Comparison of Shear Bond Strength of Four Types of Orthodontic Brackets with Different Base Technologies

Gaurang H. Chaudhary, Gianina Salton Mattevi, Peter Thiuri Gakunga

Department of Developmental Dentistry/Orthodontics, School of Dentistry, University of Texas Health Science Center at San Antonio, San Antonio, Texas, USA

Abstract

Objectives: The aim of this study was to compare the shear bond strength (SBS) of brackets systems with four different base technologies. **Materials and Methods:** Maxillary first premolars were randomly divided into four groups of thirty specimens each: (1) Master Series™ conventional twin, (2) T3™ self-ligating, (3) Victory series™ conventional twin, and (4) H4™ self-ligating brackets. Maxillary first premolars were bracketed using an acid-etch composite system, and the SBS measured using an Instron Universal Testing Machine at a crosshead speed of 2 mm/min. The ANOVA and Tukey's multiple comparison tests were performed with significance predetermined at $P \leq 0.05$. **Results:** The overall mean bond strengths were 8.49 ± 2.93, 10.85 ± 3.34, 9.42 ± 2.97, and 9.73 ± 2.62 for the Groups 1, 2, 3, and 4 brackets, respectively. One-way ANOVA test gave an $F = 3.182$ with a $P = 0.026$. The Group 1 and Group 2 were observed to have statistically significant difference with a $P = 0.014$. **Conclusions:** The T3 self-ligating one-piece design with microetched Quadra Grip™ base brackets had the highest bond strength. The SBS difference between Group 2, Group 3, and Group 4 was not significant, but the difference between Group 2 and Group 1 was statistically significant.

Keywords: *Dental bonding, orthodontic brackets, shear strength*

Introduction

Numerous factors influence the bond strength of orthodontic brackets. These include the size and design of the bracket base.[1-11] The attachment must be able to deliver orthodontic forces, withstand masticatory loads, be esthetic, and be easy to remove at the end of treatment.[4] Bracket bases do not bond chemically to enamel or resin; therefore, efforts have been made to improve mechanical retention. The increasing demand for a more esthetic metal-bonded appliance has led to, among other things, a reduction in the size of the brackets and their bases.[11] However, the smaller retentive area of the bracket base influences bond strength.

Bracket bond strength depends on several factors. This includes the type of bracket retention mechanism,[12] bonding system, and type of enamel conditioner. Bracket base retention mechanisms can be chemical, mechanical, or a combination of both systems.[13] The retention mechanism of mesh pads has been well documented since Newman[14] published his report and the improvement of these variables has been the goal of many research projects.[15-24]

A mechanical undercut in the bracket base provides a place for the orthodontic adhesive to extend before polymerization.[4] Retention of most metal brackets is achieved with a fine-brazed mesh.[5,6] Other bracket bases have a milled undercut or are sandblasted, chemically etched, or sintered with porous metal powder.[4,5] Studies have indicated that bond failure in enamel-bonded metal brackets with a mechanical interlock and 15 s of acid-etching time[25,26] occurs at the resin–bracket base interface, within the resin itself, or between the resin and enamel. However, there was relatively more bond failure between the resin and bracket because of stress concentration and defects in the resin film.[5,25,26] The need for a bracket with good retentive bonding between the resin and metal base has been the impetus for numerous studies.

Machine integral bases have been reported to be more retentive than foil-mesh bases.[27] On the other hand, brackets with welded mesh have also been reported as being more retentive in tension, whereas

Address for correspondence:
Dr. Gianina Salton Mattevi, University of Texas Health Science Center at San Antonio, 8210 Floyd Curl Drive, San Antonio, TX 78229, USA.
E-mail: gianinasmattevi@gmail.com

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metal brackets with integrated bases were more retentive in shear.[28]

The effects of sandblasted bracket base mesh surfaces, reduced base surface area, and enamel etched with various acid types have previously been evaluated. Sandblasting and microetching of foil-mesh bases increased the shear bond strength (SBS).[17]

An evaluation of the performance of fine-mesh, coarse-mesh, and undercut bracket bases found that the fine-mesh base had higher tensile bond strength than the coarse-mesh base, and both performed better than the undercut base.[29] Additional studies involved the evaluation of a variety of bracket base designs including 60, 80, and 100 gauge (0.093, 0.123, 0.154 inches, respectively) single-mesh bases, a double-mesh base, and integrated metal base.[14] The conclusion was that the bonding agent significantly affected the SBS and that base designs may influence adhesive penetration of the curing light.

There is no clear consensus regarding the effect of bracket base design on SBS when tested under conditions simulating clinical use. There is, therefore, a need for studies to clarify this important issue in clinical orthodontics. The aim of this study was to evaluate and compare SBS of four differently designed brackets using conventional macrofilled orthodontic bonding agent.

The null hypothesis of this study was that there is no difference in the SBS of photochemically etched 80-gauge mesh base, microetched Quadra Grip™ base, 80-gauge woven mesh bonding base, and Treadlok design base brackets when bonded with Transbond XT orthodontic bonding agent to human enamel.

Materials and Methods

One hundred and twenty recently extracted caries-free human first maxillary premolars were collected and immersed in normal saline solution. Prophylactic treatment was performed with pumice paste and rubber cups on the surfaces of the teeth to be bonded. The pumice and water were nonfluoridated. The teeth were randomized into four groups, of thirty teeth each.

Four different types of orthodontic brackets (for maxillary fist premolars) with mechanical interlocking bases were used in this study. The brackets were evaluated for specific design characteristics, as such cast or welded, base size, base type (retention groove, circular concave, or mesh), and mesh size. The brackets tested were as follows:

- Group 1: Master Series™ conventional twin photochemically etched 80-gauge mesh (American Orthodontics, Sheboygan, WI)
- Group 2: T3™ self-ligating one-piece design with microetched Quadra Grip™ base (American Orthodontics, Sheboygan, WI)
- Group 3: Victory series™ conventional twin 80-gauge woven mesh bonding base (3M Unitek, Monrovia, California)
- Group 4: H4™ self-ligating brackets with Treadlok™ base (Orthoclassic, McMinnville, OR).

The bonding procedure was performed as follows: acid etching was achieved by application of 37% phosphoric acid gel (Pulpdent Corporation, Watertown, MA, USA) to the buccal surface of each tooth for 15 s. The teeth were then rinsed with a water spray for 30 s and dried with an oil-free air source for 20 s until the buccal surfaces of the etched teeth appeared to be chalky white in color. The sealant (3M Unitek, Monrovia, California) was applied on the etched surfaces. The Transbond XT adhesive (3M Unitek, Monrovia, California) was placed on each bracket base. The bracket was then positioned on the tooth, excess adhesive was removed using a sharp scaler, and the bracket bonding activated by light cure (Ortholux Luminous Curing Light 3M Unitek, Monrovia, California) for 20 s.

The teeth were embedded in self-cure acrylic using a customized mold. In each acrylic block, five teeth were mounted parallel to each other. The facial surfaces of the teeth were perpendicular to the bottom of the mold and hence would be parallel to the applied force during the shear test.

Shear bond strength testing

An occlusogingival load was applied to the bracket, producing a shear force at the bracket–tooth interface. This was accomplished using the flattened end of a steel rod attached to the crosshead of an Instron Universal Testing Machine (Instron Corporation, Canton, Mass., USA). A computer connected to the Instron Universal Testing Machine recorded the results of each test in megapascals. The SBS was measured at a crosshead speed of 2 mm/min.

Statistical analysis

Descriptive statistics including the mean, standard deviation, and minimum and maximum values was calculated for the four groups tested [Table 1]. The ANOVA and Tukey's multiple comparison tests were performed. Significance for all statistical tests was predetermined at $P \leq 0.05$ and the IBM SPSS Statics version 20. Armonk, New York, United States of America was used for statistical analysis.

Results

The overall mean bond strengths were 8.49 ± 2.93, 10.85 ± 3.34, 9.42 ± 2.97, and 9.73 ± 2.62 for the Group 1, 2, 3, and 4 brackets, respectively [Figure 1]. The statistical analysis of bonding strength with one-way ANOVA [Table 2] gave an $F = 3.18$ with a $P = 0.02$ and $R^2 = 0.07$. There were statistically significant differences among means with $P < 0.05$. However, there were no significant difference on the standard deviation ($P < 0.05$) when the Brown-Forsythe and Bartlett's testes were used.

Table 1: Descriptive statistics of shear bond strength of all four groups in MPa

	Group 1 (n=30)	Group 2 (n=30)	Group 3 (n=30)	Group 4 (n=30)
Minimum	5.19	4.11	5.53	5.45
25% percentile	6.09	8.63	6.79	7.12
Median	7.51	10.81	9.04	10.24
75% percentile	10.85	13.74	11.21	11.94
Maximum	14.73	15.31	14.71	14.38
Mean	8.49	10.85	9.42	9.73
SD	2.93	3.34	2.97	2.62
SEM	0.53	0.61	0.54	0.47
Lower 95% CI	7.39	9.59	8.31	8.75
Upper 95% CI	9.58	12.09	10.54	10.71

SD – Standard deviation; SEM – Standard error of mean; CI – Confidence interval

Table 2: Analysis of bond strength between four groups with one-way ANOVA (P<0.05)

	SS	df	MS	F
Treatment	84.71	3	28.24	3.182
Residual	1030	116	8.87	
Total	1114	119		

SS – Sum of square; MS – Mean square; F – F ratio

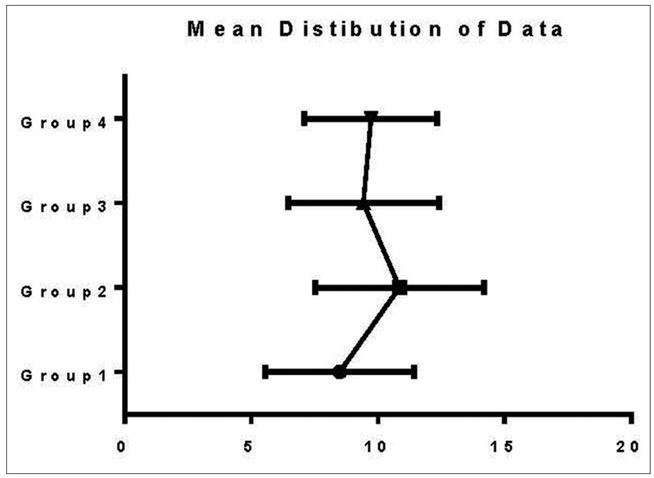

Figure 1: The overall mean bond strengths of the four groups

The Tukey's multiple comparison test was chosen (alpha = 0.05) for further analysis and comparison [Table 3]. The mean difference between Group 1 and Group 2 was −2.354, mean difference between Group 1 and Group 3 was −0.9354, mean difference between Group 1 and Group 4 was −1.23, mean difference between Group 2 and Group 3 was 1.418, mean difference between Group 2 and Group 4 was 1.114, mean difference between Group 3 and Group 4 was −0.30 [Figure 2]. Out of all the above group comparisons, only Group 1 and Group 2 were observed to have statistically significant difference with a P = 0.014.

Discussion

A conundrum exists in the design of orthodontic brackets. Reducing the size of the bracket leads to improved esthetics and eases the capacity for good oral hygiene.[11] However, this reduction results in a smaller base surface area available for bonding, with the concurrent clinical reality of increased debond rates.[17] Table 1 clearly shows that when comparing the mean SBS values, they are in the same order of magnitude for all four groups compared. Furthermore, the maximum and minimum values are in a comparable range. Each group in this study yielded relatively high mean SBS values of 8–11 MPa. Consequently, at present, it seems more important to improve and simplify the clinical operating procedures rather than to increase the adhesive strength of the currently available adhesives or brackets.[30] Moreover, increased bond strength to enamel would provoke more damage of the enamel because of the difficulties in debonding.[31] However, higher bond strengths could reduce the surface area needed for a strong bond, which would ultimately result in the use of smaller brackets. It should be pointed out that the megapascals (N/mm^2) provide an indication of the force per unit area required to dislodge the bracket. This would mean that a bracket with twice the surface area of the one tested would require twice the force to dislodge it. In each case, the bond strength would be the same when quoted in megapascals. If the same bond strength was to be quoted in Newton's or kilograms, the larger bracket would appear to have twice the bond strength.

The minimum bond strength required for clinical success is related to the forces of occlusion and not to the forces generated by an orthodontic arch wire. In children with normal lower face heights between the ages of 6 and 11 years, the occlusion force is 5.0 kg and in adults is 13.5 kg.[32] It would thus be reasonable to presume from these studies that bracket displacement forces may range from 5 to 13 kg. The force generated by an orthodontic arch wire ranges from 15 to 150 g,[32] except in situations where torquing moments are introduced, which induce much higher forces. In the current study, all the base surface areas and base treatments produced SBS that clearly exceeded these values.

The results show that bracket bases ranging in surface area from 10.82 to 14.58 mm^2 exhibited no statistically significant differences in SBS. This is in agreement with

Table 3: Tukey's multiple comparison test (α=0.05) for comparison of bond strength between the four groups

Groups comparisons test	Mean difference	95% CI of difference	Significant	Summary	Adjusted *P*
Group 1 versus Group 2	−2.35	−4.35-−0.34	Yes	*	0.014
Group 1 versus Group 3	−0.93	−2.94-1.07	No	NS	0.617
Group 1 versus Group 4	−1.23	−3.24-0.76	No	NS	0.376
Group 2 versus Group 3	1.41	−0.58-3.42	No	NS	0.258
Group 2 versus Group 4	1.11	−0.89-3.12	No	NS	0.471
Group 3 versus Group 4	−0.30	−2.30-1.70	No	NS	0.979

*Statistically significant difference. NS – Not significant; CI – Confidence interval

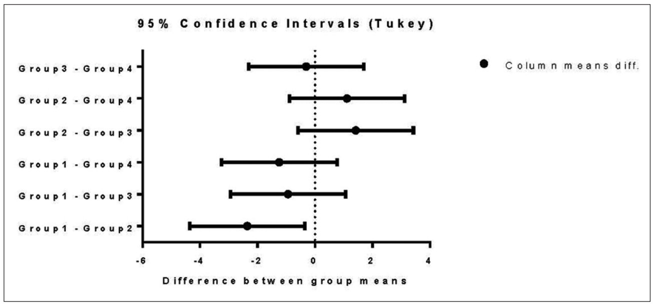

Figure 2: The differences between the four groups means with Turkey (95% confidence interval)

MacColl *et al*.[17] who found no significant differences in SBS between 6.82 and 12.35 mm^2 bracket bases. However, they found that reduction of the surface area to 2.38 mm^2 resulted in a statistically significant drop in SBS. It can be speculated that this drop would be of clinical significance. This study did not address the critical surface area below which clinical performance would be unacceptable.

Studies on bond failure at the enamel–adhesive interface indicate that fractures in the enamel can occur with bond strengths as low as 13.5 MPa.[33] This is comparable to the mean linear tensile bond strength of 14.5 MPa for enamel previously reported by Bowen and Rodriguez.[34] Although enamel can often withstand much greater forces during debonding, it is advisable to avoid using any bracket-conditioner-adhesive combination that can result in bond strengths significantly >13.5 MPa.[33] The current findings indicate that all combinations of bracket design tested produced mean bond strengths <10.85 MPa, which would appear to be relatively safe. Clinical perception is that the larger the bracket base diameter and mesh size, the better the bond that can be obtained. However, these results of the current study do not support this assertion. A smaller bracket base, independent of mesh size, does not lead to inferior bond strength. Therefore, the mini bracket, with improved patient comfort and better aesthetics, is equally effective. In addition, the smaller brackets are more hygienic and presumably are associated with decreased risk of enamel decalcification.[34] The results suggest that bracket base design significantly influences SBS and the 60-gauge foil-mesh bracket tested had higher bond strengths.[35]

According to the results of this study, there is no statistically significant difference in SBS between brackets of Group 1, Group 3, and Group 4. The Group 2 and Group 1 were observed to have a statistically significant difference of 2.354 with a *P* = 0.014.

In vitro bond strength tests are notable for producing results that have a wide variation. From a mechanical point of view, acceptable clinical direct bonding techniques require not only a high mean bond strength but also a narrow distribution about the mean because the lowest value governs the possibility of clinical failure.[11] The variations in composite material layer thickness might be a reasonable explanation for a higher variation between minimum and maximum values. Every product has its own critical thickness at which the SBS is highest.[1] This variable was controlled in the present study since all the bonding procedures were performed by one operator.

The bond strengths recorded in this study ranged from 8.49 to 10.85 MPa compared with 4–25 MPa reported in other studies.[36] These differences may be attributed to variations in types of tested samples (human or animal teeth, plastic cylinder, or a combination of these), types of teeth (incisor, canine, premolar, or molar; young or old permanent teeth, deciduous teeth, or a combination of these).[1] Other possible factors are the type and size of bracket base, contour of tooth surface, etching times, concentrations of etchant, pretreated condition (humidity, temperature, and duration of water bathing), rebonding of tooth surface, recycling of bracket, types of resin, or testing speed of the debonding machine.[17] All the above variables were the same for all the specimens in this study.

It should be mentioned that bond failures, which are failures in the enamel-adhesive interface, are likely to be due to inadequate technique (e.g., moisture contamination or disturbed setting). Failures in the adhesive–bracket interface are more likely caused by a weak adhesive. Clinically, bond failures usually occur at the adhesive-enamel interface and not at the gauze (mesh backing)–adhesive interface. This indicates that *in vivo* moisture contamination is a major factor contributing to adhesion failure in clinical orthodontics. Moisture contamination probably occurs from saliva or within the enamel itself.[37] A study *in vivo* had shown that more bracket failures were observed in the posterior region and there was no significant difference between the dental arches sides and among the quadrants.[38]

The SBS values in the four groups compared favorably to Reynolds and von Fraunhofer[37] values for minimal bond strength that are clinically acceptable (5.9–7.8MPa). Again, it needs to be emphasized that this is an *in vitro* study and the test conditions have not been subjected to the rigors of the oral environment. The retention of the bonded orthodontic attachments *in vivo* is governed partly not only by factors related to the operator but also by factors related to the patient. A careful clinical technique, moisture control, choice of appliance fitted, and instructions to the patient are all controlled by the operator. The age and sex of the patient, malocclusion type, and appliance care are not controlled by the operator, but also influence clinical success.[39] The diet in general and trauma are important factors in bonding failure.[40-42] These indicate the reasons that in vivo bond strengths are lower than in vitro bond strengths.[42,43]

A composite-enamel bond must resist the stresses induced by polymerization shrinkage and regular differential thermal changes between the composite resin and enamel. Differences exists in the type of the method of evaluation of bond strengths (shear, peel, tensile, brittleness, hardness, or compressive), machine used in testing, and the type of mounting apparatus.[44] Nevertheless, *in vitro* studies can serve as useful guides for clinical bonding applications.

Conclusions

- The Group 2 (T3 self-ligating one-piece design with microetched Quadra Grip™ base brackets) has the highest bond strength compared to Group 1, 3, and 4. Master series conventional twin photochemically etched 80-gauge mesh; Victory series conventional twin 80-gauge woven mesh bonding base; and H4 self-ligating brackets with Treadlok base
- The SBS difference between Group 2, Group 3, and Group 4 was statistically nonsignificant, but the difference between Group 2 and Group 1 is statistically significant.

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Conflicts of interest

There are no conflicts of interest

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