2008

Orthodontic Bracket Bond Strength Using Self-Etching Primer With or Without Pumice or Acid Etch Pretreatment

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

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February 19, 2008

Acknowledgment

There are so many people who played an important role in this project who I would like to thank. First, I would like to thank Dr. Steven J. Lindauer for mentoring me in every aspect of this project. I would also like to thank Dr. Bhavna Shroff, Dr. Vincent Sawicki and Dr. Eser Tüfekçi for their support and input throughout the course of this study. Much gratitude is also due to 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. In addition, I could not forget my parents, the best parents anyone can have, for their support, love, and patience during the past ten years in my journey of becoming an orthodontist. Last, but not least, I would like to thank 3M Unitek for donating all brackets and adhesives used in this study.

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Abstract

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By Ana Paula DeCastro, D.M.D.

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Major Director: Steven J. Lindauer, D.M.D., M.D.Sc.
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The purpose of this study was to compare the shear bond strength of orthodontic brackets to enamel in four bonding protocols: SEP without prior pumicing (None), Pre-etch and SEP without prior pumicing (Pre-etch), control: SEP with prior pumicing (Pumice), and Pre-etch and SEP with prior pumicing (Both). 80 extracted bovine incisors were randomly divided into 4 groups of 20, and brackets were bonded under the different experimental conditions. Debonding force was measured with an Instron universal testing machine. A two-way ANOVA comparing the four groups indicated that there was a significant difference in debonding force ($P = 0.001$). The SEP without prior pumicing group (17.69 ± 7.18 MPa) was statistically different from the SEP group with prior pumicing (25.82 ± 6.84 MPa). There was no statistical difference found among the other groups. Differences in the Adhesive Remnant Index (ARI) were analyzed by chi-square. ARI scores differed significantly ($P = 0.0048$).

Introduction

The development of bonding systems that eliminate steps without compromising bond strength and clinical reliability has been the aim of research for many years. Since the acid etch technique was introduced by Buonocore[1] in 1955, bonding to enamel has become widespread in multiple dental specialties. Conventional adhesive systems use 3 different agents: an enamel conditioner, a primer solution, and an adhesive resin.[2] Traditionally, teeth are prepared for orthodontic bonding by pumicing followed by the application of a conditioner and a priming agent. The conditioning agent is usually phosphoric acid which causes dissolution of interprismatic material in enamel, producing a roughened and porous surface for mechanical retention between the bracket adhesive and tooth.[3] After etching, the teeth are washed and dried creating high energy surfaces that can be wetted by the resin. Despite the fact that the acid-etching technique is useful, it is technique-sensitive and involves many steps. Moisture contamination is considered the most common reason for bond failure.[4]

Recently, Transbond™ Plus self-etching primer (3M Unitek, Monrovia, CA) was developed for use in orthodontics.[5] Self-etching primers (SEPs) consist of phosphoric acid and hydroxyethylmethacrylate (HEMA). Upon application, the phosphoric acid etches the surface of the tooth and the hydrophilic HEMA molecule penetrates into the deeper layers of the enamel. The acid does not need to be rinsed off as in the conventional systems because, after its penetration into the enamel, the acid is neutralized. The calcium ions that are dissolved by etching do not need to be rinsed either since, during the process, they are incorporated into the primer matrix.[6] Since it combines etchant and a primer into one solution, the use of SEP has the advantage of a faster and simplified application technique. The elimination of stages during bonding might translate into fewer procedural errors, minimizing technique sensitivity.[3]

Although using self-etching primers to bond brackets should decrease chair time, to date there appears to be no consensus on the attainable shear bond strength following their use.[7] Numerous *in vitro* studies have shown that some SEP systems exhibit lower bond strengths than the conventional phosphoric acid products. Bishara et al.[8] indicated that the use of SEP to bond orthodontic brackets to enamel resulted in significantly lower (P=0.004) bond strengths. Aljubouri et al.[9] in 2003 also found the mean shear bond strength of brackets bonded with SEP to be significantly less when compared to the conventional two-stage system *in vitro*. However, other investigators showed that SEP provides comparable bond strengths to those obtained with the conventional technique.[10-12] Furthermore, Buyukyilmaz et al.[13] and Bishara et al.[14] have shown Transbond™ SEP to produce significantly greater shear bond strength than that achieved by etching with 35% phosphoric acid. Due to the controversy caused by the different results of these studies regarding SEP, no real conclusion can be made regarding its bond strength when compared to the conventional two-stage system.

Bond failure rates using self-etching primers have also been investigated. Ireland et al.[6] investigated the bond failure rate *in vivo* of a SEP system over a 6 month period. The study produced weak evidence to suggest that bond failure with SEP was higher than that with the conventional two-stage system. However, the study was limited to 20 participants, and did not investigate whether age, gender, tooth position, or number of manipulations during bonding influenced the survival rate.[15] Murfitt et al.[15] conducted a similar study in 2006. Their study was a randomized clinical trial to investigate bond failure rates using Transbond™ self-etching primer when compared with a conventional two-step system. Thirty-nine patients were monitored during a 12-month period. The failure and survival rates of the brackets were determined based on age and gender of the patients, etching system used, operator, mode of failure, tooth position in the arch and number of manipulations prior to curing the adhesive. Statistical analysis showed that SEP had a significantly higher bond failure rate (11.2%) than the conventional etch system (3.9%; P=0.001). It has been suggested that bond failure rates below 10% are generally considered to be clinically acceptable.[16] Transbond™ self-etching primer may, therefore, be considered unacceptable.

Another concern with bonding in orthodontics is to minimize the enamel loss during debonding of brackets without compromising the bond strength.[8] Bishara et al.[17] reported that removal of adhesive remnants on the enamel surface after debonding results in a reduction of enamel of approximately 55.6 µm. Minimizing the amount of residual resin left adhering to the enamel surface should be the goal since it will minimize damage to the enamel during the clean-up procedure.[18] In 2003, Lamour et al.[12] conducted a study comparing teeth bonded using Transbond-Plus™ SEP with teeth bonded using the conventional 2-step system. The results of this *ex vivo* study suggested that the teeth bonded with the conventional 2-step system finished up with significantly more retained resin on the enamel surface after debonding than teeth bonded with Transbond-Plus™ SEP. This result is also in agreement with a study conducted by Cacciafesta et al.[19] in

2003. The fact that the conventional 2-step system leaves more retained resin on enamel following debonding means that iatrogenic damage to the enamel surface during clean-up is possible, making SEP a more desirable technique.[18]

In order to improve bond strengths, it is necessary to prepare the enamel surface by first removing the acquired organic pellicle.[20] When using SEP, the manufacturers currently recommend pumice prophylaxis. Burgess et al.[20] found that pumicing has a clinically and statistically significant effect on reducing clinical bond failure rates when self-etching primers are used. Lill et al.[21] conducted a split-mouth prospective clinical trial and also found strong evidence to suggest the need for pumice prophylaxis prior to SEP application. Their findings demonstrated significantly lower bond failure rates when pumicing was conducted. Lindauer et al.[22] showed that this stage can be safely omitted from the conventional acid-etch technique. The need for pumice prophylaxis when using self-etching primers may be due to the fact that SEP is more conservative and produces a smaller amount of demineralization and less penetration of adhesive into the enamel surface when compared with the conventional system.[3]

It would be advantageous to develop a bonding system in orthodontics that has lower bond failure rates than self-etching primer but still with a limited number of clinical steps. Van Landuyt et al.[23] reported that bond strength to enamel of Clearfil ™ SE Bond, a mild self-etching adhesive, significantly improved when prior etching with phosphoric acid was performed. Van Landuyt et al.[24] concluded that adding a preceding etching step to a mild SEP significantly improved the bond strength to enamel. A pumicing step was not conducted in either of these studies.

The aim of this study was to compare the shear bond strength of orthodontic brackets to enamel in four bonding protocols: SEP without prior pumicing (None), Pre-etch and SEP without prior pumicing (Pre-etch), control: SEP with prior pumicing (Pumice), and Pre-etch and SEP with prior pumicing (Both).

Materials and Methods

Eighty five fresh bovine incisors were collected and stored in distilled water. The criteria for tooth selection included intact buccal enamel, no cracks caused by the presence of the extraction forceps, and no other defects. Bovine teeth were used in this study because the enamel of bovine incisors has been shown to be histochemically similar to human enamel.[25] Each tooth was embedded in phenolic rings (Buehler Ltd, Lake Bluff, IL, USA) using cold cure acrylic covering the root surface up to the cementoenamel junction. The first block of 5 teeth was used in the study to standardize the evaluation process and the testing methodology on the testing machine (Instron, Canton, Mass) and to coordinate the process.

The remaining 80 teeth were randomly assigned using computer software to one of four groups according to bonding protocol: SEP without prior pumicing (None), Pre-etch and SEP without prior pumicing (Pre-etch), control: SEP with prior pumicing (Pumice), Pre-etch and SEP with prior pumicing (Both). For all groups, only maxillary central incisor adhesive pre-coated brackets (APC II Victory Twin Series-3M Unitek, Monrovia, CA) were used. The brackets were positioned in the center of the crown and firm pressure was applied. After excess adhesive removal, brackets of all groups were cured for 3 seconds from the mesial and 3 seconds from the distal using a plasma arc visible light-curing unit (Ortholite, 3M Unitek, Monrovia, CA). All experimental procedures were performed by a single operator and the brackets were bonded to the teeth according to one of the four protocols as follows:

SEP without prior pumicing (None)

Transbond^{TM} Plus self-etching primer (3M Unitek, Monrovia, CA) was scrubbed onto teeth surfaces for 5 seconds with a standard microbrush. After the priming step, an oil and moisture-free air source was used to deliver a gentle burst of air for 1-2 seconds per tooth to dry the primer into a thin film.

Pre-etch and SEP without prior pumicing (Pre-etch)

Teeth were etched with 35% phosphoric acid for 15 seconds followed by rinsing with copious amounts of water and then dried with oil free compressed air until there was a frosty white appearance. Transbond^{TM} Plus self-etching primer (3M Unitek, Monrovia, CA) was then applied to the teeth according to the manufacturer's recommendation.

SEP with prior pumicing (Pumice)

The teeth were polished with nonfluoridated pumice in rubber prophylactic cups for 10 seconds each, and then rinsed with an air-water syringe. Subsequent bonding in this group was identical to the SEP without prior pumicing group

Pre-etch and SEP with prior pumicing (Both)

Enamel preparation and subsequent bonding in this group was identical to the Pre-etch and SEP without prior pumicing group, the only difference being a pumice step prior to pre-etch. The pumice step in this group was identical to the SEP with pumicing group.

After bonding, the teeth were stored in distilled water. The debonding procedure was performed 24 hours after the bonding procedure to allow comparison with other *in vitro* bond strength studies.[9] The phenolic rings were coded according to group and sample number to assure that the debonding technician was blinded to which bonding method was used for each tooth. A mounting jig was used to align the facial surface of the tooth to be perpendicular with the bottom of the mold. The brackets were debonded using an Instron universal testing machine (Instron Corp., Norwood, MA). The flat metal debonding rod was positioned at the bracket-tooth interface, creating a shear force in the occlusogingival direction. Brackets were broken off one at a time 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 square inch were converted to megapascals (MPa) according to the following formula using the bracket base area provided by the manufacturer:

$$(\text{lbs}/.0163 \text{ sq. in.}) \times .00689476 = \text{MPa}$$

After debonding, the teeth and brackets were examined under 10X magnification. Any adhesive remaining after bracket removal was assessed according to the modified adhesive remnant index (ARI) and scored with respect to the amount of resin material that adhered to the enamel surface.[26] The ARI scale had a range of 1 to 5 as follows:

1= all the composite remained on the tooth

2= more than 90% of the composite remained on the tooth

3= between 10-90% of the composite remained on the tooth

4= less than 10% of the composite remained on the tooth

5= no composite remained on the tooth

The mean shear bond strength and standard deviation for each test group were calculated and a two-way ANOVA was used to determine significant differences in bond strength related to pumicing and pre-etching. The Tukey's HSD, simultaneous 95% confidence intervals, was used to estimate the difference in debonding between the groups. Additionally, the groups were compared using a parametric Weibull analysis. The Adhesive Remnant Index (ARI) was recorded by three raters and reliability was assessed using the Kappa statistic. The ARI scores were compared using a chi-square analysis to determine if there were significant differences in mode of bond failure among groups. All analyses were performed using JMP software, Version 6.0.3 (SAS Institute, Inc., Cary, NC).

Results

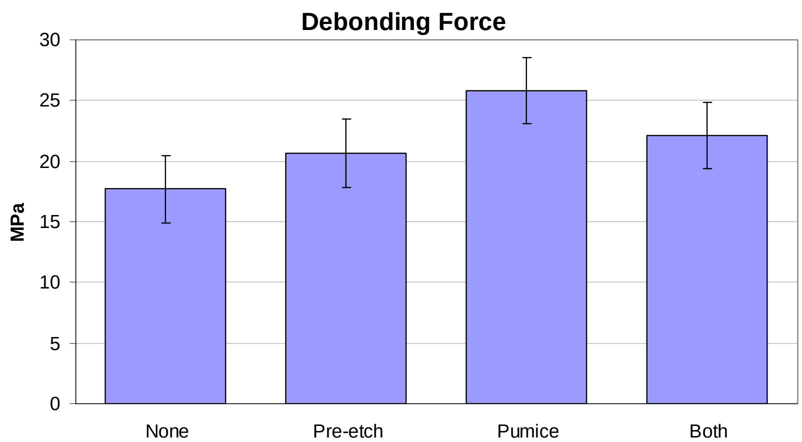
Average debonding forces are compared among the four groups in Table 1 and Fig. 1. One experimental unit in group 2 was lost because the bracket failed before the cross-head of the Instron testing machine contacted the sample. A two-way ANOVA comparing the four groups indicated that there was a significant difference among groups in debonding force (P = 0.001). The SEP without prior pumicing group (17.69 ± 7.18 MPa) was statistically different from the SEP group with prior pumicing (25.82 ± 6.84 MPa). There was no statistical difference found among the other groups. All groups exceeded clinically acceptable mean bond strengths of 6 to 8 MPa.[27] The average shear bond strength for all groups was 21.55 MPa.

Table 1: Debonding Force in the four groups

	Group			Debonding Force (MPa)			
	Pumice	Pre-etch	N	Mean	Std. Dev	95% CI	
None	N	N	20	17.69	7.18	14.94	20.44
Pre-etch	N	Y	19	20.61	5.45	17.79	23.43
Pumice	Y	N	20	25.82*	6.84	23.07	28.56
Both	Y	Y	20	22.09	4.85	19.34	24.83

* Significantly greater bond strength than None group; $P < .05$.

Figure 1: Debonding Force in the Four Groups



The Weibull parametric survival analysis was used to determine the force necessary to debond 5% of the brackets (representing 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 2.

Table 2: Force Necessary to Debond 5% of all Brackets

	Group		Debonding Force (MPa)		
	Pumice	Pre-etch	Estimate	95% CI	
None	N	N	9.92	8.19	12.00
Pre-etch	N	Y	10.53	8.78	12.64
Pumice	Y	N	13.49	11.17	16.28
Both	Y	Y	11.11	9.28	13.30

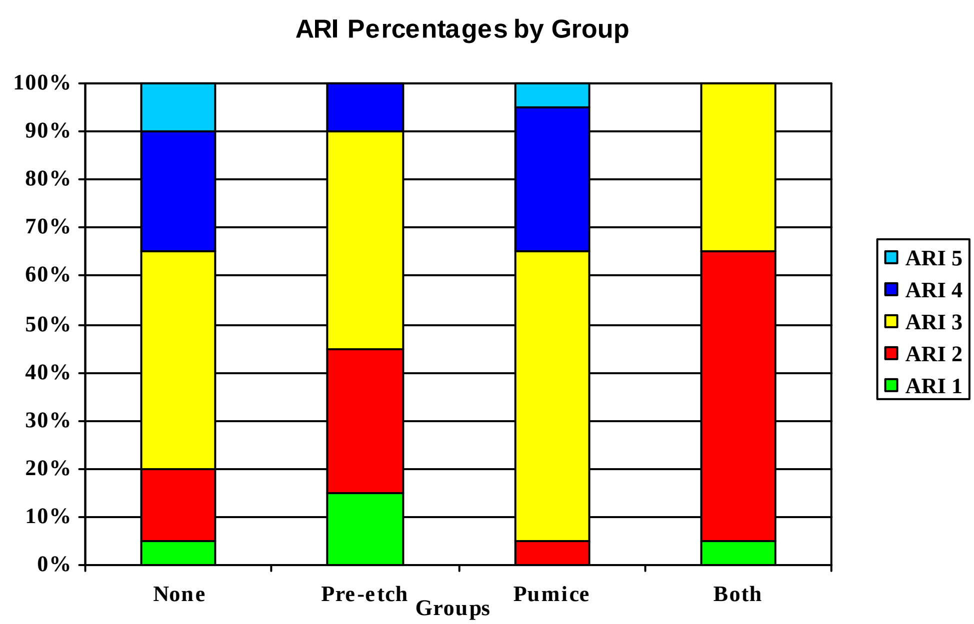
The Adhesive Remnant Index (ARI) was recorded by three raters. There was a moderate agreement between raters 1 and 2 (Kappa = 0.51), substantial agreement between raters 1 and 3 (Kappa=0.65), and an almost perfect agreement between raters 2 and 3 (Kappa = 0.84).[28] In no cases were there disagreements beyond 1 unit. The ARI used in the final analysis was the "majority rule" value.

Distributions of ARI scores within each group are shown in Figure 2 and Table 3. There was a significant difference between the groups (P = 0.0048). In the SEP with prior pumicing group there were fewer ARI scores of 2 observed: only 5%. In the Pre-etch and SEP with prior pumicing group, there were no ARI scores of 4 or 5.

Table 3: ARI values in each Group

	Group		ARI				
	Pumice	Pre-etch	1	2	3	4	5
None	N	N	1	3	9	5	2
Pre-etch	N	Y	3	6	9	2	0
Pumice	Y	N	0	1	12	6	1
Both	Y	Y	1	12	7	0	0

Figure 2: ARI Percentages by Group



Discussion

The direct bonding of orthodontic brackets has greatly improved the practice of orthodontics. The development of simplified bonding systems that eliminate steps without compromising reliability has been the focus of recent research[12] and self-etching primers were introduced for orthodontic purposes. Although using self-etching primers to bond brackets should theoretically be more efficient, there remains a great deal of controversy related to their use and clinical performance.[7]

In this study, four different bonding protocols for self-etching primers were compared. The bond strength recorded in the SEP without prior pumicing group (17.69 ± 7.18 MPa) was statistically different from the SEP with prior pumicing group (25.82 ± 6.84 MPa). There were no statistical differences found among the other groups. The Weibull analysis showed that the force required to debond 5% of the brackets in each group was above the minimum level considered to be clinically acceptable. According to Reynolds,[27] a minimum bond strength of 5.9 to 7.8 MPa was adequate for most clinical orthodontic needs.

In agreement with a previous investigation by Burgess,[20] the findings of the present study showed that pumicing did have a statistically significant effect on bond strength. When using SEPs, the manufacturers recommend the use of pumice prophylaxis.[29] The necessity of prophylactic cleaning for improved bond strength was first proposed by Miura et al. in 1973.[30] Scanning electron microscopy (SEM) studies have shown that pumice prophylaxis before acid treatment removes organic material from the enamel surface. This organic pellicle was hypothesized by some investigators to inhibit optimum etching.[30,31] In this study, pumicing significantly increased bond strength. The need to eliminate the organic pellicle by pumicing prior to the application of SEP as compared to conventional etching protocols, may be due to the fact that self-etching primers demonstrate a shallower etching pattern. This can possibly be caused by a poorer penetration of the acidic primer into enamel porosities or the result of interference from calcium precipitates on the enamel surface masking the etch pattern.[26]

Van Landuyt et al.[23] reported that bond strength to enamel of Clearfil TM SE Bond, a mild self-etching adhesive, significantly improved when prior etching with phosphoric acid was performed. However, the present study could not conclude that pre-etching had a significant effect on bond strength when TransbondTM Plus self-etching primer (3M Unitek, Monrovia, CA) was used. TransbondTM Plus self-etching primer (3M Unitek, Monrovia, CA) was especially developed for use in orthodontics and it consists of one bonding solution that allows clinicians to etch, prime and bond enamel in one step.[29] On the other hand, Clearfil TM SE Bond (Kuraray, Osaka, Japan) is a two-step bonding system consisting of a self-etching primer and a bonding agent and is currently used in operative dentistry. Therefore, it seems that more research is needed to determine the effect of pre-etching when both systems are compared.

Statistically significant differences were found in ARI scores among the groups. Overall, 90% of the brackets in each group debonded with ARI scores of 2, 3 or 4, indicating a cohesive failure. Total adhesive failures, ARI scores of 1 or 5, were only found in 10% of the samples. This agreed with other shear bond strength studies, in which total adhesive failures in less than 30% of sites and cohesive failures in more than

60% of sites were reported.[32,33] In the SEP with prior pumicing group, 95% of the brackets debonded with ARI scores of 3, 4 or 5, indicating that less composite remained on the tooth. On the other hand, in the Pre-etch and SEP with prior pumicing group there were no ARI scores of 4 or 5. In this group, 95% of brackets debonded with ARI scores of 2 or 3, indicating that more composite remained on the tooth.

The present findings indicated that converting the one-step Transbond™ Plus self-etching primer (3M Unitek, Monrovia, CA) into a two step system by pre-etching does not significantly increase bond strength *in vitro*. Pumicing, on the other hand, does have a positive effect on bond strength in comparison to not pumicing prior to applying SEP. This is in agreement with manufacturers instructions.[29] *In vivo* studies that examine the effect of etching prior to the application of self-etching primers are still needed to determine whether the incidence of bracket failure can be reduced clinically.

Conclusion

The findings of this *in vitro* study supported the importance of pumicing prior to Transbond^{TM} Plus self-etching primer (3M Unitek, Monrovia, CA) application. The results did not indicate that pre-etching prior to SEP application will further increase bond strengths if used in conjunction with pumicing.

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Appendix (Raw Data)

Tooth #	Debonding Force (lbs)	Debond Force (MPa)	ARI 1	ARI 2	ARI 3	Final ARI
Group 1						
1	52	21.996	3	3	3	3
2	20.5	8.671	4	4	4	4
3	66	27.917	2	3	3	3
4	29	12.267	2	2	2	2
5	36	15.228	2	3	3	3
6	56.5	23.899	3	3	3	3
7	56	23.688	3	3	3	3
8	59	24.956	4	4	4	4
9	47	19.881	4	4	4	4
10	57	24.111	3	4	3	3
11	34	14.382	4	4	4	4
12	10.5	4.441	5	5	5	5
13	20	8.460	5	5	5	5
14	45	19.035	3	2	3	3
15	44.5	18.823	2	2	2	2
16	70	29.609	4	4	4	4
17	19	8.037	1	1	1	1
18	28.5	12.055	3	4	3	3
19	51	21.573	2	2	2	2
20	35	14.805	3	3	3	3
Group 2						
1	44	18.612	1	1	1	1
2	13	5.499	1	1	1	1
3	53.25	22.524	1	2	2	2
4		0.000	2	3	2	2
5	45	19.035	3	3	3	3
6	58.5	24.745	2	3	3	3
7	51	21.573	2	3	3	3
8	56.5	23.899	2	3	3	3
9	45	19.035	4	4	4	4
10	38	16.074	3	3	3	3
11	59	24.956	4	4	4	4
12	68	28.763	3	3	3	3
13	56	23.688	2	2	2	2
14	45	19.035	1	1	1	1
15	51	21.573	2	3	3	3
16	48	20.304	2	3	3	3
17	55	23.265	3	3	3	3
18	28	11.844	1	2	2	2
19	67	28.340	2	2	2	2
20	44.5	18.823	2	2	2	2

Group 3						
1	58	24.534	4	5	4	4
2	51	21.573	3	3	3	3
3	56.5	23.899	4	5	4	4
4	57	24.111	3	3	3	3
5	104	43.991	3	4	3	3
6	77.5	32.782	5	5	5	5
7	40	16.920	4	5	4	4
8	78	32.993	3	4	3	3
9	70	29.609	3	3	3	3
10	51.2	21.657	3	4	4	4
11	66.5	28.129	3	3	3	3
12	51	21.573	2	3	3	3
13	37.25	15.756	3	3	3	3
14	72	30.455	2	3	3	3
15	65.5	27.706	4	4	4	4
16	68.25	28.869	3	3	3	3
17	51	21.573	4	4	4	4
18	47	19.881	2	2	2	2
19	42	17.766	3	3	3	3
20	77	32.570	2	3	3	3
Group 4						
1	56	23.688	2	3	3	3
2	57.5	24.322	1	2	2	2
3	28.5	12.055	1	1	1	1
4	48	20.304	2	2	2	2
5	37.25	15.756	3	3	3	3
6	34.5	14.593	2	2	2	2
7	62.5	26.437	3	3	3	3
8	43	18.189	2	2	2	2
9	64	27.071	2	2	2	2
10	63	26.648	3	3	3	3
11	52.5	22.207	2	2	2	2
12	50	21.150	2	3	3	3
13	66.5	28.129	1	2	2	2
14	59.5	25.168	2	3	3	3
15	42.5	17.977	2	2	2	2
16	58	24.534	2	3	3	3
17	67	28.340	2	2	2	2
18	46	19.458	1	2	2	2
19	65	27.494	2	2	2	2
20	43	18.189	2	2	2	2

Vita

Ana Paula DeCastro, was born in Brazil on May 7, 1980. She immigrated to the United States at the age of 16 and attended Miami Beach Sr. High School until 1998. She proceeded to University of Miami, FL and received in 2001 her Bachelor of Science and Arts degrees Cum Laude. On May, 2006, she graduated top 5% of her dental school class at University of Florida College of Dentistry, Gainesville, FL. She is currently a postgraduate resident in the Orthodontics program at VCU and will receive a certificate in Orthodontics and a Master of Science degree in Dentistry.