ORIGINAL ARTICLE

Bond strength of various bracket base designs

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To determine the influence of various bracket base designs on bond strength and debond interface, 6 types of metal interlock brackets of different sizes and with different base designs were evaluated. The bracket base types and mesh sizes tested were as follows: retention groove base (Dynalock, Unitek, Monrovia, Calif), circular concave base (Accuarch appliance Formula-R, Tomy, Tokyo, Japan), double mesh with 5.1×10^{-2} mm^2 mesh size (Ultratrimm, Dentaurum, Ispringen, Germany), double mesh, 3.1×10^{-2} mm^2 (Minidiagonali Roth, Leone, Florence, Italy), double mesh, 3.1×10^{-2} mm^2 (Tip-edge Rx-I, TP Orthodontics, LaPorte Ind), and double mesh, 2.9×10^{-2} mm^2 (Mini Diamond, Ormco, Glendora, Calif). The Unitek bracket is cast in 1 piece; the other brackets are welded together. Brackets were bonded to human teeth and then debonded on a testing machine. The debond interface was recorded and analyzed with scanning electron microscopy and energy-dispersive x-ray spectrometry, and the distribution of interfaces was determined. The ranking of bond strength of individual bases (kg/base) from highest to lowest was Tomy, Dentaurum, Unitek, Leone, TP Orthodontics, and Ormco. The ranking of bonding strength per area squared MPa from highest to lowest was Tomy, Dentaurum, Leone, Unitek, TP Orthodontics, and Ormco. Debond in interfaces occurred between the bracket and resin, within the resin, or between the resin and enamel. The most debonded interfaces were between the bracket and resin and between the resin and enamel. The Tomy bracket, with its circular concave base, produced greater bond strength than did the mesh-based brackets; among the mesh-based brackets, Dentaurum, with the larger mesh size, produced greater bond strength than the brackets with smaller mesh sizes. The Unitek bracket, with its 1-piece cast base with retention grooves, ranked in the midrange of bond strength. (Am J Orthod Dentofacial Orthop 2004;125:65-70)

Several factors influence the bond strength of brackets,[1-11] including the size and design of the bracket base. The attachment must be able to deliver orthodontic forces and masticatory loads, and be esthetic and easily removed at the end of treatment.[4] A mechanical undercut 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.[4-15] Studies[16,17] have indicated that bond failure in enamel-bonded metal brackets with a mechanical interlock and 15 seconds of acid etching time[17] occurs at the resin-bracket base interface, within the resin itself, or between the resin and enamel. However, there was relatively greater bond failure between the resin and bracket because of stress concentrations and defects in the resin film.[5,16,17] A bracket with good retentive bonding between the resin and metal base is needed.

Two designs of metal bracket bases are available in Taiwan: a single-piece casting formed with a retention groove on the base, and a mesh or a circular, concave form that is laser welded with silver directly to the bracket body. The size of the base and the base design might affect bond strength. The purpose of this study was to determine the bond strength and debonding interface distributions of 6 types of brackets, each representing a unique combination of base design and size.

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MATERIAL AND METHODS

Six types of direct-bond maxillary premolar metal brackets with mechanical interlocking bases were available in Taiwan market at the time of this study; those brackets were selected for testing. The brackets were evaluated for various design characteristics, including

Table I. Characteristics of 6 maxillary premolar metal brackets

Brand and bracket name	*Batch number*	*Base type and mesh spacing (mm^2)*	*Nominal area of base (mm^2)*	*Manufacturer*	*Base design*
Dynalock	018-503	Retention groove	10.54	Unitek, Monrovia, Calif	Cast
Accuarch appliance Formula-R	901-404R	Circular concave	9.9	Tomy, Chiyoda-Ku, Tokyo, Japan	Welded
Ultratrimm	713-022-5	Double mesh, 5.1×10^{-2}	9.6	Dentaurum, Ispringen, Germany	Welded
Minidiagonali Roth	7129-02	Double mesh, 3.1×10^{-2}	8.8	Leone Co. Sesto, Florentine, Florence, Italy	Welded
Tip-edge Rx-I	296-045	Double mesh, 3.1×10^{-2}	9.0	TP Orthodontics, LaPorte, Ind	Welded
Mini Diamond	351-0506	Double mesh, 2.9×10^{-2}	8.0	Ormco, Glendora, Calif	Welded

whether the bracket was cast in 1 piece or welded together, base size, base type (retention groove, circular concave, or mesh), and mesh size. The brackets tested were as follows: Dynalock (Unitek, Monrovia, Calif), Accuarch appliance Formula-R (Tomy, Tokyo, Japan), Ultratrimm (Dentaurum, Ispringen, Germany), Minidiagonali Roth (Leone, Florence, Italy), Tip-edge Rx-I (TP Orthodontics, LaPorte, Ind), and Mini Diamond (Ormco, Glendora, Calif). The characteristics of the 6 brackets are listed in Table I.

A total of 120 maxillary premolars were collected from patients (9-16 years of age) undergoing orthodontic treatment. The teeth were washed and stored in physiologic saline solution in a closed plastic box; they were used for testing within a 3 months. The criteria of tooth selection were as follows: (1) the crown was grossly perfect with no defect, (2) the tooth had never been pretreated with a chemical agent, such as hydrogen peroxide or formalin, and (3) the contour of the labial surface of the tooth crown was adapted to the base of the bracket before bonding. The teeth were randomly divided into 6 groups of 20 teeth each.

The buccal surface of each crown was polished with pumice powder (Prophypol fine particle, Myco Industries, Philadelphia, Pa) water paste containing no fluoride or oil for 10 seconds and then rinsed with abundant water spray and dried with air spray. The buccal surface of the enamel was etched for 15 seconds with 30% phosphoric acid solution.[16,17] After etching, the outline of the bracket base was demarcated on the etched buccal enamel with a pencil. The surface outside the encircled area was coated with red nail polish before bonding to standardize the bonding area of the resin. The bonding agent (Concise, 3M, St Paul, Minn) was applied to the central white surface of the pretreated crown and bracket base. Concise orthodontic composite resin was also mixed and applied to the bracket base, and the bracket was pressed onto the demarcated etched buccal enamel with a placement scaler. Once the bracket was in the correct position, the scaler was removed. Excess composite resin was removed from the margin of the bracket with a dental probe. All specimens were completed within 24 hours.

The treated specimens were incubated in a 37°C water bath for 24 hours and then tested on an Instron universal machine (Model 1000, Instron, Boston, Mass) with a tensile force of 2 mm/min crosshead speed. The debond interfaces were examined with a scanning electron microscope (Canscan, Serial 4, Cambridge, United Kingdom) and mapped with energy-dispersive x-ray spectrometry (Philips, EDAX, SW 9100, Hillegon, The Netherlands); distributive percentages were calculated. Details of these procedures were described in a previous study.[17] Bond strength and debonded interface distribution were recorded. Means and standard deviations were determined and analyzed with SAS software (SAS Institute, Cary, NC) by 1- or 2-way analysis of variance (ANOVA). The Scheffé test was used to further identify statistically significant differences. The level of statistical significance was set at $\alpha = .05$.[18]

The normal area of each bracket base was measured by planimetric photography.

RESULTS

The overall mean bond strengths were 9.67 ± 1.79, 8.56 ± 2.15, 8.12 ± 1.94, 7.19 ± 1.68, 5.60 ± 1.00, and 3.81 ± 1.17 kg/base for the Tomy, Dentaurum, Unitek, Leone, TP Orthodontics, and Ormco brackets, respectively (Table II). The statistical analysis of bonding strength with 1-way ANOVA gave an F value of 32.65 (ie, a statistically significant difference; $P < .05$). The Scheffé test was chosen ($\alpha = .05$) for further analysis and comparison. The F value of 2.29 showed that there were statistically significant differences among the brackets.

According to bonding strength, the brackets of Tomy, Dentaurum, and Unitek have relatively strong bonds. However, the brackets of Leone, TP Orthodontics, and Ormco have relatively weak bonds.

The mean bond strengths per area squared were 9.32 ± 1.77, 8.24 ± 2.26, 7.85 ± 2.26, 7.16 ± 1.77,

Table II. Tensile bond strength of 6 bracket bases (kg/base)

Bracket type	Mean	Standard deviation
Tomy (W)	9.67	1.79
Dentaurum (W)	8.56	2.15
Unitek (C)	8.12	1.94
Leone (W)	7.19	1.68
TP Orthodontics (W)	5.60	1.00
Ormco (W)	3.81	1.17

One-way ANOVA, $P < .05$.
W, welded; *C,* cast.

Table III. Tensile bonding strength (MPa) per base area squared of 6 brackets

Bracket type	Mean	Standard deviation
Tomy (W)	9.32	1.77
Dentaurum (W)	8.24	2.26
Leone (W)	7.85	2.26
Unitek (C)	7.16	1.77
TP Orthodontics (W)	5.69	1.18
Ormco (W)	4.32	1.38

One-way ANOVA, $P < .05$.
W, welded; *C,* cast.

5.69 ± 1.18, and 4.32 ± 1.38 MPa for the Tomy, Dentaurum, Leone, Unitek, TP Orthodontics, and Ormco brackets, respectively (Table III). The statistical analysis of bonding strength with 1-way ANOVA gave an F value of 20.19 (ie, a statistically significant difference; $P < .05$). The Scheffé test was chosen ($\alpha = .05$) for further analysis and comparison. The F value of 2.29 showed that there were statistically significant differences among the brackets. The bonding strengths of Tomy, Dentaurum, and Leone were relatively strong. The brackets of Unitek, TP Orthodontics, and Ormco have relatively weak bonds.

Photomicrographs of the bracket bases under scanning electron microscopy observation are shown in the Figure.

Three types of debonded interfaces were found: between the bracket base and resin, cohesive failure within the resin itself, and between the resin and enamel. The distributive percentages of the various debonded interfaces are shown in Table IV. The statistical relationships among the 6 types of brackets and the 3 types of debonded interface distributions were analyzed with 2-way ANOVA. The F value among the 6 types of brackets and 3 types of debonded interface distributions was 5.30, which indicates a statistically significant difference ($P < .05$). The F value among the 6 types of brackets was 0, and thus no statistically significant difference was indicated ($P > .05$). The F value of the 3 types of debonded interface distributions was 60.74, which indicates a statistically significant difference ($P < .05$). The α value of .05 was chosen for the post hoc treatment with the Scheffé test. The ranking of the debonded interfaces from high to low was between the bracket and resin, between the enamel and resin, and within the resin itself, among which there were statistically significant differences. All values of the simple main effect of the debonded interface of the 6 types of brackets were .001 with a statistically significant difference ($P < .05$). The Scheffé test was chosen for the post hoc treatment, and an α value of .05 was chosen. The ranking of the 3 types of debonded interfaces between the bracket and resin, between the enamel and resin, and within the resin itself.

DISCUSSION

The results of this study indicate that the relative bonding strength for the Tomy bracket was 9.67 kg/base or 9.32 MPa. This bracket has a relatively large base (9.9 mm^2) with many circular concavities that allow air to escape so that the composite resin can penetrate into the concave surfaces (Fig, *B*). This resulted in better retention and relatively less debonding between the bracket and resin (35.3%) than occurred with other bracket base designs.

MacColl et al[19] reported that there were no statistically significant differences in shear bond strength among brackets with 12.35-mm^2 and 8.41-mm^2 bases; however, 6.82-mm^2 and 2.38-mm^2 bases did differ. Our study seems to support their findings with statistical analyses: the larger the base, the greater is the bond strength.

According to Siomka and Powers,[15] the bond strength of Dynalock brackets, which are cast in 1 piece and have grooved retention bases, is greater than that of the brackets with mini-mesh bases, when bonded without acid etching of the base; this agreed with our results. Siomka and Powers used a no-mix adhesive to plastic substrates. However, they also found that etching, etching plus silanation, and etching plus surface activation of Dynalock bases or silanation and silanation plus etching treatment of mini-mesh bases significantly increased bond strength. Etching and silanation might change the surface morphology of the bracket base. The Dynalock bracket produced moderate bond strength compared with the 5 other brackets tested; however, the technique for manufacturing this bracket is more difficult and expensive.

The wire diameter and mesh spacing determine the number of openings per unit area of the bracket base.[11] The free volume between the mesh and the base will

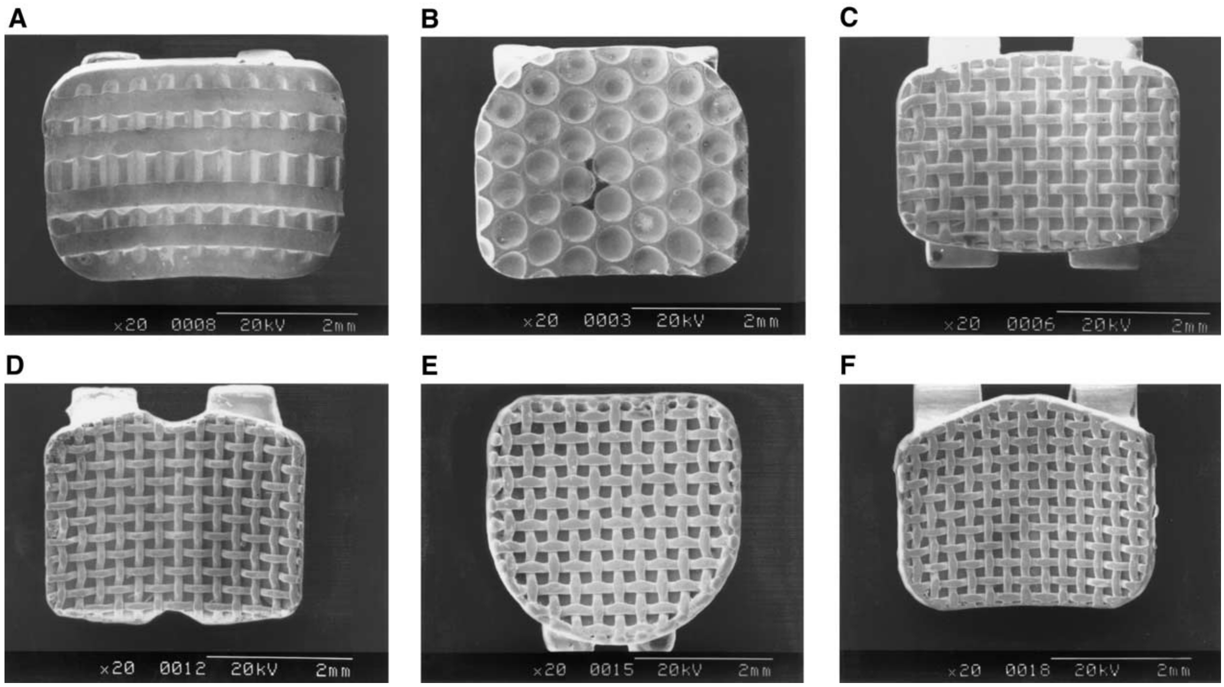

Fig. **A**, Unitek (Dynalock) bracket base bracket with horizontal retention groove; **B**, Tomy bracket base, with regular circular concave form; **C**, Dentaurum bracket, with relatively large mesh spacing; **D**, Leone bracket, with relatively small mesh spacing; **E**, TP Orthodontics bracket, with relatively small mesh spacing; **F**, Ormco bracket, with relatively small mesh spacing.

Table IV. Distribution (%) of debonded interfaces

	A		*B*		*C*			
Bracket type	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	P	*S*
Tomy	35.3	12.8	21.8	10.7	43.0	10.1	.001	A, C > B
Dentaurum	32.3	13.8	22.5	10.5	45.3	11.0	.001	A, C > B
Unitek	37.3	10.7	25.0	10.6	37.8	9.93	.001	A, C > B
Leone	41.3	9.58	27.0	8.33	31.8	10.4	.001	A, C > B
TP Orthodontics	43.8	12.3	25.0	10.4	31.3	10.4	.001	A, C > B
Ormco	41.5	11.5	26.3	10.5	32.3	7.86	.001	A, C > B

A, interface between bracket and resin; *B,* interface within resin itself; *C,* interface between resin and enamel; *P,* significance of simple main effect; *S,* Scheffé test ($\alpha = .05$); *SD,* standard deviation.

also affect the penetration of resin, the escape of air, and the effectiveness of bonding.[11] The Dentaurum, Leone, TP Orthodontics, and Ormco brackets have mesh-type bases, with mesh spacing that ranges from relatively large (Dentaurum, 5.1×10^{-2} mm^2) to small (Ormco, 2.9×10^{-2} mm^2) (Fig, *C-F*). The results showed that the larger the mesh spacing, the greater was the bond strength.

The 60-, 80-, and 100-mesh bases all have different mesh spacings. Knox et al[4] reported that the bond strength of the 100-mesh size with Concise bonding agent was greater than that of 60- and 80-mesh sizes with statistically significant differences. The bonding strength of Dynalock showed no statistically significant differences from 60-, 80-, and 100-mesh bases.[4] Those results differed from the data of our study. The larger mesh spacing produced greater bond strength, and the Dynalock brackets produced moderate bond strength compared with the mesh brackets. The different results might have been due to (1) the strength of the bracket-cement interface determined by aligning and opposing identical bracket bases and "sandwiching" a given cement between the 2 bracket bases, (2) a metal adhesive (Permabond ESP 110, Permabond UK, Eastleigh, Hants, United Kingdom) used, (3) the incisor brackets used, (4) storing the specimens in a water bath at 37°C for 1 hour before debonding, or (5) conducting the debonding tests in tension with a crosshead speed of 0.5 mm/min.[4] However, the tensile strength used in their study to detect the force was the same as that used in this study.

The bond strength of bracket bases with mesh sizes of 80 to 100 meshes was significantly greater than that of brackets with a mesh size of less than 70. The adhesive had a substantially lower percentage of filler and a finer particle size, thus possibly leading to better penetration.[11] The tensile bond strength with a 60-mesh base is greater that of 100-mesh base when used with unfilled, low-filled, or highly filled cements with plastic cylinders or natural teeth.[12] We used Concise, which is a highly filled adhesive that can have difficulty penetrating into the mesh or between the base and mesh, or allowing air to escape. Hence, the larger the size of the mesh spacing, the greater is the bond strength.

Only 1 specific bonding resin was considered in this study, although many other bonding systems are also available. These different systems have a wide range of viscosities and wetting characteristics. Different results might have been obtained with other cementing media. For example, a lower-viscosity cement that has better wetting characteristics on the bracket base could possibly take advantage of the larger number of potential mechanical hooks provided by a bracket base with a smaller mesh. This issue should be investigated further.

The old-style mesh bases were welded onto the bracket body. The weld spot reduced the retention area and bonding strength.[11] At times, the weld mesh detached from the bracket body after debonding.[11] The welding technique has been improved, and now the mesh is welded to the bracket base with silver and with a laser; this seems to eliminate the weld spot in the bracket base surface (Fig, *B-F*).

There were no differences in the bond strength with etching times of 15, 30, 60, and 90 seconds, but there was at 120 seconds. However, enamel detachment was found when the etching time exceeded 30 seconds[17] or the concentration of the phosphoric acid solution exceeded 30%.[16] This means that bonding between the enamel and resin might be limited by acid etching, including etching time and the concentration of phosphoric acid. Hence, 15 seconds of acid etching with a 30% phosphoric acid solution was used in this study.

The metal or ceramic porous or particulate-coated base might have significant advantages in retention and stability over currently used conventional metal bases[5,7]; hence, a change in base irregularity might improve retention between the bracket base and resin and bond strength.

The results of this study of tensile bond strength are consistent with those in previous reports.[1,4,5,18,20] There were no statistically significant differences between the results of tensile bonding strength and shear bonding strength.[20] In this test, only the former method was used, because it was more easily carried out on small-size brackets.

CONCLUSIONS

1. The size and design of a bracket base can affect bond strength.
2. The Tomy bracket, with a circular concave base design, produced greater bond strength than the Dentaurum, Leone, TP Orthodontics, and Ormco brackets, with their mesh bases.
3. Among the brackets with mesh-type bases, the larger the mesh spacing, the greater the bond strength.
4. The Unitek 1-piece cast bracket with a horizontal retention groove base produced moderate bond strength.
5. Most debonding interfaces are between bracket and resin and between enamel and resin.

REFERENCES

1. Bishara SE, Gordan VV, VonWald L, Olson ME. Effect of an acidic primer on shear bond strength of orthodontic brackets. Am J Orthod Dentofacial Orthop 1998;114:243-7.
2. Rix D, Foley TF, Mamandras A. Comparison of bond strength of three adhesives: composite resin, hybrid GIC, and glass-filled GIC. Am J Orthod Dentofacial Orthop 2001;119:36-42.
3. Grandhi RK, Combe EC, Speidel TM. Shear bond strength of stainless steel orthodontic brackets with a moisture-insensitive primer. Am J Orthod Dentofacial Orthop 2001;119:251-5.
4. Knox J, Hubsch P, Jones ML, Middleton J. The influence of bracket base design on the strength of the bracket-cement interface. Br J Orthod 2000;27:249-54.
5. Smith DC, Maijer R. Improvement in the bracket base design. Am J Orthod 1983;83:277-88.
6. Matasa CG. Direct bonding metallic brackets: where are they heading? Am J Orthod Dentofacial Orthop 1992;101:552-60.
7. Hanson GH, Gibbon WM, Shimizu H. Bonding bases coated with porous metal powder: a comparison with foil mesh. Am J Orthod 1983;83:1-4.
8. Rossouw PE, Titley KC, Yamin C. The relationship between bond strength and base surface area using conventional and micro-etched foil-mesh bases. Am J Orthod Dentofacial Orthop 1988;113:276-81.
9. Lopez JI. Retentive shear strengths of various bonding attachment bases. Am J Orthod 1980;77:669-78.
10. Dickinson PT, Powers JM. Evaluation of fourteen direct-bonding orthodontic bases. Am J Orthod 1980;78:630-9.

11. Maijer R, Smith DC. Variables influencing the bond strength of metal orthodontic bracket bases. Am J Orthod 1981;79:20-34.
12. Buzzitta VAJ, Hallgren SE, Powers JM. Bond strength of orthodontic direct-bonding cement-bracket systems as studied in vitro. Am J Orthod 1982;81:87-92.
13. Hanson GH, Gibbon WM, Shimizu H. Bonding base coated with porous metal powder: a comparison with foil mesh. Am J Orthod 1983;83:1-4.
14. Williams VD, Dedmon HW. The retentive capacity of re-bonded retainers to enamel. J Prosthet Dent 1984;51:205-8.
15. Siomka LV, Powers JM. In vitro bond strength of treated direct-bonding metal bases. Am J Orthod 1985;88:133-6.
16. Wang WN, Yeh CL, Fang BD, Sun KT, Arvystas MG. Effect of phosphoric acid concentration on bond strength. Angle Orthod 1994;64:377-82.
17. Wang WN, Lu ZC. Bond strength with various etching times on young permanent teeth. Am J Orthod Dentofacial Orthop 1991; 100:72-9.
18. Steel PRG, Torrie JH. Principles and procedures of statistics. 2nd ed. New York: McGraw-Hill; 1980.
19. MacColl GA, Rossouw PE, Titley KC, Yamin CY. The relationship between bond strength and orthodontic base surface area with conventional and microetched foil-mesh base. Am J Orthod Dentofacial Orthop 1998;113:276-81.
20. Schulz RP, Mayhew RB, Oesterle LJ, Pierson WR. Bond strengths of three resin systems used with brackets and embedded wire attachment. Am J Orthod 1985;87:75-80.