2007

The Effect of Pre-Cure Bracket Movement on the Shear Bond Strength of Metal Brackets

Thomas Luther Roberts IV
Virginia Commonwealth University

THE EFFECT OF PRE-CURE BRACKET MOVEMENT ON THE SHEAR BOND STRENGTH OF METAL BRACKETS

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

By

T. LUKE ROBERTS, IV
B.S., Davidson College, 2000
D.M.D., University of Pennsylvania, 2005

Director: STEVEN J. LINDAUER, D.M.D., M.D.SC.
PROFESSOR AND CHAIR, DEPARTMENT OF ORTHODONTICS

Virginia Commonwealth University
Richmond, Virginia
June 2007

Acknowledgment

The author wishes to thank several people. I would like to thank my wife, Beth, for her love, support and patience during the past six years of my dental and orthodontic training. She has also been a great help in editing this thesis. I would like to thank my parents for their love and support. I would like to thank Dr. Peter Moon for his instruction and for the use of his lab, as well as Brendan Smith and Jeff Moon for their hours spent in the lab. I would also like to thank Dr. Steven Lindauer and Dr. Eser Tüfekçi for their direction and their valuable time in helping me with this project. Last but not least, I would like to thank 3M Unitek for donating all brackets and adhesives used in this study.

Table of Contents

List of Tables

List of Figures

Abstract

THE EFFECT OF PRE-CURE BRACKET MOVEMENT ON THE SHEAR BOND STRENGTH OF METAL BRACKETS

By T. Luke Roberts, IV, D.M.D.

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Dentistry at Virginia Commonwealth University.

Virginia Commonwealth University, 2007

Major Director: Steven J. Lindauer, D.M.D., M.D.Sc., Professor and Chair, Department of Orthodontics

The effect on shear bond strength of bracket movement after seating the brackets and before light curing has not been reported. The purpose of this study was to determine the effect of linear and rotational pre-cure bracket movement on the shear bond strength of orthodontic brackets. 100 extracted human maxillary premolars were divided into 5 groups of 20 teeth each. The control group was bonded with no pre-cure bracket movement, and test groups were bonded with pre-cure bracket movement of 2 mm, 4 mm, 45˚ or 180˚. Debonding force was measured with an Instron universal testing machine. Results were analyzed by ANOVA. Weibull survival analysis was used to determine the force required to produce a 5% bracket failure rate. Differences in the Adhesive Remnant Index (ARI) were analyzed by chi-square. No significant differences between groups were found for the mean shear bond strength or Weibull estimates. ARI scores differed significantly.

Introduction

Since the introduction of direct bonding by Buonocore[1] in 1955, dentists have been searching for ways to optimize their bonding procedures. Direct bonding of orthodontic attachments to the enamel surface has been practiced since the mid 1960's.[2] Although direct bonding greatly improves the comfort, convenience, hygiene, and esthetics of orthodontics, it also has the disadvantage of frequent bond failures.[3] When using conventional two-step etching and priming systems, bond failure rates for metal brackets range from 2.5% to 14.8% after one year of treatment.[4,5] Excessive bond failures may increase the length of treatment as well as the doctor's chairside time, making the overall treatment less efficient.[3] To reduce unwanted bond failures, orthodontists have worked to improve materials and techniques for bracket bonding procedures.

In some orthodontic practices, tooth preparation and initial bracket placement is performed by an orthodontic assistant with refinement of bracket position then performed by the orthodontist prior to light curing. The 2005 JCO Orthodontic Practice Study[6] found that 10.6% of practicing orthodontists routinely delegate initial placement of brackets to an assistant. This enables orthodontists to use their time more efficiently by coming to the patient to adjust the bracket positions once initial tooth preparation and bracket positioning is achieved. The final adjustment of bracket position by the orthodontist can range from minor to major depending on the accuracy of initial placement. While the effect of this bracket movement on shear bond strength has not been studied in detail, many other aspects of the bonding procedure have been examined.

In the time period between preparation of the enamel surface and bracket placement, blood, saliva, and water contamination have been shown to significantly decrease the shear bond strength of conventional two-step bonding systems.[7-11] In a recent study by Oztoprak et al.,[7] blood and saliva contamination after priming reduced the average shear bond strength from 15.28 MPa to 3.08 MPa and 3.79 MPa, respectively. These differences were both statistically and clinically significant, as the shear bond strength was reduced below the acceptable levels of 6 to 8 MPa.[12-14] Cacciafesta et al.[8] also found a statistically and clinically significant decrease in bond strength for teeth contaminated with blood at any point in the bonding process after the etching of the enamel. Water contamination of the etched enamel can also negatively affect shear bond strength. Cacciafesta et al.[9] found that when using a conventional primer, water contamination at any point after etching the enamel and before bracket placement significantly reduced the bond strength to insufficient levels.[9] Therefore, to maximize the efficiency of orthodontic treatment by reducing bond failures, each member of the orthodontic team must be careful to prevent enamel contamination during the bonding processs.

Delayed bracket placement after the teeth have been etched and primed may also be a problem in orthodontic bonding. 3M Unitek, in their product information for Transbond™ Plus Self-Etching Primer (SEP),[15] states that after application of the SEP, bracket placement can be delayed for up to 2 minutes. If bracket placement is delayed for more than 2 minutes, another application of SEP is recommended. However, a recent study by Arnold et al.[16] showed that, when using a self-etching primer, a delay in placement of brackets for 10 minutes after primer placement did not significantly affect the bond strength. Therefore, it seems that more research is needed to determine whether delayed bracket placement should be a concern for assistants and orthodontists during bonding.

Additionally, delayed light exposure can be a problem if the assistant places the brackets and then has to wait for extended periods of time for the orthodontist to come to the chair for the adjustment of bracket positions prior to light curing. Komori et al.[17] tested the effect of delayed light exposure on light cured composite resin and found significant decreases in tensile strength when light exposure was delayed more than five minutes after bracket placement, with a maximum decrease of 81% at 20 minutes. Shear bond strength was also significantly decreased as a result of delayed light exposure, but to a lesser degree than tensile strength. It took 40 minutes of delayed light exposure to significantly decrease the shear bond strength. However, even after 40 minutes of delayed light exposure, all shear bond strengths exceeded clinically acceptable levels. Therefore, loss of tensile strength appears to be more of a concern than loss of shear bond strength due to delayed light exposure.

The adhesive thickness between the bracket base and the enamel surface influences shear bond strength. Both the pressure used to seat the bracket and the viscosity of the composite resin are factors affecting the adhesive thickness. In 1993, McAlarney and Brenn[18] noted at that time that a consistent yet minimum resin thickness was believed to be necessary for maximum bond strength. However, in 2005 Arici et al.[19] found that the shear bond strength actually increased as the adhesive thickness increased from 0.0 to 0.5 mm for light cured composite resin. Interestingly, they also found that the tensile strength decreased as adhesive thickness increased. This suggests that complete seating of brackets may favor a higher tensile strength, while sacrificing maximum shear bond strength. Årtun and Zachrisson[20] found that there was an ideal viscosity at which exact bracket positioning could be achieved without subsequent drifting out of position. This resistance to drift is especially important when an assistant places the brackets and may have to wait several minutes before the orthodontist is available to perform the final bracket positioning, or when an orthodontist positions multiple brackets before light curing.

Another factor that may affect shear bond strength is the amount of bracket manipulation that takes place after the bracket is seated and before light curing of the adhesive. Murfitt et al.[21] found that more than three minor adjustments did not affect the failure rate of brackets bonded with a conventional two-step bonding system, but almost doubled the failure rate of brackets bonded with self-etching primer from 7.8% to 15.3%. While their study did not quantify or control the type or degree of pre-cure bracket movement that occurred, it did record the number of adjustments prior to light curing and relate this to shear bond strength. Other authors have suggested that pre-cure bracket movement could have an effect on bond strength. Årtun and Zachrisson[20] found that a chemically cured adhesive began to change consistency in the last 15 seconds before it had set completely and warned that any manipulation of bracket position during this period would result in fracture lines in the adhesive, causing the bracket to come loose after a short period of time. Additionally, Oztoprak et al.[7] noted that with the SmartBond® adhesive system, the clinician had 3 to 5 minutes to adjust the placement of the bracket before the adhesive started to set. 3M Unitek claims[22] that once their brackets have been seated and the adhesive squeezed out, further bracket movement may result in incomplete adhesive coverage under the bracket and may result in bond failure. Therefore, they recommend removing the bracket, applying additional adhesive, and proceeding with bonding if movement is required after seating. The effect of specific pre-cure bracket movements on the shear bond strength of orthodontic appliances has never been reported. However, it seems reasonable that initial bracket placement should be as close as possible to the ideal position to avoid the need for large adjustments of bracket position that could affect bond strength.

The aim of this study was to determine whether movement of the bracket along the enamel surface, after seating and before light curing, affected the shear bond strength, and if there was any permissible amount of bracket movement that could occur before the bond strength was significantly diminished. This study evaluated both linear and rotational movements to determine their effect on bond strength. The null hypothesis was that linear and rotational pre-cure bracket movements have no effect on the shear bond strength of metal brackets bonded with a conventional two-step bonding system.

Materials and Methods

Teeth

100 extracted human maxillary premolar teeth with intact buccal surfaces were collected to complete this study. Teeth were stored in a solution of 0.1% (wt/vol) thymol (Alfa Aesar, Ward Hill, MA) from the time of collection to the time of bonding. They were mounted in 2.54 cm round phenolic rings (Buehler, Lake Bluff, Illinois) using acrylic resin.

Brackets and Bonding Materials

All brackets and bonding materials were provided by 3M Unitek, Monrovia, CA. The brackets used were APC II Victory Series metal brackets with a bracket base area of 0.096129 cm^2 as reported by the manufacturer. The etchant was 35% phosphoric acid Transbond XT Etching Gel. The primer was Transbond Moisture Insensitive Primer (MIP).

Bonding Procedures

The teeth were pumiced for 5 seconds, rinsed for 10 seconds, air dried, etched for 15 seconds, rinsed for 15 seconds, air dried, primed for 3 seconds, air dispersed, and then brackets were placed as noted in Table 1. Upon placing each bracket, a measured 150 g force (Correx Force Gauge, Haag-Streit, Bern, Switzerland) was used to initially seat the brackets. This was enough force to cause the composite to be gently expressed from under the bracket. Then, within 30 seconds, each bracket was moved to its ideal position and reseated with a measured 300 g force. This force was sufficient to fully seat the brackets on the enamel surface. Flash was carefully removed and the brackets were light cured with a calibrated plasma arc curing light (OrthoLite, 3M Unitek, Monrovia, CA) for 3 seconds mesial, and 3 seconds distal as recommended by the manufacturer. All bonding was performed by a single researcher (TLR).

Groups Tested

The teeth were divided into 5 groups of 20 teeth each as summarized in Table 1. Brackets were moved along the tooth surface from their initial position to the final ideal position according to Table 1. Thus, in the treatment groups, the initial placement of the bracket differed from the ideal bracket position by the distance or degree of rotation noted. The control group was bonded ideally with no pre-cure bracket movement, though brackets were subjected to the same bracket seating protocol as the treatment groups.

Table 1: Groups Tested

	Pre-Cure Bracket Movement	N
Group 1	0 mm, 0˚	20
Group 2	2mm occlusogingival	20
Group 3	4mm occlusogingival	20
Group 4	45˚ counterclockwise rotational	20
Group 5	180˚ counterclockwise rotational	20

Debonding Procedure

To assure that the debonding technician was blinded as to which bonding method was used for each tooth, the acrylic mounting rings were coded according to group and sample number. A mounting jig was used to align each specimen so that the bracket base paralleled the direction of the force. The flat metal debonding rod was positioned at the bracket-tooth interface, creating a shear force in the occlusogingival direction, and the brackets were debonded in random order using an Instron universal testing machine (Instron Corp., Norwood, MA) with a cross-head speed of 0.5mm/min. The weight, in pounds (lbs), required to debond each bracket was recorded. From this raw data, pounds per cm^2 were converted to megapascals according to the following formula:

$$(\text{lbs} * (0.45359237\ \text{lbs/kg}) / 0.096129\ \text{cm}^2) \times 0.0980665 = \text{MPa}$$

Adhesive Remnant Index

The mode of bond failure was determined using the Adhesive Remnant Index (ARI). The ARI was scored using a 10x binocular microscope as follows:

0: No composite remaining on the tooth surface

1: Less than 50% of the composite remaining on the tooth surface

2: More than 50% of the composite remaining on the tooth surface

3: All of the composite remaining on the tooth surface, with a distinct impression of the bracket mesh left in the composite.

Statistics

Average debonding forces among the groups were compared using one-way ANOVA. Significance was declared at alpha < 0.05. For each group, the force necessary to debond 5% of the brackets was estimated using a Weibull survival analysis. The ARI scores were compared using a chi-square analysis to determine if there was a significant difference in mode of bond failure among groups. All analyses were performed using JMP software, Version 6.0.3 (SAS Institute, Inc., Cary, NC).

Results

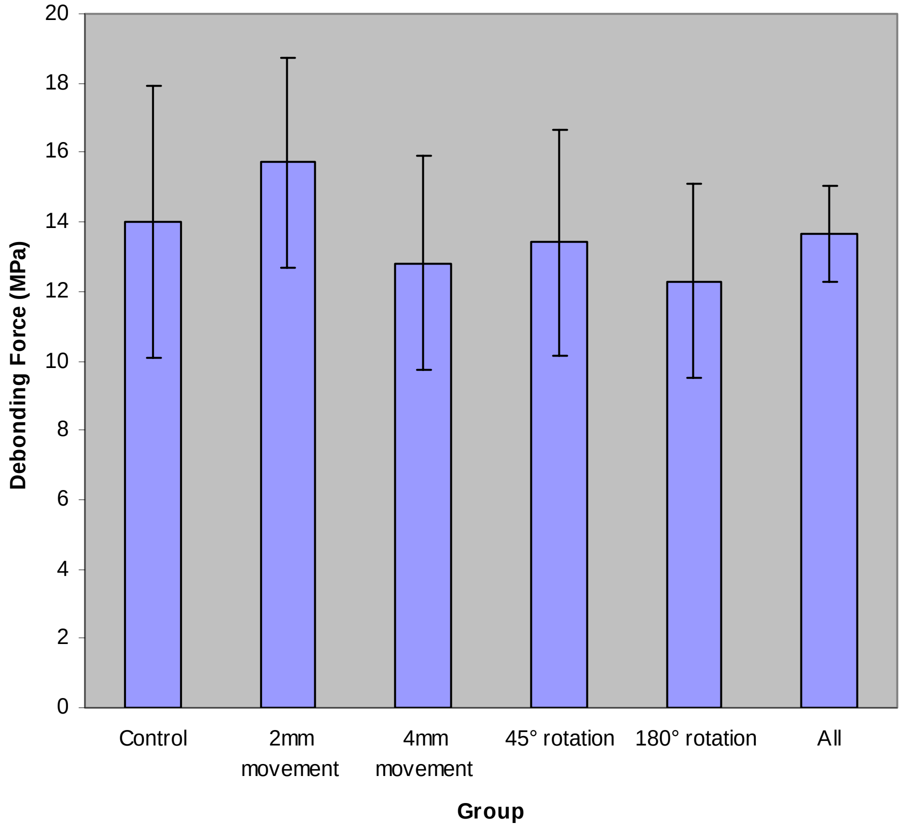
Average debonding forces are compared among the five groups in Table 2 and Fig. 1. The mean force necessary to debond the brackets ranged from 12.30 MPa for the 180˚ rotation group to 15.72 MPa for the 2 mm movement group and was not significantly different between the groups (p= 0.57). All groups exceeded clinically acceptable mean bond strengths of 6 to 8 MPa.[12-14] The average shear bond strength for all groups was 13.65 MPa.

Table 2: Debonding Force (MPa) in the five groups

	Debond Force (MPa)				
Group	N	Mean	SD	95% Confidence Interval	
Control	20	14.01	8.41	10.08	17.95
2mm movement	20	15.72	6.45	12.70	18.74
4mm movement	20	12.82	6.55	9.76	15.89
45° rotation	20	13.41	6.95	10.15	16.66
180° rotation	20	12.30	5.99	9.50	15.10
All	100	13.65	6.88	12.29	15.02

* Significance level *P* < .05.

Figure 1: Debonding Force (MPa) in the Five Groups



A Weibull parametric survival analysis was used to determine the force necessary to debond 5% of the brackets (representing a 5% bond failure rate, or the force level at which 95% of the brackets remained bonded to the teeth). The results are shown in Table 3. There were no significant differences between groups.

Table 3: Force Necessary to Debond 5% of all Brackets

	Debond Force (MPa)		
Group	Estimate	95% Confidence Interval	
Control	4.11	2.96	5.69
2mm movement	4.25	3.11	5.80
4mm movement	3.61	2.62	4.98
45° rotation	3.79	2.75	5.23
180° rotation	3.43	2.50	4.70

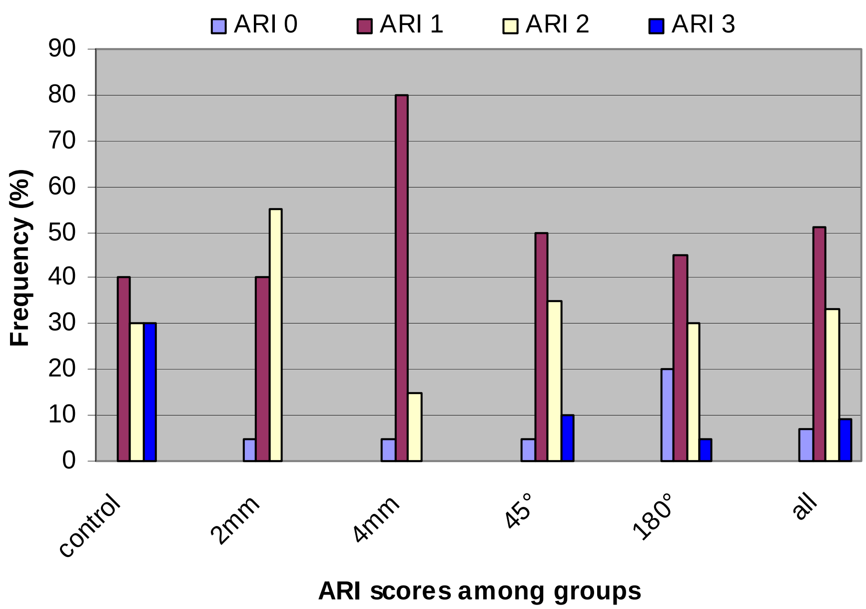
Note: Estimates are Weibull parametric survival estimates.

The ARI scores were compared across the five groups and the results are shown in Table 4. Distributions of ARI scores within each group are shown in Figure 2. The results of the chi-square comparisons indicated that there was a significant difference among the groups ($p = 0.0038$). The differences were as follows: while only 7% of all teeth debonded with an ARI score of 0, the highest percentage was in the 180° rotation group with 20% of these teeth in this category. Overall, 51% of all brackets were debonded with an ARI score of 1, but brackets with 4 mm of movement had a larger percentage in this category (80%). Overall, 33% of all the brackets debonded with an ARI score of 2, but brackets with 2 mm of movement had a higher percentage (55%) in this category. Whereas the overall percentage of teeth with an ARI score of 3 was 9%, the control group had a higher frequency (30%) in this category. The ARI profile of the 45° rotation group was not significantly different from the other groups, and its ARI profile closely matched the overall profile of all groups combined.

Table 4: ARI Scores (Percentages and Absolute Frequency (N))

ARI Score	Percentage (N) 0		1		2		3		All
Control	0	(0)	40	(8)	30	(6)	30	(6)	(20)
2mm movement	5	(1)	40	(8)	55	(11)	0	(0)	(20)
4mm movement	5	(1)	80	(16)	15	(3)	0	(0)	(20)
45° rotation	5	(1)	50	(10)	35	(7)	10	(2)	(20)
180° rotation	20	(4)	45	(9)	30	(6)	5	(1)	(20)
All	7	(7)	51	(51)	33	(33)	9	(9)	(100)

Figure 2: ARI Percentages by Group



Discussion

No significant differences were found in the mean shear bond strengths or the Weibull 95% survival estimates among the groups. Although mean shear bond strengths exceeded clinically acceptable bond strengths in all groups, the force required to debond 5% of the brackets in each group was below the minimum level considered clinically acceptable (6 MPa). This indicates that, with the bonding protocol used in this study, a bracket failure rate of greater than 5% would occur in all groups at clinical force levels. However, these values are consistent with other shear bond strength studies that have performed a Weibull analysis.[23,24]

Statistically significant differences were found in ARI scores among the groups. Overall, at least 70% of brackets in each group debonded with an ARI score of 1 or 2, which means that greater than 0% and less than 100% of composite was left on the tooth. Thus, the majority of bracket failures were cohesive. This is consistent with other shear bond strength studies, in which ARI scores of 0 and 3 (total adhesive failures) occurred in less than 30% of sites and ARI scores of 1 and 2 occurred in more than 60% of sites.[25-27] Significantly more brackets were debonded with an ARI score of 0 in the 180˚ rotational group (57% of all ARI scores of 0 occurred in this group), indicating that total adhesive failure between the composite and enamel was particularly common in this group. Interestingly, the 180˚ rotational group also had the lowest average mean shear bond strength (12.30 MPa) and lowest Weibull 95% survival estimate (3.43 MPa), although these values were not significantly different than those of other groups. Brackets bonded with 4 mm of pre-cure movement had a significantly higher number of debonds with an ARI score of 1, and ARI scores of 2 were found in significantly higher numbers in the 2 mm movement group. Both of these ARI scores signify cohesive failures, and with the subjectivity inherent in ARI scoring, the statistical differences found between the 2mm and 4mm groups should not be considered clinically meaningful. Also, only 9% of debonds had an ARI score of 3, indicating a complete adhesive failure between the bracket mesh and the composite; significantly more of these occurred in the control group than any other group. Finally, the group bonded with 45˚ rotational pre-cure bracket movement did not differ significantly from the other groups in any test that was performed.

The results of this study suggest that neither linear nor rotational pre-cure bracket movements affect the shear bond strength of metal brackets when bonded with a conventional two step bonding protocol. Therefore, the accuracy of initial bracket placement may not be as important a factor affecting shear bond strength as intuitively expected, as the brackets can be moved at least 4 mm or rotated at least 180˚ along the enamel surface while still maintaining mean shear bond strength values that exceed the recommended 6 to 8 MPa. This information is encouraging for orthodontists who routinely delegate initial bracket placement to chairside assistants. However, this study did not examine the effect of bracket movement after complete seating of the brackets or the effect of combining both linear and rotational movements. Both of these are common during clinical bracket placement. Exploring bracket movement after complete seating of the brackets and combined linear and rotational pre-cure bracket movement could be areas of future research.

Conclusions

- Shear bond strength of brackets was not significantly affected by pre-cure linear movements of up to 4 mm or rotational movements of up to 180˚.
- Force levels required to debond 5% of the brackets were not significantly affected by pre-cure linear movements of up to 4 mm or rotational movements of up to 180˚.
- Mode of bond failure (ARI) was significantly affected by pre-cure bracket movement.

List of References

1. Buonocore MG. A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces. *J Dent Res*. 1955;34:849-853.
2. Newman GV. Epoxy adhesives for orthodontic attachments: progress report. *Am J Orthod*. 1965;51:901-912.
3. Bishara SE, Laffoon JF, Vonwald L, Warren JJ. The effect of repeated bonding on the shear bond strength of different orthodontic adhesives. *Am J Orthod Dentofacial Orthop*. 2002;121:521-525.
4. Thiyagarajah S, Spary DJ, Rock WP. A clinical comparison of bracket bond failures in association with direct and indirect bonding. *J Orthod*. 2006;33:198-204.
5. House K, Ireland AJ, Sherriff M. An investigation into the use of a single component self-etching primer adhesive system for orthodontic bonding: a randomized controlled clinical trial. *J Orthod*. 2006;33:38-44
6. Keim RG Gottleib EL, Nelson AH, Vogels DS. 2005 JCO Orthodontic Practice Study. Part 1: trends. *J Clin Orthod*. 2005;39:641-650.
7. Oztoprak MO, Isik F, Sayinsu K, Arun T, Aydemir B. Effect of blood and saliva contamination on shear bond strength of brackets bonded with 4 adhesives. *Am J Orthod Dentofacial Orthop*. 2007;131:238-242.
8. Cacciafesta V, Sfondrini MF, Scribante A, De Angelis M, Klersy C. Effects of blood contamination on the shear bond strengths of conventional and hydrophilic primers. *Am J Orthod Dentofacial Orthop*. 2004;126:207-212.
9. 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 Dentofacial Orthop*. 2003;123:633-640.
10. Cacciafesta V, Sfondrini MF, Gatti S, Klersy C. Effect of water and saliva contamination on the shear bond strength of a new light-cured cyanoacrylate adhesive. *Prog Orthod*. 2007;8:100-111.
11. Zeppieri IL, Chung CH, Mante FK. Effect of saliva on shear bond strength of an orthodontic adhesive used with moisture-insensitive and self-etching primers. *Am J Orthod Dentofacial Orthop*. 2003;124:414-419.
12. Reynolds IR. A review of direct orthodontic bonding. *Br J Orthod*. 1975;2:171-178.
13. Øgaard B, Bishars SE, Duschner H. Enamel effects during bonding-debonding and treatment with fixed appliances. In: Graber TM, Eliades T, Athanasiou AE, eds. *Risk Management in Orthodontics: Experts' Guide to Malpractice*. Hanover Park, Ill: Quintessence; 2004:19-46.

14. Powers JM, Messersmith ML. Enamel etching and bond strength. In: Brantley WA, Eliades T, eds. *Orthodontic Materials: Scientific and Clinical Aspects*. Stuttgart, Germany: Stuttgart-Thieme; 2001:105-122.
15. 3M Unitek. Transbond™ Plus Self Etching Primer: Frequently Asked Questions. Available at: http://multimedia.mmm.com/mws/mediawebserver.dyn?6666660Zjcf6lVs6EVs666pb9COrrrrQ-. Accessed June 3, 2007.
16. Arnold RW, Combe EC, Warford JH Jr. Bonding of stainless steel brackets to enamel with a new self-etching primer. *Am J Orthod Dentofacial Orthop.* 2002;122:274-276.
17. Komori A, Ishikawa H. The effect of delayed light exposure on bond strength: light-cured resin-reinforced glass ionomer cement vs light-cured resin. *Am J Orthod Dentofacial Orthop*. 1999;116:139-145.
18. McAlarney ME, Brenn P. A modified direct technique versus conventional direct placement of brackets: in vitro bond strength comparison. *Am J Orthod Dentofacial Orthop*. 1993;104:575-583.
19. Arici S, Caniklioglu CM, Arici N, Ozer M, Oguz B. Adhesive thickness effects on the bond strength of a light-cured resin-modified glass ionomer cement. *Angle Orthod*. 2005;75:254-259.
20. Artun J, Zachrisson B. Improving the handling properties of a composite resin for direct bonding. *Am J Orthod*. 1982;81:269-276.
21. Murfitt PG, Quick AN, Swain MV, Herbison GP. A randomised clinical trial to investigate bond failure rates using a self-etching primer. *Eur J Orthod*. 2006;28:444-449.
22. 3M Unitek. APC™ Plus Adhesive Coated Appliance System: Frequently Asked Questions. Available at: http://multimedia.mmm.com/mws/mediawebserver.dyn?6666660Zjcf6lVs6EVs666rUZCOrrrrQ-. Accessed June 3, 2007.
23. Cal-Neto JP, Miguel JA, Zanella E. Effect of a self-etching primer on shear bond strength of adhesive precoated brackets in vivo. *Angle Orthod*. 2006;76:127-131.
24. Northrup RG, Berzins DW, Bradley TG, Schuckit W. Shear Bond Strength Comparison between Two Orthodontic Adhesives and Self-Ligating and Conventional Brackets. *Angle Orthod*. 2007;77:701–706.
25. Hildebrand NK, Raboud DW, Heo G, Nelson AE, Major PW. Argon laser vs conventional visible light-cured orthodontic bracket bonding: an in-vivo and in-vitro study. *Am J Orthod Dentofacial Orthop*. 2007;131:530-536.
26. Gronberg K, Rossouw PE, Miller BH, Buschang P. Distance and time effect on shear bond strength of brackets cured with a second-generation light-emitting diode unit. *Angle Orthod*. 2006;76:682-688.
27. Endo T, Yoshino S, Shinkai K, Ozoe R, Shimada M, Katoh Y, Shimooka S. Shear Bond Strength Differences of Types of Maxillary Deciduous and Permanent Teeth Used as Anchor Teeth. *Angle Orthod*. 2007;77:537–541.

Appendix (Raw Data)

Group and Sample	Debonding Force (lbs)	Debond Force (MPa)	Sample #
A1	79.00	36.55	1
A2	50.84	23.52	2
A3	34.40	15.91	3
A4	5.15	2.38	4
A5	12.20	5.64	5
A6	35.50	16.42	6
A7	24.75	11.45	7
A8	26.00	12.03	8
A9	9.00	4.16	9
A10	38.00	17.58	10
A11	40.25	18.62	11
A12	38.75	17.93	12
A13	16.50	7.63	13
A14	8.50	3.93	14
A15	7.50	3.47	15
A16	47.00	21.74	16
A17	24.75	11.45	17
A18	46.00	21.28	18
A19	30.00	13.88	19
A20	31.50	14.57	20
B1	26.25	12.14	21
B2	35.00	16.19	22
B3	48.00	22.21	23
B4	14.50	6.70	24
B5	16.50	7.63	25
B6	6.50	3.00	26
B7	47.00	21.74	27
B8	48.50	22.44	28
B9	42.50	19.66	29
B10	29.00	13.41	30
B11	50.00	23.13	31
B12	29.00	13.41	32
B13	35.00	16.19	33
B14	41.50	19.20	34
B15	26.25	12.14	35
B16	24.00	11.10	36

B17	63.00	29.15	37
B18	32.50	15.03	38
B19	23.00	10.64	39
B20	41.50	19.20	40
C1	33.00	15.27	41
C2	33.75	15.61	42
C3	14.25	6.59	43
C4	39.25	18.16	44
C5	32.00	14.80	45
C6	9.50	4.39	46
C7	14.25	6.59	47
C8	31.00	14.34	48
C9	65.00	30.07	49
C10	15.02	6.95	50
C11	17.00	7.86	51
C12	45.50	21.05	52
C13	36.50	16.88	53
C14	39.50	18.27	54
C15	13.00	6.01	55
C16	34.00	15.73	56
C17	22.50	10.41	57
C18	17.00	7.86	58
C19	31.25	14.46	59
C20	11.00	5.09	60
D1	24.25	11.22	61
D2	28.95	13.39	62
D3	45.00	20.82	63
D4	33.75	15.61	64
D5	21.00	9.71	65
D6	28.75	13.30	66
D7	13.75	6.36	67
D8	49.00	22.67	68
D9	62.00	28.68	69
D10	12.20	5.64	70
D11	12.50	5.78	71
D12	19.25	8.90	72
D13	17.50	8.09	73
D14	57.00	26.37	74
D15	16.00	7.40	75
D16	19.00	8.79	76
D17	23.00	10.64	77
D18	39.00	18.04	78

D19	18.03	8.34	79
D20	39.50	18.27	80
E1	29.50	13.65	81
E2	31.65	14.64	82
E3	44.25	20.47	83
E4	26.00	12.03	84
E5	16.25	7.51	85
E6	3.00	1.38	86
E7	49.50	22.90	87
E8	23.75	10.98	88
E9	15.00	6.94	89
E10	32.00	14.80	90
E11	41.50	19.20	91
E12	6.75	3.12	92
E13	35.00	16.19	93
E14	31.50	14.57	94
E15	21.50	9.94	95
E16	30.50	14.11	96
E17	19.25	8.90	97
E18	9.50	4.39	98
E19	20.25	9.37	99
E20	45.00	20.82	100

Vita

Thomas Luther Roberts, IV, was born in Charlottesville, VA on November 10, 1977. He graduated from Spartanburg High School, Spartanburg, SC in 1996. He received his Bachelor of Science degree from Davidson College, Davidson, NC in 2000. He graduated valedictorian of his dental school class at the University of Pennsylvania, Philadelphia, PA in 2005.