Retentive Shear Strengths of Various Bonding Attachment Bases: An *in vitro* Study

Abhishek Goyal, Anil Kumar Chandna, Vikas Sehgal, Sridhar Kannan, Ashish Gupta, Amit Rajain, Gaurav Gupta

**ABSTRACT**

The increasing demand for a more esthetic metal bonded appliance has led to a reduction in the size of the brackets and their bases. The reduction of bracket size improves esthetics and produces a more easily cleansed appliance. This reduction results in less base surface area available for bonding with the concomitant clinical reality of increased debonding rates.

**Objectives:** To compare the shear bond strength and to evaluate and compare the surface design characteristics (mesh type, mesh wire size) of different commercially available direct bonding metal brackets.

**Materials and methods:** Maxillary first premolar brackets of six different manufacturing companies were bonded on freshly extracted human premolars preserved in artificial saliva, with the same adhesive and then debonded using a universal testing machine. The bracket bases were also examined under the scanning electron microscope (SEM).

**Results:** The bond strength obtained with different commercially available bracket bases was statistically variable. The size of bracket bases influenced the shear bond strength values. The mesh size and its configuration also affect the bond strength.

**Conclusion:** Gemini brackets provided the best bond strengths clinically, followed by Mini Diagonali, Nu-Edge, Mini Twin, Mini Diamond and the Sapphire brackets in decreasing order as measured using the Weibull analysis.

**Keywords:** Bracket bases, Mesh configuration, Open area percentage, Shear bond strength.


**INTRODUCTION**

Manufacturers are introducing various styles of metal attachment bases with reduced sizes, designed to improve the mechanical retention of the attachment to the resin system. Improvements are also being made in the resin system. Approaches to improve retention included using laser-structured bases, using metal plasma-coated bracket bases, and fusing metallic or ceramic particles to the bases. With time, efforts have been made to improve mechanical retention with various designs, as a result of which many bracket base designs are now available for clinical use. The literature provides conflicting reports regarding the effect of using different retentive bracket base designs on the shear bond strength. This study was carried out to authenticate the information provided by the manufacturer and to gather further information about bracket bases (mesh wire diameter, aperture diameter) considered as industrial secrets.

**MATERIALS AND METHODS**

**Brackets**

Pre-adjusted edgewise maxillary first premolar brackets (0.022” Roth Prescription) of six different manufacturers were used in this study, (Table 1) with brackets of each manufacturer forming a separate study group. For each study group thirteen brackets were taken, out of which 10 brackets were allocated randomly for bond strength testing and the remaining three brackets were subjected for examination under scanning electron microscope (SEM).

The study sample consisted of 60 recently extracted human maxillary first premolars preserved in artificial saliva. Selected premolars were embedded in aluminum cubes of 2.5×1×1 cm³ with help of self-cure acrylic so as to prevent any displacement of teeth during shear bond testing (Fig. 1). A prophylactic treatment was performed with a pumice paste and rubber cups on the buccal surfaces of the teeth to be bonded. The standard protocol for bonding of premolars was followed using adhesive (Enlight Light Cure, Ormco). The samples were stored in saline solution till bond strength testing.
The shear bond strength testing was carried out using universal testing machine (Lloyd universal testing machine). The teeth were debonded after 24 hours from the time of initial bonding. A sharpened chisel type blade was used to apply occlusogingival load for shear bond strength testing. The occlusogingival load (Fig. 2) was applied at bracket base-resin interface with the cross-head speed of 1 mm/min. The force producing failure was recorded in Newtons and converted into force per unit area (MPa) by dividing the measured force values by the surface area of the brackets.

The SEM examination was done to evaluate the bracket base design of different brackets as well as to calculate the surface areas of different bracket bases. For each group, three premolar brackets (one bracket used for base view, and two brackets used for occlusal and gingival view) were mounted on aluminum stubs (Fig. 3), for examination under LEO – 435VP SEM (LEO Co Ltd). During examination, the teeth were viewed at different magnifications between 20× to 125× at 15kV and were photographed at magnifications that were found to be the most representative. SEM view of each bracket base was used to study the characteristics of mesh design. Following characteristics were noted from each base view-mesh type, form of weave, mesh wire diameter and aperture width.

After debonding the brackets, the enamel surface of each tooth was examined under 10× magnifying glass. The amount of adhesive remaining on each tooth surface was analyzed and scored according to the adhesive remnant index (ARI) as described by Artun and Bergland (1984).14

The scoring system is as follows:
• Score 0 = No adhesive left on the tooth.
• Score 1 = Less than half of the adhesive left on the tooth.

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1Information as provided by the respective manufacturer; 2Information as provided by the dealer (Sawbros International, Noida, India) of the company; 3Information as provided in the article of Dr Claude G Matasa (Ref No 6); 4Information as provided by the dealer (Libral traders, New Delhi, India) of the company
• Score 2 = More than half of the adhesive left on the tooth.
• Score 3 = All adhesive left on the tooth, with distinct impression of the bracket mesh.

STATISTICAL ANALYSIS

Shear bond strengths obtained for each group were subjected to SPSS-12 (statistical package for the social sciences-12) to carry statistical analysis. Mean, standard deviation and minimum and maximum stress values were calculated for each of the experimental groups. One-way analysis of variance was used to determine whether significant differences existed between the means of the various experimental groups. To determine if means were significantly different from each other, a post hoc test (Scheffe’s test) was done. Kruskal-Wallis test (nonparametric ANOVA) was done to determine any significant differences between the experimental group’s ARI scores. A level of significance (p ≤ 0.05) was used for the above statistical tests.

Orthodontic bonding resins are brittle materials and produce a wide scattering of the bond strength data (Mojon et al, 1989). The use of a survival analysis, such as the Weibull analysis is appropriate in such cases. It enables the researcher to come to a more realistic evaluation of the bond strength than can be achieved by using normal distributions. Thus Weibull analysis was used to calculate the Weibull modulus, characteristic strength and the required stress for 10 and 90% probabilities of failure.15

**RESULTS**

Nu-Edge brackets (TP Orthodontics) achieved the highest mean bond strength followed by Mini Twin brackets (Ortho Organizers), Mini Diamond brackets (Ormco), Gemini brackets (3M Unitek) Mini Diagonali brackets (Leone) and Sapphire brackets (Modern Orthodontics) (Table 2). The difference in bond strength between various bracket groups was statistically significant (Table 3). Table 4 lists the frequency of ARI scores. The Gemini brackets (3M Unitek) obtained the highest Weibull modulus followed by Mini Diagonali brackets (Leone), Nu-Edge brackets (TP Orthodontics), Mini Twin brackets (Ortho Organizers) and Mini Diamond brackets (Ormco). Sapphire brackets (Modern Orthodontics) scored the lowest Weibull modulus (Table 5).

Table 2: Shear bond strength (megapascals) of all groups comparison among the groups using ANOVA test

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Gemini bracket</th>
<th>Sapphire bracket</th>
<th>Mini Twin bracket</th>
<th>Mini Diamond bracket</th>
<th>Nu-Edge bracket</th>
<th>Mini Diagonali bracket</th>
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<td>F = 7.129</td>
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</table>

*p < 0.05—statistically significant

Table 3: Post-hoc multiple comparisons using Scheffe’s test (p-value)

<table>
<thead>
<tr>
<th>Groups</th>
<th>Sapphire bracket</th>
<th>Mini Twin bracket</th>
<th>Mini Diamond bracket</th>
<th>Nu-Edge bracket</th>
<th>Mini Diagonali bracket</th>
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<tr>
<td>Gemini bracket</td>
<td>p = 0.088 (NS)</td>
<td>p = 0.878 (NS)</td>
<td>p = 1.000 (NS)</td>
<td>p = 0.663 (NS)</td>
<td>p = 0.816 (NS)</td>
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<td>Sapphire bracket</td>
<td>p = 0.002*</td>
<td>p = 0.028*</td>
<td>p = 1.000 (NS)</td>
<td>p = 0.000*</td>
<td>p = 0.817 (NS)</td>
</tr>
<tr>
<td>Mini Twin bracket</td>
<td>p = 0.982 (NS)</td>
<td>p = 0.887 (NS)</td>
<td>p = 1.000 (NS)</td>
<td>p = 0.122 (NS)</td>
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<tr>
<td>Mini Diamond bracket</td>
<td>p = 0.982 (NS)</td>
<td>p = 0.887 (NS)</td>
<td>p = 1.000 (NS)</td>
<td>p = 0.560 (NS)</td>
<td></td>
</tr>
<tr>
<td>Nu-Edge bracket</td>
<td>p = 0.043*</td>
<td>p = 0.043*</td>
<td>p = 1.000 (NS)</td>
<td>p = 0.817 (NS)</td>
<td></td>
</tr>
</tbody>
</table>

p < 0.05*: Statistically significant; NS: Not significant
SEM Observations of Bracket Bases

All the bracket bases were of single mesh configuration (Figs 4 to 9). All the bracket bases had plain weave type of mesh. No weld spots were observed in any of the brackets groups. Among all the bracket groups, Gemini brackets (Fig. 4) and Sapphire brackets (Fig. 5) showed diagonal mesh framework whereas Mini Twin brackets (Fig. 6), Mini Diamond brackets (Fig. 7), Nu-Edge brackets (Fig. 8) and Mini Diagonali brackets (Fig. 9) showed vertical pattern of mesh framework. The bracket bases seem to be rolled during the treatment so that flattening of the mesh created sharp edges on the mesh wires (Figs 4B to 9B). The measured wire diameter (Figs 4C to 9C) and aperture width (Figs 4D to 9D) for each group appeared grossly symmetrical for the respective bracket groups. Broken mesh wires were seen at few places in case of Sapphire brackets (Figs 5E and F). In the SEM view of Mini Twin brackets some surface roughness was seen (Figs 6A and B).

DISCUSSION

In the present study only one type of adhesive was used in an attempt to ensure that every variation of the bond strength values would depend on the characteristics (design and dimension) of the considered bases. The adhesive viscosity is...
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Figs 4A to D: Gemini brackets: (A) SEM view of bracket base, (B) enlarged SEM view of bracket base, (C) measurement of wire diameter—107 µ, (D) measurement of aperture width—201 µ

Figs 5A to F: Sapphire brackets: (A) SEM view of bracket base, (B) enlarged SEM view of bracket base, (C) measurement of wire diameter—90 µ, (D) measurement of aperture width—263 µ, (E and F) broken mesh wires

Figs 6A to D: Mini Twin brackets: (A) SEM view of bracket base, (B) enlarged SEM view of bracket base, (C) measurement of wire diameter—115 µ, (D) measurement of aperture width—240 µ

Figs 7A to D: Mini Diamond brackets: (A) SEM view of bracket base, (B) enlarged SEM view of bracket base, (C) measurement of wire diameter—110 µ, (D) measurement of aperture width—160 µ

Figs 8A to D: Nu-Edge brackets: (A) SEM view of bracket base, (B) enlarged SEM view of bracket base, (C) measurement of wire diameter—97 µ, (D) measurement of aperture width—200 µ

Figs 9A to D: Mini Diagonali brackets: (A) SEM view of bracket base, (B) enlarged SEM view of bracket base, (C) measurement of wire diameter—103 µ, (D) measurement of aperture width—214 µ

a characteristic that influences the adhesive penetration into the mesh; it’s presence in the space between the base and the mesh, in the mechanical retention and the escape of air. Possibly, the use of a different adhesion system could have yielded different results. For example, an adhesive with low viscosity
can penetrate better into a smaller mesh. Also, the influence of the filler concentration on the viscosity remains an important clinical argument.16

For *in vitro* bond strength testing, suggestions by Fox et al17 for standardization of the *in vitro* test procedure were followed in the study. Debonding was carried out on Lloyd universal hardness testing machine at a cross-head speed of 1.0 mm per minute. The cross-head speed suggested by Fox was 0.1mm per minute. On the contrary Klocke and Nieke18 suggested that cross-head speed variation between 0.1 and 5.0 mm per minute did not seem to influence debonding force measurements or failure mode of brackets bonded to enamel with a composite adhesive. So for convenience cross-head speed of 1.0 mm per minute instead of 0.1 mm per minute was chosen.

Among all the study groups, Nu-Edge brackets achieved the highest mean shear bond strength followed by Mini Twin brackets while Gemini brackets and Mini Diamond brackets had comparable mean shear bond strengths. Whereas the Sapphire brackets with the second largest surface area showed the lowest mean SBS value which appears to be influenced by the flaws in the mesh configurations. The bracket base showed broken mesh wires (Figs 7E and F) which perhaps prevented adequate mechanical interlocking thus compromising the shear bond values.

In the present study, surface area of the bracket groups ranged from 8.57 to 11.28 mm². The size of bracket bases seems to have influenced the shear bond strength values as Mini Diagonali brackets with the lowest surface area of 8.57 mm² recorded lower mean SBS value (15.66 ± 2.71 MPa) in comparison to other brackets. Sapphire brackets were not considered due to faulty mesh bases. The results of this study are not in accordance with MacColl et al2 study which considered that surface area of bracket bases between 6.82 to 12.35 mm² may be expected to resist shear forces in a comparable manner.

In the study Weibull analysis was used because it allowed predicting the probability of failure at various stress levels. Weibull statistics can be used to relate survival in clinical trials from data obtained from laboratory studies. This survival analysis takes into account the weaker values of the distribution. A high value of Weibull modulus (m) indicates a close grouping of the fracture stress values and a high level of reliability of samples.15,19 The higher the value of bond strength at 10% probability of failure, lesser is the chance of bond failure expected in clinical use.14 Shear stress at 90% probability of bond failure can be considered clinically relevant because this indicates a 90% bond failure rate, which is acceptable clinically.15,19

Gemini brackets (m = 6.01) showed the highest values for Weibull modulus. The bond strengths at 10% probability of failure (14.5 MPa) were also very high among all the groups. These values are sufficiently higher than minimal bond strength of 8 MPa adequate for most clinical orthodontic needs as suggested by Maijer and Smith.18 Thus, the group showed reliable and high bond strength values for clinical purpose. Gemini brackets were closely followed by Mini Diagonali brackets (m = 5.80) with the bond strength at 10% probability of failure (11.5 MPa) higher than minimal bond strength of 8 MPa. Nu-Edge brackets achieved an intermediate Weibull modulus (m = 4.42) with highest value for bond strengths at 10% probability of bond failure (15.99 MPa). Mini Twin (m = 3.72) and Mini Diamond brackets (m = 3.14) recorded very low values for Weibull modulus even though the mean SBS values for the groups were very high (23.12 and 20.74 MPa respectively). Low value for Weibull modulus suggests that there was wide scattering of shear bond values for these groups. The bond strengths at 10% probability of bond failure for Mini Twin and Mini Diamond brackets were 12.7 and 10.5 MPa respectively.

The Weibull analysis shows that there is a certain probability of bond failure at low tensile forces even for a bracket-bonding system of high mean tensile strength. Therefore, it may sometimes be preferable to choose a bracket-bonding system with a lower mean tensile strength but with a higher Weibull modulus. Sapphire brackets produced lowest value for Weibull modulus (m = 2.81) and for bond strengths at 10% probability of bond failure (7.2 MPa) among all other bracket groups making it least clinically reliable.

Mesh gauze size for each bracket group was calculated with help of mesh wire diameter and aperture width noted during SEM examination. (Table 6). There was difference in mesh number that was provided by the manufacturers from the one that was calculated in the study which could be due to the fact that mesh underwent some distortion during manufacturing of bracket or it could be a deliberate attempt by the manufacturer to maintain the secrecy of their product.

Gemini brackets followed by Mini Diagonali brackets followed by Nu-Edge brackets produced the most clinically reliable shear bond strength values (Weibull analysis). These brackets had comparable mesh gauze size as well as open area percentage (Table 6). A higher percentage of open area allows better penetration of the adhesive particles thus enhancing mechanical interlocking between the mesh and the adhesive, leading to improved bond strength and clinically reduced bond failures. For Sapphire brackets highest open area percentage (55.5%) and for Mini Diamond brackets lowest open area percentage (35.1%) was observed. For Gemini brackets the open area percentage was 42.6%. For rest of the groups open area percentage ranged from 45.4 to 45.7% (Table 6). The Mini Diamond brackets with the finest mesh (95) and least open area percentage among all groups, was considered less clinically reliable as compared to other study groups. A lower percentage of open area probably restricted the penetration of the adhesive particles.

Studies11 have considered the bracket resin interface as the weakest link in the enamel-resin-bracket continuum for the *in vitro* studies. Clinically, more failures may be observed at the enamel adhesive interface than are observed *in vitro*,
because ideal bonding to enamel is much more difficult to achieve in vivo. Improvements in bond strength of direct bonding systems in vivo, therefore, are dependent not only upon improved retention to bases but also on improved techniques to achieve more ideal bonding of the adhesive to the enamel. However, the emphasis in the present study was given on evaluation of design characteristics of metal bases.

For Sapphire brackets majority of debonding failures occurring at bracket-resin interface (Table 4) can be explained on the basis of faulty mesh framework. Imperfections in mesh design might have lead to stress concentration at the bracket resin interface making it prone to early bond failures. Also faulty mesh design prevents proper penetration of the resin into the mesh which creates air voids at the interface. Air entrapment will result in oxygen inhibition of polymerization and a layer of uncured resin. Presence of air voids and layer of uncured resin are certainly responsible for low bond strength. For Gemini, Mini Twin and Mini Diamond brackets, majority of debonding failures were seen at bracket resin interface (Table 4) but the threshold for bond failure for these three groups was definitely much higher than the Sapphire brackets. For Mini Diamond brackets one of the factors for weak bracket resin interface could be low open area percentage. For Nu-Edge and Mini Diagonali brackets the bracket resin interface proved to be stronger than rest of the study bracket groups as no debonding occurred at that site (Table 4). Both these groups also had comparable open area percentage. The differences in the SBS values of different bracket bases might also have been influenced by the difference in treatment of bracket bases by the respective manufacturers.

Thus, results of this study indicate that bond strengths obtained with different commercially available bracket bases are different when using the same adhesive.

CONCLUSION

The results of the present study can be concluded as:

- Gemini brackets proved to be the most clinically reliable brackets followed by Mini Diagonali brackets and Nu-Edge brackets. These brackets are expected to show lower clinical bond failures. Mean shear bond strength of Nu-Edge brackets was highest among all bracket groups.
- Sapphire brackets recorded the least mean shear bond strength inspite of larger surface area, high open area percentage and large aperture width. Faulty mesh framework with broken mesh wires was seen in Sapphire brackets. Sapphire brackets were the least clinically reliable bracket group.
- There was a difference in calculated mesh gauze size from that of the provided mesh gauze size (by the manufacturers, dealers and literature). Except for Mini Diagonali brackets, there was a difference in the calculated mesh gauze size and the provided mesh gauze size. The largest difference was seen for Nu-Edge brackets followed by Gemini, Mini Diamond, Mini Twin and Sapphire brackets.
- The differences in the shear bond strength values seen in the study could not be attributed to differences in the mesh gauze sizes.
- For Nu-Edge and Mini Diagonali brackets, bracket resin interface appeared to be the strongest among all other groups as no bond failure was seen at this site.
- For Gemini, Sapphire and Mini Twin brackets, bracket resin interface proved to be the weakest interface as maximum bond failure was seen at this site.

REFERENCES