamel for the application of an adhesive. The acid roughens the surface microscopically, increasing retention of resin sealant.
5. Bonding Materials: A term used to indicate supplies that attach the orthodontic brackets onto teeth. Synonyms: bonding adhesives, orthodontic adhesives, APC, APC Flash-Free.
6. APC™ Flash-Free Adhesive: A light curable bonding agent for orthodontic brackets that requires no removal of excess material off the enamel surface.
7. APC™ II Adhesive: A light curable bonding agent for orthodontic brackets that requires limited removal of excess material off the enamel surface.
8. Shear Bond Strength: Stress required to separate a bonded bracket from a tooth when on portion is forced to slider over another portion.
9. Tensile Bond Strength: Stress required to separate a bonded bracket from a tooth when it is pulled apart with forces acting opposite and away from each other.
10. Fixed Appliance: An orthodontic material that has attachments which are bonded or cemented to the teeth that are not removable.
11. Conventional Bonding: Gold standard bonding protocol that involves phosphoric acid etch, primer, and adhesive.

ASSUMPTIONS

1. There was one operator, C.B., who has been calibrated and the expertise for accurate and precise bracket placement.
2. There was no contamination of teeth or brackets during the study.

3. Bracket base area measurements are obtained from the manufacturer and not verified for each individual bracket.
4. Brackets will be bonded in the center of the facial surface of permanent premolars.

LIMITATIONS

1. Extracted teeth may vary in mineral content, possibly fluoride, hypocalcification, carious lesions, and dental work.
2. The laboratory environment of bonding brackets was different than that of the oral cavity, i.e. salivation, mastication, deglutition, and parafunction
3. Forces applied by the Instron (Instron Corp., Canton, MA) mechanical testing machine will simulate a peel and shear force rather than that of a pure shear force.

DELIMITATIONS

1. Samples will be limited to extracted permanent premolars.
2. Extracted teeth will be stored in distilled water and 0.2% thymol, up to one year
3. Orthodontic brackets will be bonded to intact enamel.
4. One operator will perform the bonding and debonding procedure.

CHAPTER 2: REVIEW OF THE LITERATURE

HISTORY

Amongst the innovations that have changed the practice of dentistry over the course of the past century, acid-etch technique and the use of composite resins may be the two most influential. In 1955, Michael Buonocore, a researcher in New York made the keen observation of weak inorganic acids altering the surface enamel for bonding resin to take place⁵. Initially, acrylic resins were used for enamel bonding but were proven to be too weak to withstand the stresses exerted by the mouth. The word “composite” was still new in dentistry and not mentioned once in Dr. Rafael Bowen, the pioneer of dental composites, landmark research.⁶ In materials science, the term “composite” means a physical mixture of any phases (metal-metal, metal-ceramic, ceramic-ceramic, ceramic-polymer, polymer-metal, polymer-polymer).⁶ Bulk properties of any composite depend on volume fraction and properties of each phase and the characteristics of the interfaces connecting those phases. Without strong internal interfaces, composites behave poorly. In the decades that have passed from Dr. Bowen’s initial discovery many attempts have been made to improve bond strength, bonding procedures, color stability, resistance to indentation and toxicity, shrinkage, solubility and more.

Newman, in 1964, introduced the possibility of direct bonding an orthodontic bracket to enamel surface of a tooth using an adhesive resin.⁵ He aimed to have plastic attachments which would directly bond to enamel surface for an appropriate period, withstand chewing forces, stresses from archwires and chains, changes in temperature, and be removed by the operator with none to minimal enamel defect. Additionally, the resin needed to be non-irritating to the oral mucosa, bond in hydrophilic conditions, and cure at the operator’s convenience. Direct bonding

orthodontic appliances have several advantages including elimination of separation, bands, and post band spaces, enhanced ability for plaque removal, and more esthetic appearance.

The first bonding materials include a two-paste chemically activated composite resin. This includes a two-paste catalyst and base system and no mix primer and one paste systems.⁷ The two-paste system was activated by mixing equal parts catalyst and base to start polymerization of resin. In the no mix primer and one paste system, a primer was painted on the attachment and tooth then a paste was applied on the attachment and placed on the tooth.⁷ When the primer and paste come into contact the polymerization of resin occurs. Chemical cure adhesives were found to have adequate bond strength to resist the forces routinely applied in orthodontics. A major disadvantage of chemical cure adhesives was the operator was unable to adjust the setting time and must position brackets rapidly. Excess cement cannot be removed until the bonding material has reached its final set, if the operator removes excess adhesive prematurely the materials maximum bond strength can decrease.⁷

In 1979, Tavas and Watts introduced light cure resin adhesives that activated polymerization by transillumination with a wavelength of 460 to 480nm.⁸ The amount of activated photo initiator depends on the concentration of photoinitiator in the material, the number of photons to which the material was exposed and the energy of the photons (wavelength), the latter depending on the curing light. The most common photoinitiator used in dentistry for light cure resin material is camphorquinone, which has peak activity near 468nm wavelength. Commercially available curing units have different light intensities and light sources, with energy levels in QTH, LED and other LCUs ranging from 300 to more than 2000 mW/cm. Light cure resin materials offer several advantages over the chemically cured activation method. Light cure resins require no mixing that results in less porosity and greater strength, as

well as having entire control over working time. The command set provided with light cure resins allows the operator to adjust individual brackets without harming the bond strength due to late adjustments. Excess bonding material was more easily removed while not affecting the bond strength during the process. The factors affecting polymerization include filler type, size and loading, the thickness and shade of the restorative material, the effectiveness of light transmission (guide tips being free from debris and scratches), exposure time, distance of the light source from the restorative material and light intensity. In orthodontics, the accessories, brackets, buttons and chains, are made from stainless-steel which light is not able to penetrate. Dual cure composite resins were introduced to dentistry in the 1980s.⁹ These resins work through a chemical cure polymerization and light activation. The dual cure allowed for complete polymerization of the resin if there was not complete cure by light activation, thus, increasing bond strength of the composite.⁹ The clinician can be assured of complete polymerization due to the chemical process however the working time becomes limited due to the chemical cure. Advancements in bonding material has greatly improved bonding of orthodontic appliances with resin adhesives and resins have become the material of choice for orthodontic bonding.^{2,6,10-13} However, the bonding procedure requires strict adherence to dry field, acid etch, and hydrophobic adhesive materials.

As we are moving forward in the new millennium, it is important for us to examine the past. As previously mentioned, Buonocore founded the principles of adhesion dentistry and subsequently found that etching enamel with phosphoric acid increased the strength of adhesion. Buonocore suggested, and later confirmed, that the formation of resin tags caused the principal adhesion of etched enamel.¹⁴ As time continued, variation in duration and concentration of phosphoric acid etch were tested on enamel. The current thinking is 30 to 40 percent phosphoric

acid etch of 15-30 seconds is acceptable.¹⁵ In the field of orthodontics, ninety percent of bonding is to tooth enamel and the other ten percent is to restorative material i.e. stainless-steel, amalgam, composite resin restoration, lithium disilicate or zirconia. The original bonding agents used a total etch system, that is etch, primer and adhesive. From many authors point of view, 3M Unitek Transbond MIP can still be regarded as the gold standard for bonding brackets to enamel.¹¹ The total etch technique, with any primer agent, requires a completely dry environment to yield the greatest strengths, and however, the oral cavity does not warrant a hydrophobic environment. In the absence of saliva, water, and any other aqueous solution touching the tooth the patients breathe is humid. This humidity will invariably cause a decrease in bond strength which is why self-etching primer and hydrophilic primers are in vogue.

Watanabe and Nakabayashi developed a self-etching primer that was an aqueous solution of 20 percent phenyl-P in 30 percent HEMA for bonding to enamel.¹⁶ The combination of etching and priming steps reduces chair-side time, although this is tempered by the requirement for judicious pumicing before bonding procedures to minimize the risk of failure, reduced sensitivity to moisture, and reduced inventory requirements. Additionally, self-etching primers are designed to be used in a slightly wet environment. Posterior and mandibular regions in the oral cavity are difficult to isolate and maintain a hydrophobic environment, which is why self-etch bonding systems or self-etch primers (SEPs) are routinely used by 29.5% of practitioners in the United States.¹⁷ However, self-etching primer has its disadvantages. The effectiveness on properly etched enamel is less predictable than the results obtained with phosphoric acid. According to Yoshiyama et al, laboratory test does not show a statistical difference between self-etching primer and phosphoric acid etch, however, Ferrari et al states that in laboratory and

clinical demonstrations self-etching primer has a weaker enamel margin seal than phosphoric acid etch.^{18,19}

The two major hydrophilic, self-etching primers on the market are Reliance Self-Etch Primer and 3M Transbond Plus. These products are packed in a one-time use syringe or lollipop design. The solution must be refreshed continuously because these systems typically incorporate methacrylated phosphoric acid esters; after application to enamel, the phosphate group dissolves and removes calcium ions from hydroxyapatite, becoming incorporated in the network before the primer polymerizes, neutralizing the acid.¹⁷ Fleming et al stated a small but statistically significant time saving was also associated with the self-etch primer technique, about 23.2 seconds per bracket, the difference translates to a reduction of 8 minutes per dual-arch bracket placement.¹⁷

A novel Flash-Free bracket adhesive system was created by 3M Unitek in May 2013, called APC™ Flash-Free bracket adhesive.^{12,20} This promising approach is realized by a nonwoven, polypropylene fiber mat, which is directly positioned on the base of the bracket.¹² This mat is soaked with a low-viscosity resin. The purpose of the mat is to be slightly compressible while being pushed on the tooth but to hold back excess adhesive that is squeezed out during bracket application. 3M Unitek places the brackets in a holding tray that is sealed to not allow light to initiate polymerization of the adhesive. Key advantages include elimination of the flash removal step in bonding and significant reduction of bonding time by up to 40%, according to David Cinader. Additionally, the adhesive formulation protects the tooth enamel during treatment and makes debonding and cleanup easier at the end of treatment. With APC™ Flash-Free adhesive, a small amount of resin flows out from under the bracket during seating on the tooth. This resin forms a meniscus or fillet around the edges of the bracket which, once

cured, has been proven to stay in place throughout the entire course of treatment.¹² While other products may require sealant application every six months, data from 3M states that APC™ Flash-Free adhesive withstands acid erosion on enamel and toothbrush wear.

DECALCIFICATION

Decalcification is basically broken down mineral elements, specifically calcium and phosphate within the tooth structure, this generally occurs when the oral environment is at a decreased pH.^{21,22} Decalcification or demineralization is caused by ineffective oral hygiene and retention of bacterial plaque on the enamel surface for an extended period of time.^{23,24} The white spot lesion is the early stage of a carious lesion, however, decalcification is a back and forth process with alternating phases of demineralization and remineralization.^{18,25} Decalcification may develop within a month of bracket placement due to prolonged accumulation and retention of plaque next to the brackets.^{21,23,26} Decalcification can be found in both the orthodontic and non-orthodontic populations. Misrahi conducted a study of high school aged children and found that nearly 85% of the group had clinical evidence of enamel decalcification of unknown etiology.²⁶ Several studies have indicated increase plaque retention with orthodontics brackets and greater concentrations of bacteria (*S. Mutans* and *Lactobacillus*).²¹ Gwinnett and Ceen proposed that the presence of excess bonding agent known as “flash” around the base of the bracket can allow for plaque accumulations.²⁷ However, Moritz Foersch et al stated that excess resin around APC Flash-Free brackets expanded 0.16 to 0.08 mm over the bracket margin and the new technology seems to facilitate a smooth and sufficient marginal surface of the adhesive, which clinically might improve reduction of plaque accumulation.²

PREVENTION OF DECALCIFICATION

Currently several methods exist that will hinder enamel decalcification including thorough oral hygiene instructions and supervision, fluoride administration, sealant application, and proper appliance selection and placement.^{24,28}

Oral hygiene can reduce or control the amount of plaque in contact with enamel which can prevent or limit decalcification.²⁹ Continuous reinforcement of oral hygiene habits and evaluation of oral health status of the patient should be maintained throughout treatment.³⁰ Mitchell suggest that plaque removal by mechanical or chemical means can be effective in the reduction of the rate of enamel decalcification. Tooth brushing is the most common form of mechanical plaque removal and can be performed with manual or electric toothbrushes. Electronic toothbrushes have been found to be more effective than manual brushes.^{31,32} Other studies have shown that sonic toothbrushes are 20 to 47% more effective in removing supragingival plaque than manual toothbrushes.^{33,34}

SEALANTS

Sealant, a protective chemical barrier on the tooth surface is an acceptable modality for reducing enamel decalcification.³⁵ Enamel sealants have been evaluated for effectiveness in inhibiting enamel decalcification during orthodontic treatment. Ceen et al stated the thinness of the applied sealant layer was cited as the reason for the ineffectiveness in inhibiting enamel decalcification.³⁶ Brant and Zachrisson stated that the effectiveness of a low viscosity resin sealant is due to its penetration into the acid-etched enamel where it polymerizes and protects the enamel against a cariogenic challenges.³⁷ Chemical cure sealants were shown to be ineffective as a result of incomplete polymerization of thin sealant layers. Chemically cured sealants also

contained numerous voids within the sealant layer. Light cured sealants appear to have more complete polymerization and are more effective.³⁸ Pro Seal L.E.D by Reliance Corporation is a popular sealant used in orthodontics. Pro Seal L.E.D is applied on the facial surface of the tooth which is subsequently light cured. Even after the thin sealant layer has worn away, the sealed teeth were more resistant to demineralization. Joseph explained that the presence of resin tags in the enamel occupied potential sites of demineralization.³⁸ 3M Unitek has stated that the meniscus formed around the bracket of Flash-Free Adhesive acts like a sealant on the tooth. This comment has not been proven and needs further research to verify the effectiveness.

SELF-ETCHING PRIMERS

Conventional adhesive systems use 2 different agents (an etchant conditioner and adhesive resin) in the process of bonding orthodontic brackets to enamel. A unique characteristic of self-etching primers is that they combine the conditioning and priming agents into a single solution.^{39,40} Combining conditioning and priming into a single treatment step result in improvement in both time, to the patient and provider.⁴¹ Two of these are Transbond Plus Self-Etching Primer (3M Unitek) and Reliance Self-Etching Primer (Reliance Corp) that employ this chemistry.

A self-etch approach to bonding involves either a two or one step application procedure. The self-etch effect should be ascribed to monomers to which one or more carboxylic or phosphate acid groups are grafted.⁴² Depending on etching aggressiveness, they can be subdivided into a “strong” or “mild” self-etch adhesive based on the pH.⁴³ The chemistry of Transbond Plus Self-Etching primer (pH = 1) is similar to that of phosphoric acid, with two primer chains that form a solid primer matrix upon curing.⁴³ The ingredients of Transbond Plus

self-etching primer consists of two groups; 75-85% by weight of methacrylate ester derivative and 15-25% by weight of water. The component is then rubbed on the surface of the tooth causing a mass transfer of product deep into the enamel, causing no damage to the enamel rods. The liquid begins to etch the enamel as soon as it is applied, but it changes to a primer once the two-hydroxide chains are converted and hydrogen is released. Because the monomers that cause the etching are also responsible for bonding, there is no need to for rinsing and the depth of penetration of the monomers to be polymerized is exactly the same as the depth of demineralization, resulting in a complete hybrid layer.⁴⁴ Since orthodontic bonding surfaces are only enamel the etch patterns are consistently similar to those produced by etching with phosphoric acid.⁴⁵ Padhraig S. Fleming et al stated there is weak evidence indicating higher odds of failure with self-etch primer than acid etch over 12 months in orthodontic patients, however, there has been contradicting research stating self-etch bond strength is greater than conventional bonding technique. A significant reason why self-etch primers are used and will continue to be used into the future is the time savings, 8 minutes for full bonding, compared with acid etch.¹⁷

BOND STRENGTH

One of the most widely used laboratory tests is shear bond strength (SBS). It measures the ability of adhesive resins to bond to tooth structure. The definition of shear bond strength is that shearing stress is an action or a stress caused by an applied force that causes two parts of a body to slide over one another. Measuring the force required to separate a bonded bracket from a tooth when one portion is forced to slide over another portion is how shear bond strength is calculated. The shear bond strength is calculated by dividing the break force applied (in Newtons) by the area of the bracket base. The value is recorded in Megapascals (MPa). Tensile

bond strength can also be measured and is defined as any induced force which resists deformation caused by a load which tends to stretch or elongate a body.⁴⁶ The tensile bond strength is the stress required to separate a bonded bracket from a tooth when it is removed with forces acting in opposite directions from each other. Tensile bond strength is equal to the load (kg) divided by the square area (cm²). To convert the kg/(cm²) to MPa, a multiplier of 0.0981 is used.⁴⁷ This procedure typically uses a chisel-shaped tool mounted in a universal testing machine to forcefully fracture a disc or bonded material (bracket) from the bonding substrate (tooth surface). A higher shear bond strength is equated with enhanced performance, and cohesive failures within tooth structure or composite resins are considered superior to failures within the adhesive layer.¹⁸ In orthodontics, excessively high shear bond strengths pose a problem because enamel fractures can occur during debonding procedures which lead to tooth damage and possible pulpal involvement

The variable when testing bond strength with the widest disparity has almost certainly been the crosshead speed selected to fracture bond samples.¹⁸ The viscoelastic nature of dental adhesive suggests that shear bond strength and failure mode could be affected by the rate of stress application. Slower crosshead speeds could allow for a deformation period during which stress and strain are compensated for by the elasticity of the bonding agent. Resins behave like a viscous material at lower speeds, deforming more as increased pressure is applied. An increase in shear bond strength then results. The potential for higher shear bond strengths also exists with faster crosshead speeds. At higher crosshead speeds, the resin may perform as a brittle solid with increased energy directed toward fracture of the specimen rather than molecular deformation and flexure^{48,49}. If either statement is valid, significant differences in SBS between tested materials could result just from altering the crosshead speed. Lindemuth and Hagge tested SBS of 5 groups

with 10 samples each. Each group was tested using a different crosshead speed. The 5 speeds selected were 0.1, 0.5, 1.0, 5.0, and 10.0 mm/min.¹¹ Their results showed that SBS and specimen failure mode (cohesive vs. adhesive) of composite resin bonded to enamel were essentially unaffected by variation in crosshead speed. It has been suggested by Reynolds, that a minimum SBS of 5.9 to 7.8 MPa is required for clinically acceptable orthodontic adhesive results.¹¹

IN VITRO LITERATURE REVIEW

There are an abundance of studies involving shear bond strength of metal and ceramic brackets with all types of bonding agents, however, there are not as many studies available with Flash-Free Ceramic brackets. YG Reddy et al stated that shear bond strength for ceramic brackets was twice as high (20.68MPa) as metal brackets (12.15MPa).⁵⁰ This study used 37% phosphoric etch, however, they used a chemical cure polymerization adhesive which is significantly different than the current study. Due to silane bonding of ceramic and enamel, YG Reddy found the bond strength to be significantly strong in ceramic brackets than metal brackets. Due to the significant bond strength, there is a greater chance of enamel fracture during debonding. Sharma et al. tested stainless-steel brackets with four different etchant and primers, 37% phosphoric acid etch and Transbond MIP (3M Unitek), 37% phosphoric acid and Rely-a-bond (Reliance Corp.), Transbond Plus, and self-etching primer Xeno V (Dentsply, Konstanz, Germany). Transbond MIP (15.49 MPa) attained the highest bond strength compared to self-etching primers, however, Xeno V (13.51 MPa) and Transbond Plus (11.57 MPa) showed clinically acceptable shear bond strength values and almost clean enamel surface after debonding.⁵¹ Using Transbond Plus all-in-one system lead to acceptable bond strengths with stainless-steel brackets. Lee and Kanavakis tested APCTM Flash-Free Clarity Adhesive coated

brackets and manually pasted Clarity ADVANCED Ceramic bracket to the control group of APC Plus Adhesive Coated Brackets. The APC™ Flash-Free Clarity Adhesive coated brackets had significantly greater SBS (13.7 MPa) compared with the control group (10.8 MPa) and the manual group (10.4 MPa) of Clarity ADVANCED Ceramic bracket.^{1,52} Lee and Kanavakis showed that with self-etching primer and no phosphoric acid etch that Flash-Free Clarity Adhesive coated brackets had a significantly greater shear bond strength the traditional adhesive coated. Bishara et al performed a study using APC™ II Adhesive Coated Victory brackets and APC™ Flash-Free Clarity Adhesive coated brackets and testing shear bond strength.^{41,53,54} The conventional bonding technique (phosphoric acid etch, primer) and new (self-etching primer) bonding technique used. With metal brackets, the conventional method found a SBS of 4.6 MPa and the new method 8.6 MPa. With the Clarity brackets, the conventional method found a SBS of 7.8 MPa and the new method 10.0 MPa. Additionally, there is a precoated bracket that uses traditional Transbond, but a non-contaminated consistent amount is placed on brackets. The precoated bracket takes out many provider variables, such as excessive adhesive, adhesive base engagement, excessive contamination, that can affect bonding strength. Bishara found the self-etching method had greater SBS than the conventional method, however, the conventional method results are significantly lower when compared to other studies.⁵³ In a study by Vicente and Bravo, SBS of APC Plus Coated Victory Metal brackets and uncoated Victory Metal brackets (3M Unitek) was tested using self-etching primer Transbond Plus.^{41,53,54} There was no significant difference between the SBS of uncoated and precoated brackets, 12.2 MPa and 14.3 MPa respectively. The bond strength values achieved by the two groups was greater than the minimum established by Reynolds¹¹. In studies that have followed there has not been unanimous

agreement with Bishara's results, if anything, his findings of SBS being greater for self-etching primers seem to be an outlier in the field of orthodontics.

THERMOCYCLING

Most studies are conducted in the lab without any thermocycling. The oral environment is extremely complex and different than a laboratory setting. Thermocycling allows a person to simulate the oral environment after brackets have been bonded to teeth in temperatures ranging from 5°C to 55°C.^{55,56} In a study by Mirzakouchaki et al., thermocycling was performed on brackets bonded to extracted premolars at temperature ranges from 37°C to 55°C.⁵⁶ Metallic and ceramic brackets were bonded with self-etching primer protocol and conventional protocol. All groups were placed in an incubator and simulated oral conditions through thermocycling at 5°C and 55°C. The shear bond strength of metallic brackets in the conventional and self-etching primer were 9.20 MPa and 8.50 MPa, respectively.⁵⁶ The SBS of non-flash free ceramic brackets were 6.20 MPa and 5.70 MPa, respectively. Mirzakouchaki did not test the SBS prior to thermocycling, therefore, it cannot be stated by how much bond strength changed. It can be expected for bond strength to decrease when the oral environment is simulated in vitro. According to this study, bond strength is less than other studies without thermocycling, but different bonding techniques and different bracket bases were used.

ARI RESULTS

Adhesive remnant index, ARI, is a visual examination to determine if orthodontic adhesive maintains on the tooth, the bracket, or tooth and bracket after debond. The original ARI scale was developed by Artun and Bergland⁵⁷ and consists of four scoring categories, 0 to 3. The

following scores were given: 0 = no adhesive left on the tooth, 1 = less than half of the adhesive left on the tooth, 2 = more than half of the adhesive left on the tooth, 3 = all adhesive left on the tooth. The modified adhesive remnant scale was developed to more accurately depict the amount of adhesive remaining on the bracket, and consists of five scoring categories, 0 to 5^{55,58}.

Assessment using the 5-point ARI scale was capable of yielding results similar to those that could be obtained through the use of expensive, high-precision, time-consuming quantitative assessment methods.⁵⁸ While these results might suggest that the modified 5-point ARI scale is more accurate than its original version, it should be kept in mind that the 5-point scale may also tend to mask minor differences.⁵⁸

According to Foersch, looking at the adhesive remnant index of APCTM Flash-Free Clarity Adhesive coated ceramic brackets (3M Unitek) shows that more than 50% of the adhesive remains on the enamel.² According to Grunheid et al., there is a significant difference between the ARI scores of conventional vs flash-free adhesives. It appears the mesh coating of the flash-free technology might pose a failure point during the debonding process, which leads to a fairly unpredictable amount of adhesive left on the tooth. Sharma et al stated that teeth with ARI score of 3 to be most prevalent in 35% phosphoric acid etch and Transbond MIP adhesive (40%), followed by 35% phosphoric acid etch and Rely-a-Bond (30%), Transbond Plus with Transbond MIP (15%), and Xeno V with Xeno Ortho (10%).⁵¹ Under SEM, enamel surfaces after debonding of the brackets appeared porous when an acid-etching process was performed on the surfaces of Rely-a-Bond and Transbond MIP, whereas with self-etching primers enamel presented smooth and almost clean surfaces (Transbond Plus and Xeno V group). Mirzakouchaki et al. stated that the changes in bond strengths are parallel with the changes in the ARI index.⁵⁶ The greater the bond strength the more likelihood there will be adhesive left on tooth enamel

than if there is weaker bond strength. According to Vicente and Bravo, APC Plus Precoated Metal brackets leave less adhesive on the tooth surface than uncoated brackets.⁵⁹ This implies a reduction in chair-side time spent on adhesive removal after debonding.

In the discussion of the benefit of low or high modified ARI scores, low modified ARI scores indicate a reduced risk of enamel tear, which might be beneficial to the patient. Nevertheless, high modified ARI scores appear to be favorable if the chair time should be reduced.

CHAPTER 3: METHODS AND MATERIALS

IN VITRO

This chapter describes the samples, methods of data collection, statistical analysis, materials, and equipment that were used in the in vitro study.

One-hundred and five human permanent premolars were collected to study the shear bond strength ceramic and stainless-steel brackets precoated adhesive brackets with different bonding protocols. The criteria for selection includes minimally restored and/or carious teeth intact facial enamel. The teeth were cleaned of debris, polished with non-fluoridated paste and stored in 0.2% thymol. The one-hundred and five human permanent premolars were randomly divided into seven groups based on bonding protocol. All brackets were bonded on the facial surface of the anatomical crown:

Group 1 (Control Group): 15 mounted teeth were orthodontically bracketed with 37% phosphoric acid etch (Dentsply), followed by Transbond™ MIP (3M Unitek, Monrovia, CA), followed by stainless-steel APC™ II Adhesive bracket (3M Unitek, Monrovia, CA).

Group 2: 15 mounted teeth were orthodontically bracketed with 37% phosphoric acid etch (Dentsply), followed by Transbond™ MIP (3M Unitek, Monrovia, CA), followed by ceramic APC™ Flash-Free adhesive bracket (3M Unitek, Monrovia, CA).

Group 3: 15 mounted teeth were orthodontically bracketed with Transbond™ Plus Self Etching Primer (3M Unitek, Monrovia, CA), followed by ceramic APC™ Flash-Free adhesive bracket (3M Unitek, Monrovia, CA).

Group 4: 15 mounted teeth were orthodontically bracketed with 37% phosphoric acid etch (Dentsply), followed by Transbond™ Plus Self Etching Primer (3M Unitek, Monrovia, CA), followed by ceramic APC™ Flash-Free adhesive bracket (3M Unitek, Monrovia, CA)

Group 5: 15 mounted teeth were orthodontically bracketed with 37% phosphoric acid etch (Dentsply), followed by Assure® Plus All Surface Bonding Resin (Reliance Orthodontic Products Inc., Itasca, IL), followed by ceramic APC™ Flash-Free adhesive bracket (3M Unitek, Monrovia, CA)

Group 6: 15 mounted teeth were orthodontically bracketed with 37% phosphoric acid etch (Dentsply), followed by Assure® Plus All Surface Bonding Resin (Reliance Orthodontic Products Inc., Itasca, IL), followed by Pro Seal L.E.D (Reliance Orthodontic Products Inc., Itasca, IL) applied over the entire facial surface and cured for 6 seconds, followed by ceramic APC™ Flash-Free adhesive bracket (3M Unitek, Monrovia, CA)

Group 7: 15 mounted teeth were orthodontically bracketed with Transbond™ Plus Self Etching Primer (3M Unitek, Monrovia, CA), followed by Pro Seal L.E.D (Reliance Orthodontic Products Inc., Itasca, IL) applied over the entire facial surface and cured for 6 seconds, followed by ceramic APC™ Flash-Free adhesive bracket (3M Unitek, Monrovia, CA).

PREPARING TEETH FOR MOUNTING

Prior to mounting, 2-3mm of the tooth apex of the extracted tooth was removed by a dental carbide bur to flatten the apex. A hole was drilled through each tooth approximately 5mm from the apex. A 0.040 stainless-steel wire was placed through each hole for additional retention when mounted in the epoxy resin (Buehler, Lake Bluff, IL) (see Figure 1) The base of round stainless-steel rings were filled with wax to prevent leakage of the epoxy resin (see Figure 2). The teeth

were embedded in epoxy resin up to the cementoenamel junction in stainless-steel rings. The teeth were stored in 0.2% thymol until orthodontic bonding.

Figure 1: Epoxy resin for tooth mounting

Figure 2: stainless-steel rings w/wax base

Figure 3: Mounted tooth with bracket bonded parallel to facial surface

All brackets were positioned with the aid of a dental surveyor so the bracket bases would be parallel to the buccal surface of the tooth (see Figure 3).

BONDING PROCEDURES

Group 1

1. Prophyl tooth with non-fluoride oil-free pumice
2. Air dry thoroughly using oil and moisture-free air source
3. Apply etching agent with applicator (37% phosphoric acid)
4. Allow 30 seconds for etching, rinse tooth for 5 seconds
5. Dry tooth thoroughly, area should appear frosty white
6. Apply thin coat of Transbond MIP to tooth
7. Air dry to remove alcohol and excess water
8. Apply stainless-steel APC™ II Adhesive bracket
9. Remove excess flash
10. Light cure each side of bracket for 3 seconds, total of 12 seconds

Group 2

1. Prophyl tooth with non-fluoride oil-free pumice
2. Air dry thoroughly using oil and moisture-free air source
3. Apply etching agent with applicator (37% phosphoric acid)
4. Allow 30 seconds for etching, rinse tooth for 5 seconds
5. Dry tooth thoroughly, area should appear frosty white
6. Apply thin coat of Transbond MIP to tooth
7. Air dry to remove alcohol and excess water
8. Apply ceramic APC™ Flash-Free adhesive bracket
9. Light cure each side of bracket for 3 seconds, total of 12 seconds

Group 3

1. Prophyl tooth with non-fluoride oil-free pumice
2. Air dry thoroughly using oil and moisture-free air source
3. Apply Transbond™ Plus Self Etching Primer vigorously for 5 seconds
4. Air dry for 5 seconds to remove alcohol and excess water
5. Apply ceramic APC™ Flash-Free adhesive bracket
6. Light cure each side of bracket for 3 seconds, total of 12 seconds

Group 4

1. Prophyl tooth with non-fluoride oil-free pumice
2. Air dry thoroughly using oil and moisture-free air source
3. Apply etching agent with applicator (37% phosphoric acid)
4. Apply Transbond™ Plus Self Etching Primer vigorously for 5 seconds
5. Air dry for 5 seconds to remove alcohol and excess water
6. Apply ceramic APC™ Flash-Free adhesive bracket
7. Light cure each side of bracket for 3 seconds, total of 12 seconds

Group 5

1. Prophyl tooth with non-fluoride oil-free pumice
2. Air dry thoroughly using oil and moisture-free air source
3. Apply etching agent with applicator (37% phosphoric acid)
4. Assure® Plus All Surface Bonding Resin
5. Air dry for 5 seconds to remove alcohol and excess water
6. Apply ceramic APC™ Flash-Free adhesive bracket
7. Light cure each side of bracket for 3 seconds, total of 12 seconds

Group 6

1. Prophyl tooth with non-fluoride oil-free pumice
2. Air dry thoroughly using oil and moisture-free air source
3. Apply etching agent with applicator (37% phosphoric acid)
4. Assure® Plus All Surface Bonding Resin
5. Air dry for 5 seconds to remove alcohol and excess water
6. Apply thin coat of Pro Seal L.E.D to facial surface
7. Light cure facial surface for 6 seconds
8. Apply ceramic APC™ Flash-Free adhesive bracket
9. Light cure each side of bracket for 3 seconds, total of 12 seconds

Group 7

1. Prophyl tooth with non-fluoride oil-free pumice
2. Air dry thoroughly using oil and moisture-free air source
3. Apply Transbond™ Plus Self Etching Primer vigorously for 5 seconds
4. Air dry for 5 seconds to remove alcohol and excess water
5. Apply thin coat of Pro Seal L.E.D to facial surface
6. Light cure facial surface for 6 seconds
7. Apply ceramic APC™ Flash-Free adhesive bracket
8. Light cure each side of bracket for 3 seconds, total of 12 second

Group (n=15)	Metal or Ceramic bracket	Conventional/ Flash-Free Adhesive	Phosphoric Acid Etch (+/-)	Transbond MIP	Transbond Plus (+/-)	Assure Plus (+/-)	Pro Seal L.E.D. (+/-)
1 (control)	Metal	Conventional	+	+	-	-	-
2	Ceramic	Flash-Free	+	+	-	-	-
3	Ceramic	Flash-Free	-	-	+	-	-
4	Ceramic	Flash-Free	+	-	+	-	-
5	Ceramic	Flash-Free	+	-	-	+	-
6	Ceramic	Flash-Free	+	-	-	+	+
7	Ceramic	Flash-Free	-	-	+	-	+

Metal: 3M Unitek Victory bracket

Ceramic: 3M Unitek Advanced Clarity

Conventional: APC™ II Adhesive Coated

Flash-Free: APC™ Flash-Free

Sealant: Pro Seal L.E.D.

Table 1. Groups included in sample

THERMOCYCLING

Samples were placed in an Indberg/Blue thermocycling machine for 24 hours. The samples will sit in a cold-water bath, 5°C, for 1 minute, 10 second transfer time, and then sit in a hot water bath, 55°C, for 1 minute. The cycle will repeat for a total of 24 hours. (Figure 4)

Figure 4. Thermocycle bath with samples

BOND STRENGTH TESTING

Debonding forces were determined using an Instron testing machine (Instron Corp., Canton, MA) with a crosshead speed of 1mm/minute. The stainless-steel rings were mounted on an adjustable base jig to ensure the applied force is parallel to the long axis of the tooth. A 0.016-inch stainless-steel wire was placed under the tie wings to exert a gingivo-occlusal load. A nitrile glove was placed over the tooth, bracket, and stainless-steel ring to secure the bracket have debond (see Figure 5). The force required to debond the bracket will be recorded in Newtons and converted to megapascals (MPa) by dividing the force in newtons by the area of the bracket base (provided by manufacturer). Teeth that fracture prior to the orthodontic bracket debonding were excluded from the results.

Figure 5. Sample ready for testing with Instron Mechanical testing machine

ADHESIVE REMNANT INDEX

Debonded orthodontic brackets were compared with the naked eye and 10x magnification optical microscopy. Evaluation and scoring of the adhesive remnant were carried out by the same evaluator. Evaluation was carried out with the naked eye, under 10x magnification. The ARI evaluation used the 5-point scale, where 1 indicates no adhesive left on the bracket base, implying that bond fracture occurred at the resin/bracket interface; 2 indicates less than 10% of composite remaining on the bracket surface, implying that bond fracture occurred predominantly at the resin/bracket interface; 3 indicates that more than 10% but less than 90% of composite remaining on the bracket surface, implying that bond fracture occurred predominantly as a cohesive failure; 4 indicates that more than 90% of composite remaining on the bracket surface, implying that bond fracture occurred at the enamel/resin interface; and 5 indicated all composite remaining on the bracket base, implying that bond fracture occurred predominantly at the enamel/resin interface. (see Table 2)

Score	Definition
1	No adherence of composite on the bracket base
2	Less than 10% of composite remaining on the bracket surface
3	More than 10% but less than 90% of composite remaining on the bracket surface
4	More than 90% of composite remaining on the bracket surface
5	All composite remaining on the bracket base.

Table 2. Modified ARI Scoring

The bracket bases were examined with an optical microscope at 10x magnification to determine the location of the remaining adhesive (Figure 6).

Figure 6: Optical Microscope

STATISTICAL ANALYSIS

All statistical tests were conducted using SAS (version 9.4, 2013, SAS Institute Inc., Cary, NC). To compare the difference in shear bonding strength between different materials and ARI degrees, we utilized one-way ANOVA followed by Tukey honestly significant difference (HSD) test. All statistical tests were two-sided and p-value of less than 0.05 was considered statistically significant.

CHAPTER 4: RESULTS

BOND STRENGTH

The mean shear bond strength of the seven test groups is shown in Table 3.

Groups	N	Mean Shear Bond Strength (MPa)	SD
1 (control)	15	12.49	1.94
2	15	9.02	1.89
3	15	7.45	2.15
4	15	9.42	0.88
5	15	10.46	0.86
6	15	9.92	2.12
7	15	5.35	1.05

Table 3. Comparison of mean shear bond strength (SBS)

^ap-value from one-way ANOVA, ***<0.001

Group 1, control, had the highest shear bond strength (SBS) than all other groups with group 7 having the lowest SBS of all groups. There was significant difference in mean shear bonding strength (SBS) between groups ($p < 0.001$); stainless-steel APCTM II Adhesive brackets with phosphoric acid etch followed by Transbond MIP had a significantly higher SBS than all other groups (2, 3, 4, 6, 7) except Group 5, the ceramic APCTM Flash-Free adhesive brackets bonded with phosphoric acid etch followed by Assure Plus. Group 7, ceramic APCTM Flash-Free adhesive bracket bonded with Transbond Plus followed by Pro Seal L.E.D., had significantly lower SBS than all other materials (See Table 4). Group 5, ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, followed by, Assure Plus and Group 6, ceramic APCTM Flash-Free bracket bonded with phosphoric acid etch, followed by, Assure Plus, Pro Seal L.E.D had significantly greater shear bonding strength than Group 3, ceramic APCTM Flash-Free bracket bonded with phosphoric acid etch (See Table 4). There were no significant difference in shear bonding strength in any other comparisons.

Groups	Difference ^a (MPa)	95% Confidence Interval	P-value
1-2	3.47	1.31-5.63	*
1-3	5.04	2.81-7.28	*
1-4	3.08	0.84-5.31	*
1-6	2.57	0.42-4.73	*
1-7	7.14	4.99-9.30	*
2-7	3.68	1.73-5.63	*
3-5	-3.02	-5.09—0.94	*
3-6	-2.47	-4.51—0.44	*
3-7	2.10	0.06-4.14	*
4-7	4.07	2.03-6.11	*
5-7	5.12	3.12-7.11	*
6-7	4.57	2.62-6.52	*

Table 4. Significant results of multiple comparisons groups

Difference^a - difference in shear bond strength (MPa)

*p-value <0.05 from Tukey's HSD test

Figure 7. Boxplot of mean shear bond strength for all groups

ADHESIVE REMNANT INDEX (ARI)

The mean ARI scores for all 7 groups are shown in Table 5.

Group	Min ARI	Max ARI	Mean ARI	SD
1	1	5	3	1.41
2	1	5	2.54	1.81
3	1	5	3.27	1.56
4	1	3	1.82	0.98
5	1	3	2.25	1.22
6	1	5	2.31	1.55
7	4	5	4.62	0.51

Table 5. Comparison of mean ARI score by group

Groups 2, 4, and 5 had a significantly lower ARI score than Group 7. (See Table 6). Group 7 had a mean ARI score of 4.62 while Group 2, 4, and 5 had mean ARI score of 2.54, 1.82, and 2.25, respectively. There were no significant differences between any other groups.

Groups	Difference ^a (MPa)	P-value
2-7	-2.08	<0.01
4-7	-2.80	<0.01
5-7	-2.37	<0.01

Table 6. Significant results of multiple comparisons in SBS between different groups

Difference^a = difference in shear bonding strength between two materials

*p-value <0.01 from Tukey's HSD test

The significant difference in mean SBS between different degrees of ARI ($p < 0.0004$); 1 ARI (difference=3.0, $p < 0.05$), and 3 ARI (difference=3.62) have better a greater SBS than a 5 ARI (Tables 8). There is no significant difference in shear bonding strength between any other ARI degrees.

ARI Score	N	Mean shear bond strength (MPa)	SD
1	26	9.76	1.83
2	9	9.07	2.30
3	24	10.40	1.96
4	23	8.35	2.91
5	23	6.77	2.63

Table 7 Comparison of mean shear bond strength between ARI scores

^ap-value from one-way ANOVA, ***<0.001

ARI Score	Difference in Shear bond strength	95% CI	P-value
1-5	3.00	0.69-5.31	*
3-5	3.62	1.29-5.96	*

Table 8 Significant results of multiple comparisons in shear bond strength between different degrees of ARI

*p-value <0.05 from Tukey's HSD test

Figure 8. Boxplot of shear bonding strength for different degrees of ARI

NULL HYPOTHESIS TESTING

NULL HYPOTHESIS

1. Rejected: There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch and TransbondTM MIP, Ortholux LED Curing Light; in vitro
2. Rejected: There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with TransbondTM plus, Ortholux LED Curing Light; in vitro
3. Rejected: There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, TransbondTM plus, Ortholux LED Curing Light; in vitro
4. Accepted: There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light; in vitro
5. Rejected: There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with TransbondTM Plus, Pro Seal L.E.D., Ortholux LED Curing Light; in vitro

6. Rejected: There was no significant difference in shear bond strength of stainless-steel APCTM II Adhesive Coated bracket bonded with phosphoric acid etch, TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Pro Seal L.E.D., Ortholux LED Curing Light; in vitro
7. Accepted: There was no significant difference in shear bond strength of ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch and TransbondTM MIP, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with TransbondTM plus, Ortholux LED Curing Light; in vitro
8. Accepted: There was no significant difference in shear bond strength of ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, TransbondTM plus, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light
9. Rejected: There was no significant difference in shear bond strength of ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light; in vitro
10. Rejected: There was no significant difference in shear bond strength of ceramic APCTM Flash-Free adhesive bracket bonded with Transbond Plus, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light
11. Rejected: There was no significant difference in shear bond strength of ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Transbond Plus, Ortholux

LED Curing Light compared with ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light

12. Rejected: There was no significant difference in shear bond strength of ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Transbond Plus, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light
13. Rejected: There was no significant difference in shear bond strength of ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light
14. Rejected: There was no significant difference in shear bond strength of ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free bracket bonded with phosphoric acid etch, Assure Plus, Pro Seal L.E.D., Ortholux LED Curing Light
15. Rejected: There was no significant difference in adhesive remnant index score for ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Transbond MIP, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light
16. Rejected: There was no significant difference in adhesive remnant index score for ceramic APC™ Flash-Free adhesive bracket bonded with phosphoric acid etch, Transbond™ plus, Ortholux LED Curing Light compared with ceramic APC™ Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light

17. Rejected: There was no significant difference in adhesive remnant index score for ceramic APCTM Flash-Free adhesive bracket bonded with phosphoric acid etch, Assure Plus, Ortholux LED Curing Light compared with ceramic APCTM Flash-Free adhesive bracket bonded with Transbond Plus, Pro Seal L.E.D., Ortholux LED Curing Light

CHATER 5: DISCUSSION

Ceramic brackets are made of aluminum oxide in two different forms, that are polycrystalline and monocrystalline, depending on method of manufacturing.⁶⁰ The major difference in two types of brackets is their optical clarity⁶⁰. Monocrystalline brackets are more translucent than polycrystalline brackets.^{60,61} Both types are resistant to staining and discoloration in oral cavity. Ceramic brackets are nine times harder than stainless steel brackets and can cause enamel abrasion if there is contact between bracket and tooth.⁶² Since, majority of ceramic brackets depend on the mechanical retention to form an acceptable bond, the base designs play an important role in the SBS values.⁵² The advantage of the ceramic bracket over metal bracket is affinity of the ceramic brackets to incident light which allows more transmission of light onto the bracket base resulting in a higher polymerization of the adhesive compared to stainless-steel brackets.⁶² The study measured the shear bond strength of seven different bonding protocols with the use of stainless-steel APCTM II Adhesive brackets and ceramic APCTM Flash-Free adhesive brackets. The force of bracket debonding was expressed using Newton meters (Nm). Megapascals (MPa) units was calculated by taking the Nm and dividing that by the area of the orthodontic bracket base. This study investigated; a universal maxillary bicuspid stainless-steel bracket and a universal maxillary bicuspid ceramic bracket. According to the manufacturer, the maxillary premolar ceramic bracket dimensions were 3.81mm by 3.86mm; a total surface area of 14.71mm². According to the manufacturer, the maxillary premolar stainless-steel bracket dimensions were 3.6mm by 3.0mm; a total surface area of 10.80mm².

The literature predominantly reported bond strengths in MPa, however, some authors reported bond strengths in Newtons. In this study, bond strengths were reported in Mpa. The mean bond strengths of ceramic APCTM Flash-Free adhesive bracket protocol groups

(2,3,4,5,6,7) was less than the stainless-steel APC™ II Adhesive coated bracket; which was the control group (Group 1); (see Table 3). The shear bond strength of Group 1, control group, was 12.49 MPa. In previous literature there has been a significant range of 4.6 MPa – 20.4 MPa.^{1,53} There was not a significant difference in shear bond strength between Group 5, 10.46 MPa, and group 1. In contrast to the moisture-insensitive primer, group 1, moisture-active adhesives, group 5, require rather than tolerate the presence of moisture to induce polymerization initiation. While some manufacturers claim acceptable performance for their moisture-insensitive products in a wet environment, others have introduced moisture-active adhesives.⁶³ The type of product which may be termed a moisture-resistant adhesive, is available in a primer formulation that replaces the moisture insensitive bonding agents applied to the enamel surface, and consists of an aqueous solution of methacrylate-functionalized polyalkenoic acid co-polymer and hydroxyethyl-methacrylate.⁶³ According to the results in this study, while using a moisture insensitive primer with phosphoric acid etch, group 1, compared to a moisture-active adhesive, group 5, there was not a significant difference in SBS.

The bond strength to withstand normal orthodontic forces is thought to be within the range of 5.9 to 7.8 MPa, proposed by Reynolds.¹¹ According to this recommendation, the mean shear bond strength of groups 1-6 (12.49, 9.02, 7.45, 9.42, 10.46, 9.92 MPa, respectively) have the potential to resist forces during orthodontic treatment. Group 1 (12.49 MPa) had the greatest shear bond strength which agrees with the findings of Schanerveldt et al stating moisture-insensitive primers have greater shear bond strength in a dry environment.⁶⁴ Bonding without phosphoric acid etch and using only a self-etch primer, as was the case in Group 3 and Group 5, yielded the lowest mean shear bond strengths, 7.45 MPa and 5.35 MPa, respectively. The values determined from this study do state the shear bond strength falls within the acceptable SBS

provided by Reynolds¹¹, except Group 7 which falls below the minimum recommended values. Manufacturer of the ceramic brackets used in this research, 3M Unitek, recommend phosphoric acid etch to be included in the bonding protocol, even if a self-etch primer is used. According to Fleming Et al there was weak evidence indicating higher odds of failure with only self-etch primer than acid etch.¹⁷ The placement of a light curable sealant without the use of phosphoric acid etch significantly decreases the shear bond. According to the results of this research, not using phosphoric acid etch has the greatest negative impact on shear bond strength.

The modified adhesive remnant index (ARI) allows a research to study the adhesion failure for orthodontic brackets.. The modified-ARI developed by Bishara and Trulove was used to score the amount of adhesive left on the bracket after debonding. The scores range from 1 to 5 and a correlation can be made by the amount of adhesive left on the bracket. A low score, 1 or 2, would be interpreted as a failure between the adhesive and bracket interface, or a strong bonding of the adhesive to the enamel. A high score would indicate a failure at the adhesive enamel interface or a weak bonding of adhesive to the enamel. Clinically it would be preferred for the failure to occur between the adhesive and the enamel which allow for easier cleanup at debonding. However, the debond must be strong enough to allow the bracket to remain bonded throughout orthodontic treatment. Vice versa, a high score would be preferable for adhesive removal during an orthodontic debonding procedure. Most frequently during this research, the debond failure occurred as a cohesive failure. This type of failure occurred in groups 1-6, with majority of the adhesive remaining on the tooth. Groups 1-6 ARI score range from 1.82 to 3.27. It appears that the mesh coating of the flash-free technology might pose a failure point during the debonding process, which leads to a fairly unpredictable amount of adhesive left on the tooth. According to Table 5, the mean ARI score for ceramic Flash-Free adhesive brackets

was lower than what was previously found by Lee and Kanavakis¹, ARI of 3.6, but comparable to Ansari et al⁵², with more than half or all adhesive remaining on the tooth.⁶⁵ Group 7 had significantly higher ARI score (4.62) than the other groups. The bond failure was always between the enamel and adhesive which could be favorable for patient clean up, however, the SBS of 5.35 MPa is not above the clinically acceptable minimum.

Additionally, this study compared the ARI score to mean shear bond strengths (See Table 8). It was determined that an ARI score of 1 and 3 had a significantly greater shear bond strength (9.76 MPa and 10.40 MPa, respectively) than an ARI of 5 (6.77 MPa). According the ARI score of 5 and SBS of 6.77 MPa, the bond failure occurred at the enamel-adhesive interface and it can be surmised that enamel etchant, is a significant reason the ARI score is high with a low SBS strength. Additionally, there were four instances where the ceramic bracket fractured in half. The ceramic brackets used in this study, ADVANCED Clarity ceramic brackets, have a score line occluso-gingivally, as described by the manufacturer. This score line is placed on the bracket to allow for easy debonding by fracturing the bracket mesial, distally and eliminate previous problems of enamel fracturing during debonding of ceramic brackets. It can be surmised there was manufacturer error in fabrication of the score line or the bracket was not removed in a total shear force direction which affected the integrity of the ceramic bracket.

CLINICAL IMPLICATIONS

Not all bonding protocols are created equal. Minute details can greatly affect the outcome of bonding orthodontic brackets to enamel. Using phosphoric acid etch, primer and adhesive will provide greater bond strengths that may be able to withstand occlusal forces or trauma when

compared to the ceramic APC™ Flash-Free adhesive on 3M Unitek Advanced Clarity brackets. However, according to this study using Flash-Free adhesive with ceramic brackets, phosphoric acid etch and primer the bond strengths can be greater than the clinically recommended values. To maintain greater mean bond strength, it is important to use phosphoric acid etch with or without a self-etch primer. According to Bishara et al there is around a 10 second/tooth time saving⁵³ with the use of self-etch primer without phosphoric acid etch, however, one will need to weigh the risk/benefit of decreased mean shear bond strength.

Finally, the use of a sealant material, Pro Seal L.E.D. in this study, has the possibility to provide shear bond strength greater than the clinically recommended values of 5.9 MPa and 7.8 MPa.¹¹ Pro Seal L.E.D. has been studied and shown to be more effective in protecting enamel, in comparison to brushing alone,⁴ and with the findings from this study a clinician can place Pro Seal L.E.D. after phosphoric acid etch and Assure Plus and be confident the shear bond strength is able to withstand the force of the oral cavity.

RECOMMENDATIONS

Future *in vitro* studies can investigate the effects of newer adhesives, primers and different orthodontic brackets. Brackets are not created equal. The difference in orthodontic brackets can be profound, relating to total surface area of the base that is in contact with enamel, the material of the bracket being used, the mesh of the base, and the gauge of the base. *In vivo* studies should be completed to identify if a moisture insensitive primer or a moisture resistant primer yields greater shear bond strength in the oral cavity. Additionally, mastication, parafunction, and heavy occlusal trauma can identify brackets and bonding protocols that do not meet the clinically recommended shear bond values if early debond occurs.

CHAPTER 5: SUMMARY AND CONCLUSION

SUMMARY

The purpose of this study was to compare the in vitro shear bond strengths of brackets bonded with different bonding protocol with ceramic APCTM Flash-Free adhesive bracket compared with stainless-steel APCTM II Adhesive Coated bracket with phosphoric acid etch followed by a primer; the gold standard bonding protocol. The stainless-steel APCTM II Adhesive Coated bracket had significantly greater shear bond strength, 12.49 MPa, when compared to all bonding protocols with ceramic APCTM Flash-Free adhesive brackets except when using APCTM Flash-Free adhesive brackets with phosphoric acid followed by Assure Plus which yielded a shear bond strength of 10.46 MPa. Using self-etch primer with or without phosphoric acid etch can obtain a shear bond strength that falls above the minimum recommended values of 5.9 MPa and 7.8 MPa.

However, the use of Pro Seal L.E.D. must be used with phosphoric acid etch to obtain adequate shear bond strengths. When phosphoric acid etch followed by Assure Plus, followed by Pro Seal L.E.D. (10.46 MPa) the shear bond strength is similar to phosphoric acid etch followed by Assure Plus (9.92 MPa).

This cannot be said for teeth etched with self-etch primer followed by a sealant. According the results from this study, the shear bond strength of group 7 was 5.35 MPa, which is below the recommended force range provided by Reynolds.¹¹

There was a significant difference of ARI score of groups 2 (2.54), 4 (1.82), and 5 (2.25) which had more adhesive remaining on enamel versus group 7 (4.62) which had greater than 90% or all adhesive remaining on the bracket. Additionally, an ARI score of 1 and 3 has significantly greater bond strengths, 9.76 MPa and 10.40 MPa, respectively than an ARI score of 5 with a shear bond strength of 6.77 MPa.

CONCLUSIONS

Based on the results of this study, the following conclusions have been reached:

1. Stainless-steel APCTM II Coated adhesive brackets with phosphoric acid etch followed by a primer have a greater mean shear bond strength compared to ceramic APCTM Flash-Free adhesive brackets with phosphoric acid etch followed by a primer
2. Ceramic APCTM Flash-Free adhesive brackets with phosphoric acid etch followed by a primer or self-etch primer were identified to have a mean shear bond strength above the minimum clinical recommended values
3. Ceramic APCTM Flash-Free adhesive brackets with self-etch primer were identified to have a mean shear bond strength above the minimum clinical recommended values
4. Ceramic APCTM Flash-Free adhesive brackets with phosphoric acid etch followed by a primer followed by a sealant were identified to have a mean shear bond strength above the minimum clinical recommended values
5. Changing bonding protocol and materials can significantly affect the shear bond strength
6. Adhesive remaining on ceramic Flash-Free adhesive brackets can be scattered, however, majority of the time the adhesive remains on the tooth
7. Higher shear bond strength yields a lower adhesive remnant index and results in more cohesive resin failures

REFERENCES

1. Lee M, Kanavakis G. Comparison of shear bond strength and bonding time of a novel flash-free bonding system. *Angle Orthod.* 2016;86(2):265-270. doi:10.2319/011715-37.1
2. Foersch M, Schuster C, Rahimi RK, Wehrbein H, Jacobs C. A new flash-free orthodontic adhesive system: A first clinical and stereomicroscopic study. *Angle Orthod.* 2016;86(2):260-264. doi:10.2319/050415-302.1
3. Cacciafesta V, Sfondrini MF, De Angelis M, Scribante A, Klersy C. Effect of water and saliva contamination on shear bond strength of brackets bonded with conventional, hydrophilic, and self-etching primers. *Am J Orthod Dentofac Orthop.* 2003;123(6):633-640. doi:10.1016/S0889-5406(03)00198-7
4. Pithon MM, Santos M de J, Souza CA de, et al. Effectiveness of fluoride sealant in the prevention of carious lesions around orthodontic brackets: an OCT evaluation. *Dental Press J Orthod.* 2015;20(6):37-42. doi:10.1590/2177-6709.20.6.037-042.oar
5. Newman G V. Adhesion and orthodontic plastic attachments. *Am J Orthod.* 1969;56:573-588. doi:10.1016/0002-9416(69)90193-6
6. Jacobsohn PH, Kantor ML, Pihlstrom BL. Beginnings of the dental composite revolution. *J Am Dent Assoc.* 2013;144(2):138-142.
<https://liverpool.idm.oclc.org/login?url=http://search.ebscohost.com/login.aspx?direct=true&db=ddh&AN=85341781&site=ehost-live&scope=site>.
7. Greenlaw R, Way D, Kalil G. In Vitro evaluation of visible light-cured resin system used in bonding. *Am J Orthod.* 1989;96:214-220.
8. M. A. Tavas DCW. Bonding of Orthodontic Brackets by Transillumination of a Light Activated Composite: an In Vitro Study. *Br J Orthod.* 1979;6:207-208.
doi:10.1177/0192513X12437708
9. Smith R, Shivapuja P. Evaluatin of dual cement resins. *Am J Orthod.* 1993;103:448-451.
10. Hocevar RA. Direct Bonding Update. *J Clin Orthod.* 1979;March:172-175.
doi:10.1177/0192513X12437708
11. Reynolds IR. A Review of Direct Orthodontic Bonding. *Br J Orthod.* 2(3):171-178.
doi:10.1177/0192513X12437708
12. Razavi M. Featured Articles First Impressions of APCTM Flash-Free Adhesive : What To Do with the Free Time ? Evaluators Give APCTM Flash-Free Adhesive Rave Reviews. *Orthod Perspect Innova.* 2013;20(3).
13. Millett DT, McCabe JF. *Orthodontic Bonding with Glass Ionomer Cement-a Review.* Vol 18. European Orthodontic Society; 1996. <https://academic.oup.com/ejo/article-abstract/18/4/385/380021>.
14. Michael G. Buonocore, DMD MS. A Simple Method Increasing The Adhesion of Acrylic Filling Materials to Enamel Surfaces. *J Dent Res.* 1955;34(6):849-853.
doi:10.1002/2016WR019535.Received
15. Ewoldsen N, Demke RS. A review of orthodontic cements and adhesives. *Am J Orthod*

- Dentofac Orthop.* 2001;120(1):45-48. doi:10.1067/mod.2001.117207
16. Giannini M, Makishi P, Almeida Ayres AP, et al. Self-Etch Adhesive System: A Literature Review. *Braz Dent J.* 2015;26(1):3-10. doi:10.1590/0103-6440201302442
 17. Fleming PS, Johal A, Pandis N. Self-etch primers and conventional acid-etch technique for orthodontic bonding: A systematic review and meta-analysis. *Am J Orthod Dentofac Orthop.* 2012;142(1):83-94. doi:10.1016/j.ajodo.2012.02.023
 18. Col L, Lindemuth JS. *Effect of Universal Testing Machine Crosshead Speed on the Shear Bond Strength and Bonding Failure Mode of Composite Resin to Enamel and Dentin.* Vol 165.; 2000. <https://academic.oup.com/milmed/article-abstract/165/10/742/4832282>.
 19. Mortazavi V, Fathi M, Ataei E, Khodaeian N, Askari N. Shear bond strengths and morphological evaluation of filled and unfilled adhesive interfaces to enamel and dentine. *Int J Dent.* 2012;2012. doi:10.1155/2012/858459
 20. Brennan J V, Ph D, Soo PP, James D. APC TM PLUS Adhesive Coated Appliances: A Bonding Study. *Orthod Perspect Vol XII.* 2005;1:1-3.
 21. Chang HS, Walsh LJ, Freer TJ. Enamel desmineralization during orthodontic treatment: Aetiology and prevention. *Aust Dent J.* 1997;42(5):322-327.
 22. Mosby-YearBk I. *The Art and Science of Operative Dentistry.* St. Louis; 1995.
 23. O'Reilly M, Featherstone J. Demineralization and remineralization around orthodontic appliances. *Am J Orthod Dentofac Orthop.* 1987;111:260-265.
 24. Underwood ML, Ralph Rawls H, Zimmerman Topeka BF, Antonio S. Clinical Evaluation of a Fluoride-Exchanging Resin as an Orthodontic Adhesive. *Am J Orthod Dentofac Orthop.* 1989;96(2):93-99.
 25. Van Palenstein Holderman WH, Matee MI, van der Hoeven J, Mikx F. Cariogenicity depends more on diet than on the prevailing mutal streptococcal species. *J Dent Res.* 1996;75:535-545.
 26. Mizrahi E. Enamel opacities in primary and high school pupils. *J Dent.* 1982;10:28-38.
 27. Gwinnett A, Ceen R. Plaque Distribution on bonded brackets: a scanning microscope study. *Am J Orthod.* 1979;75:667-677.
 28. Augusto Mendes Miguel J, Antonio Almeida M, Chevitarese O. Clinical comparison and a composite for orthodontic brackets between a glass ionomer cement direct bonding of. *Am J Orthod Dentofac Orthop.* 1995;107(5):484-487.
 29. Zachrisson B. Cause and prevention of injuries to teeth and supporting structures during orthodontic treatment. *Am J Orthod.* 1976;69:285-300.
 30. Schwaninger B, Vickers-Schwaninger N. Developing an effective oral hygiene program for the orthodontic patient: review, rationale, and recommendations. *Am J Orthod.* 1979;75:447-452.
 31. Boyd R, Murray P, Roberston P. effect on periodontal status of rotary electric toothbrushes vs. manual toothbrushes during periodontal maintenance. I. Clinical results. *Am J Orthod Dentofac Orthop.* 1996;109:466-472.
 32. Wilcoxon D, Ackerman R, Killoy W, Love J, Sakumura J, Tira D. The effectiveness of

- counterrotational-action power toothbrush on plaque control in orthodontic patients. *Am J Orthod Dentofac Orthop*. 1991;99:7-14.
33. White L. Efficacy of sonic toothbrush in reducing plaque and gingivitis in adolescent patients. *J Clin Dent*. 1996;30:85-90.
 34. Ho H, Niederman R. Effectiveness of Sonicare sonic toothbrush on reduction of plaque, gingivitis, probing pocket depth and subgingival bacteria in adolescent orthodontic patients. *J Clin Dent*. 1997;8:15-19.
 35. Mitchell L. Decalcification during orthodontic treatment with fixed appliances: An overview. *Br J Orthod*. 1992;19:199-205.
 36. Ceen R, Gwinnett A. White spot formation associated with sealants used in orthodontics. *Pediatr Dent*. 1981;3:174-178.
 37. Brant Z. Dr. Bjorn Zachrisson on iatrogenic damage in orthodontic treatment. *J Clin Orthod*. 1978:208-220.
 38. Joseph B, Rossouw P, Basson N. Some “sealants” seal: A scanning electron microscopy (SEM) investigation. *Eur J Orthod*. 1994;16:19-25.
 39. Chigira H, Koike T, Hasegawa T, Itoh K, Wakumoto S, Hyakawa T. effect of the self etching dentin primers on the bonding efficacy of dentine adhesive. *Dent Mater J*. 1989;8:86-92.
 40. Nishida K, Yamauchi J, Wada T, Hosoda H. Development of a new bonding system (abstract). *J Dent Res*. 1993;72:137.
 41. Bishara S, VonWald L, Laffoon J, Warren J. Effect of a self-etch primer/adhesive on the shear bond strength of orthodontic brackets. *Am J Orthod Dentofac Orthop*. 2001;119:621-624.
 42. Van Meerbeek B, De Munck J, Yoshida Y. Adhesion to enamel and dentin: Current status and future challenges. *Oper Dent*. 2003;28:215-235.
 43. Tay F, Pashley D. Aggressiveness of contemporary self-etching systems. I: Depth of penetration beyond dentin smear layers. *Dent Mater J*. 2001;17:296-308.
 44. Miller R. Laboratory and clinical evaluation of self-etching primer. *J Clin Orthod*. 2001;35:42-45.
 45. Garcia-Goday F. Bond strength of Prompt L-Pop to enamel and dentin, report to ESPE. *Univ Texas Heal Sci Cent*. 2001.
 46. Phillips R. *Science of Dental Material*.; 2002.
 47. Munshi BMS and AK. Laser vs Visible-Light Cured Composite Resin: An In Vitro Shear Bond Study. *J Clin Pediatr Dent*. 1995;19(2):121-125. doi:10.1177/0192513X12437708
 48. R. Van Noort, G.E. Cardew, I.C. Howard and SN. The Effect of Local Interfacial Geometry on the Measurement of the Tensile Bond Strength to Dentin. *J Dent Res*. 1991. doi:10.1159/000477440
 49. Warning N, Copyright C. Why Do Shear Bond Tests Pull Out Dentin? *A Vershuis, D Tantbirojn, WH Douglas*. 1997;76(6):1298-1307. doi:10.1177/0192513X12437708
 50. Reddy YG, Sharma R, Singh A, Agarwal V, Agrawal V, Saurab C. The shear bond

- strengths of metal and ceramic brackets: An in-vitro comparative study. *J Clin Diagnostic Res.* 2013;7(7):1495-1497. doi:10.7860/JCDR/2013/5435.3172
51. Sharma S, Singh G, Singh A, Tandon P, Nagar A. A comparison of shear bond strength of orthodontic brackets bonded with four different orthodontic adhesives. *J Orthod Sci.* 2014;3(2):29-33. doi:10.4103/2278-0203.132892
 52. Ansari MY, Agarwal DK, Gupta A, Bhattacharya P, Ansar J, Bhandari R. Shear bond strength of ceramic brackets with different base designs: Comparative in-vitro study. *J Clin Diagnostic Res.* 2016;10(11):ZC64-ZC68. doi:10.7860/JCDR/2016/20624.8910
 53. Bishara SE, Oonsombat C, Soliman MMA, Warren JJ, Laffoon JF, Ajlouni R. Comparison of bonding time and shear bond strength between a conventional and a new integrated bonding system. *Angle Orthod.* 2005;75(2):237-242. doi:10.1043/0003-3219(2005)075<0233:COBTAS>2.0.CO;2
 54. Bishara SE, Ortho D, Ajlouni R, Laffoon J, Warren J. *Effects of Modifying the Adhesive Composition on the Bond Strength of Orthodontic Brackets.* Vol 72.; 2002.
 55. Signorelli MD, Kao E, Ngan PW, Gladwin MA. Comparison of bond strength between orthodontic brackets bonded with halogen and plasma arc curing lights: An in-vitro and in-vivo study. *Am J Orthod Dentofac Orthop.* 2006;129(2):277-282. doi:10.1016/j.ajodo.2004.07.043
 56. Mirzakouchaki B, Kimyai S, Hydari M, Shahrbaaf S, Mirzakouchaki-Boroujeni P. Effect of self-etching primer/adhesive and conventional bonding on the shear bond strength in metallic and ceramic brackets. *Med Oral Patol Oral Cir Bucal.* 2012;17(1):164-170. doi:10.4317/medoral.17024
 57. Artun JB. Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. *Am J Orthod.* 1984;85:333-340.
 58. Cehreli SB, Polat-Ozsoy O, Sar C, Cubukcu HE, Cehreli ZC. A comparative study of qualitative and quantitative methods for the assessment of adhesive remnant after bracket debonding. *Eur J Orthod.* 2012;34(2):188-192. doi:10.1093/ejo/cjq191
 59. Vicente A, Bravo LA. Shear bond strength of precoated and uncoated brackets using a self-etching primer: An in vitro study. *Angle Orthod.* 2007;77(3):524-527. doi:10.2319/0003-3219(2007)077[0524:SBSOPA]2.0.CO;2
 60. Kaur S, Singh R, Soni S, Garg V, Kaur M. Esthetic orthodontic appliances – A review. *Ann Geriatr Educ Med Sci.* 2018;5(1):11-14. doi:10.18231/2348-7240.2018.0003
 61. Jena AK, Duggal R, Mehrotra AK. Physical properties and clinical characteristics of ceramic brackets: A comprehensive review. *Trends Biomater Artif Organs.* 2007;20(2):123-138.
 62. Brown D. Orthodontic Materials Update. *Br J Orthod.* 2014;16(2):127-131. doi:10.1179/bjo.16.2.127
 63. Eliades T, Katsavrias E, Eliades G. Moisture-insensitive adhesives: Reactivity with water and bond strength to wet and saliva-contaminated enamel. *Eur J Orthod.* 2002;24(1):35-42. doi:10.1093/ejo/24.1.35
 64. Schaneveldt S, Foley TF. Bond strength comparison of moisture-insensitive primers. *Am J*

Orthod Dentofac Orthop. 2002;122(3):267-273. doi:10.1067/mod.2002.126594

65. Grünheid T, Sudit GN, Larson BE. Debonding and adhesive remnant cleanup: An in vitro comparison of bond quality, adhesive remnant cleanup, and orthodontic acceptance of a flash-free product. *Eur J Orthod.* 2015;37(5):497-502. doi:10.1093/ejo/cju080

APPENDIX

DATA RESULTS

Group	Tooth #	Shear Force (Newtons)	Shear bond Strength (MPa)	ARI Score
1	1	117.23	10.81	4
1	2	126.48	11.67	3
1	3	156.93	14.48	4
1	4	178.53	16.47	3
1	6	139.03	12.83	0
1	7	134.41	12.40	5
1	8	110.30	10.18	1
1	9	122.45	11.30	4
1	10	181.15	12.31	2
1	11	145.36	13.41	4
1	12	131.16	12.10	3
1	13	128.67	11.87	3
1	14	153.06	14.12	3
1	15	120.32	11.10	3
	average	138.94	12.49	3
2	16	117.63	8.00	5
2	17	120.00	8.16	5
2	18	165.71	11.27	1
2	19	172.36	11.72	1
2	20	129.59	8.81	5
2	21	92.46	6.29	1
2	22	107.72	7.32	1
2	23	131.25	8.92	1
2	24	135.65	9.22	4
2	25	95.66	6.50	4
2	26	142.94	9.72	1
2	27	132.27	8.99	3
2	28	182.50	12.41	1
2	29	125.92	8.56	1
2	30	139.01	9.45	4
	average	132.71	9.02	2.54
3	31	124.95	8.49	4
3	32	114.85	7.81	5

3	33	119.56	8.13	3
3	36	93.21	6.34	2
3	37	163.08	11.09	4
3	38	131.49	8.94	5
3	39	93.30	6.34	1
3	40	96.50	6.56	4
3	41	110.48	7.51	2
3	42	122.12	8.30	1
3	43	35.81	2.43	5
3	44	109.59	7.45	3
3	45	122.09	8.3	4
3	46	106.06	7.21	4
3	47	103.26	7.02	2
	average	109.76	7.45	3.27
4	46	136.10	9.25	2
4	47	135.24	9.19	1
4	48	132.74	9.02	3
4	49	110.30	7.50	3
4	51	154.53	10.51	1
4	52	140.15	9.53	0
4	53	135.15	9.19	1
4	54	148.45	10.09	3
4	55	144.15	9.80	3
4	56	157.21	10.69	1
4	57	129.90	8.83	0
4	58	132.54	9.01	2
4	59	143.42	9.75	3
4	60	132.83	9.03	2
4	61	148.87	10.12	3
	average	138.77	9.42	1.82
5	61	161.41	10.97	1
5	62	135.86	9.24	3
5	63	170.19	11.57	3
5	64	164.00	11.15	4
5	66	151.14	10.27	3
5	67	134.04	9.11	3
5	68	167.12	11.36	3
5	69	155.65	10.58	1
5	70	144.44	9.82	3
5	71	169.74	11.54	0
5	72	146.32	9.95	2

5	73	147.29	10.01	0
5	74	152.98	10.4	3
5	75	154.60	10.51	3
5	76	153.28	10.42	2
	average	153.87	10.46	2.25
6	76	149.85	10.19	3
6	77	133.59	9.08	1
6	78	170.34	11.58	3
6	79	154.35	10.49	4
6	80	87.35	5.94	4
6	81	150.24	10.21	1
6	82	140.66	9.56	0
6	83	172.81	11.75	3
6	84	166.65	11.33	0
6	85	145.72	9.91	5
6	86	189.07	12.85	1
6	87	155.62	10.58	3
6	88	81.10	5.51	0
6	89	152.98	10.4	4
6	90	138.57	9.42	3
	average	145.93	9.92	2.31
7	91	86.91	5.91	4
7	92	83.21	5.66	4
7	93	95.10	6.46	5
7	94	79.94	5.43	4
7	95	81.74	5.56	5
7	96	65.93	4.48	5
7	97	39.80	2.71	5
7	98	77.59	5.27	5
7	99	71.19	4.84	5
7	100	66.10	4.49	4
7	101	86.20	5.86	5
7	102	90.08	6.12	4
7	103	99.00	6.73	5
7	104	82.08	5.58	5
7	105	75.02	5.1	4
	average	78.66	5.35	4.62