



## Comparison of Shear Bond Strength of Different Orthodontic Metal Bracket-bases Bonded on Enamel Surface – an *In vitro* Study

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### Authors' contributions

*This work was carried out in collaboration between all authors. Author ND designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors HD, MSD and NP managed the analyses of the study. Authors RA and NA managed the literature searches. All authors read and approved the final manuscript.*

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### ABSTRACT

**Aim:** To compare the shear bond strength of different metal bracket bases bonded on enamel surface and further to evaluate the Adhesive Remnant Index score to localize the sites of adhesive fracture.

**Materials and Methods:** Four types of premolar metal brackets were selected according to their different mesh designs: (G1, Gemini Series, 3M Unitek; G2, Micro Sprint, Forestadent; G3, Equilibrium 2, Dentaurum and G4, Mini-Master Series, American Orthodontics). One hundred brackets for each type were used and bonded on enamel surfaces of extracted human premolars (Transbond XT, 3M Unitek) and were tested to evaluate shear bond strength with an Instron Universal Testing Machine (Star Testing Systems, India). All data were analysed with ANOVA, Tukey's HSD Post hoc test, and with descriptive statistics. The adhesive fracture site was also evaluated and classified with ARI score.

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**Results:** G2 showed greater shear bond strength when compared with other samples ( $P < 0.001$ ). G2 and G3 showed statistically significant differences in comparison with other groups with respect to shear bond strength. There was no statistically significant difference between G1 and G4. The ARI index demonstrated a large variability. G2 showed 70% of the adhesive fracture at cement-enamel interface.

**Conclusion:** G2 showed the highest shear bond strength in comparison with other groups. ARI score showed that G2 resulted in 70% adhesive fractures at the cement-enamel interface. An increased size of the bracket-base enhances adhesion but affects the adaptability to surface morphology of the enamel, increasing the risk of fracture at the interface with the bracket.

*Keywords: Bracket-base; shear bond strength; adhesion; ARI score.*

## 1. INTRODUCTION

The acid etching technique, introduced by Buonocore, has allowed the replacement of metal bands with directly cemented brackets [1]. The use of metal bracket with a retentive base was first reported by Mitchell in 1967 [2].

The bond strength of bracket is influenced by various factors, including the size and design of bracket base [3-12]. The material and design of the bracket must be having ability to deliver orthodontic forces and masticatory loads. It should also be an aesthetic and at the end of treatment, there should not be any damage to enamel surface during removal of the bracket [6]. The mechanical interlock between base-adhesive and resin-enamel plays an important role for the adhesion of metal brackets.

There are so many types of metal brackets with different types of bracket bases available in the market. They can be classified into two principle groups: Brackets having soldered base and brackets having integral bases. In the first group, the metal bases are soldered to the bracket bodies. In this group, various types of bases are used such as perforated bases, mesh foils, and photo-etched bases. In the second group, the base and the remaining parts of the bracket are a single casted. Four types of bases are categorised under this group: retention groove bases, mesh bases, waffle bases, and laser-structured bases.

There is a mechanical undercut which provides a room for the orthodontic adhesives to extend before polymerization. Most of the metal brackets with fine brazed mesh provide good retention [7]. Metal bracket bases have two types of designs: a single-piece casting formed with a retention groove on the base, and a mesh or a concave, circular form that is welded by laser with silver directly to the bracket body.

The laser-structured bases have many hole-shaped cavities on the base of the brackets that are realized by a laser beam scanned over the base surface. This type of design provides the retention. Other bracket bases are sandblasted, chemically etched, or sintered with porous metal powder [6-12].

Several studies [13,14] have reported that bond failure in metal brackets bonded to enamel surface occurs with 15 seconds of acid etching time in three possible areas: between the resin and enamel, within the resin itself, or at the resin-bracket base interface. However, they also found that there were relatively greater chances of bond failure between the resin and bracket because of concentration of stress and defects in the resin film. So to overcome all these problems, a bracket with sufficient retentive bonding between the resin and metal bracket base is needed.

Among all these factors the base retentive system is only one of the factors that influence the shear bond strength of metal brackets effectively. Furthermore, the entire bonding procedure and moisture contamination of an etched enamel can also modify the retention of metal brackets as well as affect the shear bond strength [15,16].

Many studies have compared the shear bond strength of metal brackets with different types of retentive bases [11,15,17-19].

The aim of this study was to evaluate and compare the shear bond strength of different types of retentive bases. Furthermore, the specimens were examined by using an adhesive remnant index (ARI) to localize the sites of adhesive fracture.

## 2. MATERIALS AND METHODS

Four types of premolar metal brackets were selected for this study: Gemini Series (G1) (3M

Unitek, Monrovia, Calif) (Fig. 1), Micro Sprint (G2) (Forestadent, Pforzheim, Germany) (Fig. 2), Equilibrium 2 (G3) (Dentaurum, Inspringen, Germany) (Fig. 3) and Mini-Master Series (G4) (American Orthodontics) (Fig. 4). One hundred brackets for each type were used. The mean base surface area of the brackets was calculated by measuring length and width and computing the area.

Four hundred human premolars were extracted, washed, and the pulp removed. The criteria of tooth selection were grossly perfect crown with absence of cracks caused by extraction forceps. The teeth were then embedded in self-curing acrylic resin (DPI), leaving the labial enamel exposed. The specimens were stored in normal saline solution for 1 week until testing.

A bracket placement site was prepared with pumice-powder paste-water with absence of fluoride content, rinsed it for 10 seconds, and dried. Before bonding, the enamel was etched with a 35% orthophosphoric acid gel solution for 15 seconds, sprayed for 20 seconds, and dried.

The adhesive primer (Transbond XT Primer, 3M Unitek) was uniformly applied on the enamel and sprayed with air to enhance the complete penetration of the resin matrix. After photopolymerization for 10 seconds, brackets with an adhesive (Transbond XT, 3 M Unitek) were positioned with the help of bracket positioning instrument and pressed it on the labial surfaces of the teeth. The excess of adhesive was removed, and the adhesive was cured by applying the light (Curing Light XL 3000, 3 M Unitek) for 10 seconds each (Fig. 5).

All specimens were tested on an Instron Universal Testing Machine (Star Testing Systems, India. Model No. STS 248): A blade of an unit was placed at the bracket base-enamel interface with a crosshead speed of 6 mm/min and a 50-kg load cell [20]. In this way all the brackets were shear tested to failure (Fig. 6). The force producing failure was recorded first in newtons and then converted it into megapascals by dividing the measured force values by the mean surface area of the brackets.



Fig. 1. Gemini series



Fig. 2. Micro sprint



Fig. 3. Equilibrium 2



Fig. 4. Mini master series



**Fig. 5. An extracted premolar with bracket bonded on exposed labial surface**



**Fig. 6. Instron universal testing machine with a sample**

The ARI score was used to evaluate and compare the amount of adhesive left on the enamel surface after debonding and to check the sites of adhesive fracture [21]. Brackets were observed with a stereomicroscope at 10x magnification while the remaining part of adhesive was scored with respect to the amount of resin material left on the enamel:

ARI 0, less than 10% of the adhesive left on the enamel;

ARI 1, 10-50% of the adhesive left on the enamel;

ARI 2, 50-90% of the adhesive left on the enamel;

ARI 3, more than 90% of the adhesive remained on the enamel, where one can see a clear impression of the bracket base on the adhesive-enamel surface.

## 2.1 Statistical Analysis

The descriptive statistics was used to include mean and standard deviation (SD) for each and every group, in newton and in megapascal. A one-way analysis of variance (ANOVA) was used to compare the shear bond strength between four groups. The Tukey's HSD Post hoc test was carried out to analyse the effect of bracket base design on mean shear bond strength of each group with other groups.

## 3. RESULTS

The overall mean shear bond strengths are shown in Table 1. The one-way ANOVA test was performed to compare the shear bond strength among four groups and it showed that there were statistically significant differences among the four groups ( $P = .001$ ).

The mean bonding force per area squared is shown in Table 2, which demonstrated that G2

and G3 showed a significantly greater shear bonding force when data were expressed in megapascals.

The Tukey's HSD post hoc test showed significant differences between brackets evaluated. The G2 and G3 presented significantly higher shear bond strength as compared to other samples ( $P = < 0.001$ ). There were no significant differences between G1 and G4 ( $P = > 0.001$ ) (Table 3).

The site of the fracture for each sample was evaluated with the Adhesive Remnant

Index (ARI) (Table 4). Three possible types of fractures were observed: (1) cohesive fracture, within the body of the cement; (2) adhesive fracture, at the adhesive-bracket base or enamel-adhesive interface, and (3) mixed fracture.

#### 4. DISCUSSION

In this study, all metal brackets had different types of base patterns and base surface areas, except G1 and G4, where the difference was only in base surface area.

**Table 1. Descriptive statistics of shear bond strength (N) and nominal area (mm<sup>2</sup>)**

Brackets	Area (mm <sup>2</sup> )	Mean (N)	SD	SE	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
Victory series G1	8.97	89.58	36.43	3.64	82.35	96.81	6.52	141.37
Micro sprint G2	7.90	150.49	35.11	3.51	143.53	157.46	110.11	218.79
Equilibrium 2 G3	10.4	153.03	83.87	8.39	136.38	169.67	80.41	368.14
Mini master series G4	10.8	114.66	78.37	7.84	99.11	130.21	7.89	308.76

**Table 2. Descriptive statistics of shear bond strength (MPa) and nominal area (mm<sup>2</sup>)**

Brackets	Area (mm <sup>2</sup> )	Mean (N)	SD	SE	95% CI for mean		Minimum	Maximum
					Lower bound	Upper bound		
Victory series G1	8.97	9.99	4.06	0.41	9.19	10.80	0.72	15.78
Micro sprint G2	7.90	19.06	4.44	0.44	18.18	19.94	13.93	27.71
Equilibrium 2 G3	10.4	14.72	8.06	0.81	13.12	16.32	7.72	35.42
Mini master series G4	10.8	10.65	6.10	0.61	9.44	11.86	4.02	25.61

**Table 3. Statistical comparison (Tukey's HSD post hoc test)**

Bracket base comparison			Newton's (N)	Megapascals (MPa)	
Victory series	G1	G2	Micro sprint	-60.9130000	-9.0660000
		G3	Equilibrium 2	-63.4440000	-4.7280000
		G4	Mini master series	-25.0760000	-.6600000
Micro sprint	G2	G1	Victory series	60.9130000	9.0660000
		G3	Equilibrium 2	-2.5310000	4.3380000
		G4	Mini master series	35.8370000	8.4060000
Equilibrium 2	G3	G1	Victory series	63.4440000	4.7280000
		G2	Micro sprint	2.5310000	-4.3380000
		G4	Mini master series	38.3680000	4.0680000
Mini master series	G4	G1	Victory series	25.0760000	.6600000
		G2	Micro sprint	-35.8370000	-8.4060000
		G3	Equilibrium 2	-38.3680000	-4.0680000

**Table 4. Adhesive remnant index (ARI) scores in percentage**

Value	Criterion	Interpretation	G1	G2	G3	G4
ARI 0	No adhesive left on tooth (<10%)	Adhesive fracture at cement-enamel interface	0	70	0	40
ARI 1	Less than half of the adhesive left on the tooth	Mixed fracture	50	30	40	40
ARI 2	More than half of the adhesive left on the tooth	Cohesive fracture	40	0	30	10
ARI 3	All adhesive left on tooth (>90%)	Adhesive fracture at bracket-cement interface	10	0	30	10

G1 presents with a mesh foil having the most retentive size to allow more space for the penetration of the adhesive and the curing light during bonding procedure [11,22]. However, in some studies, the authors consider that the size of the bracket-base does not influence the retention significantly or that it also depends on the filler particles of the adhesive used [16,23] (Fig. 1).

G2 presents with the smallest base surface area among all those brackets selected in this study (7.9 mm<sup>2</sup>). In such brackets, a waffle base, which consists of metallic indentations coming out from the base of the bracket, enhances the retention. The photograph shows that waffle base is having unique design in which each indentation has been projected occluso-gingivally, creating adequate undercuts and the presence of free volume of space among the indentations allows the escape of air and excess resin (Fig. 2). The results for G2 obtained in this study are similar with previous study where such type of bracket base used [20].

G3 presents with laser-structured base with many hole-shaped cavities on the base of the brackets that are obtained by a laser beam scanned over the base surface, which provides the mechanical interlock and also enhances the retention. The photograph shows the presence of projecting metallic margins derived from the laser beam. It also presents with the quadrangular, anatomic and more concave base shape (Fig. 3).

G4 presents with similar mesh foil to G1, providing large space for the penetration of the adhesive and the curing light. The only difference is with the base surface area, which is larger than G1 (Fig. 4). In a previous study, similar brackets were used to evaluate shear bond strength and it was 10.68 MPa, which is similar to this study (10.65 MPa) [24].

Previous study [25] stated that the difference in designs of metallic meshes of bracket-bases gives contributions to more adherence of the adhesive material to the base of the bracket, achieving greater shear bond strength.

The shear bond strength also depends on the adhesive materials. Transbond XTTM is one of the most recommended products in current orthodontics. It has been a part of various comparative adhesion studies. In this study, all data were obtained with Transbond XTTM, which strongly associated with previous studies [26-29].

Reynolds and von Fraunhofer [30] stated that all the retentive designs used in the brackets tested should have an acceptable bond force levels (6–8 MPa). However, there are various factors related to an oral environment or moisture contamination that may affect the shear bond strength. The moisture contamination of bracket-bases with water, saliva and blood has been shown to adversely affect the shear bond strength due to deposits of an organic adhesive layer immediately after exposure that is resistant to washing and subsequently it reduces the shear bond strength of brackets [17,31-33]. Ahmad Sheibaninia et al. [34] evaluated the effect of an acidic food simulating environment on shear bond strength of self-ligating brackets and stated that the margins of bracket-bases allows an acidic food to penetrate, which gradually decreases the shear bond strength. So care should be taken in predicting the results to those conditions. Arunima Goswami [35] et al. stated that moisture contamination did not affect the shear bond strength. It has been suggested that an adverse effect of moisture contamination on orthodontic bonding can be associated with water adsorption, which produce formaldehyde so causing the plasticizing effect. In fact, this is an *In vitro* study and the aim of this study was to determine the retention capacity.

So *In vivo* conditions have not been considered.

Generally, the shear bond strength is expressed in newton and the bonding force is expressed in megapascals while comparing the retention capacity of brackets selected. The values in megapascal can be obtained by dividing the values in newtons by the base surface areas, which directly reflect the effectiveness of the retention mechanism. When values are expressed in newton, G3 shows the highest shear bond strength. This value is not significantly greater than G2, but it is significantly greater than the values shown by the other specimens. When the values are expressed in megapascal, G2 shows the highest shear bonding force with respect to the others. Comparing the results, it is evident that the latter factor can influence the shear bond strength, which indicates that while increasing the surface area of the bracket, the load carrying capacity also increases, as observed in previous studies [11,16].

Cucu et al. performed an *In vitro* study to evaluate the effect of bracket-base size on shear bond strength and found no significant difference between bracket-base size and shear bond strength which confirms present findings where G2 having the smallest base surface area has the highest shear bond strength [36].

Finally, a large variability is seen in the fracture sites according to ARI index analysis in this study. G2 and G4 showed 70% and 40%, respectively, bond failures located at the enamel-adhesive interface (ARI 0) and 30-50% were having mixed fractures (ARI 1). There was no ARI 2 or ARI 3 score present for G2. This result is similar to previous study.[20] This seems to be a confirmation of the high retention of these bracket bases but there are high chances of enamel damage. Previous studies evaluated the shear bond strength of self-ligating brackets 24 h after immersion in water found higher frequencies of ARI score 3 [37,38]. Other study [31,39] stated that under moisture contamination water and saliva, there is a higher frequency of ARI score 0. In general, ARI results are very subjective and they should be evaluated carefully [40].

## 5. CONCLUSION

- In this study, shear bond strength of all four types of brackets tested is clinically acceptable.

- The waffle base of micro sprint brackets showed the highest shear bond strength followed by laser-structured base of equilibrium 2 brackets compared with other samples.
- By increasing the base surface area of the bracket, the load carrying capacity can be increased, but causes a decrease in adaptation.
- The ARI index score values showed a large variability. Waffle base of Micro sprint brackets showed 70% of adhesive fracture at the enamel-adhesive interface (ARI 0), which is the highest retention of these bracket-bases when compared with other brackets but on other side there are higher chances of enamel damage.
- So shear bond strength of the bracket does not solely depend on the base surface area, but it also depends on the base surface characteristics and the properties of the adhesive materials.

## CONSENT

It is not applicable.

## ETHICAL APPROVAL

Institutional Ethics Committee (IEC) for Research Manubhai Patel Dental College, Hospital and Oral Research Institute, Vadodara. REF. NO.: IEC/MPDC\_069/Ortho-16/15

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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