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Shear bond strength of a new polycarbonate bracket—an *in vitro* study with 14 adhesives

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SUMMARY Shear bond strength and failure location were used to evaluate the effectiveness of plastic bracket primers for bonding diacrylate adhesives on a new fibre-reinforced polycarbonate bracket.

Maxillary incisor polycarbonate and mesh-based brackets as control were bonded to human incisors with 14 different adhesives (four filled diacrylate two-paste, six diacrylate one-step and four powder–liquid acrylic adhesives), and after thermo-cycling for 2000 cycles between 5° and 55°C, tested in shear. A non-parametric test (Mann–Whitney *U* test) was used to compare the shear bond strength of the polycarbonate brackets with the mesh based brackets and a One-way test (according to Scheffe) to compare the shear bond strength of different adhesives. The following conclusions can be made:

1. Seven of the 14 adhesives used in this study with both types of brackets demonstrated adequate shear bond strength values for the clinical application. The exceptions were: Achieve Mix, No-Mix:30 Silkon, Lee Insta-Bond, Ortho-Loc and Bond-Eze, all with too low a shear bond strength for one or both types of brackets, and finally Quasar, which used with the plastic brackets sometimes caused enamel fractures, due to a very high bond strength.
2. The adhesives with their own plastic primer demonstrated higher bond strength values than those without plastic primer, and two-paste adhesives used with plastic primer displayed a higher bond strength than the other adhesives.
3. Generally, the shear bond strength values of the one-step adhesives were lower compared with the two-paste adhesives.
4. The liquid-powder adhesives demonstrated very different values for bond strength.

Introduction

Since the introduction of the acid-etch technique in 1955 by Buonocore, bonding to enamel has found a number of applications in all disciplines of dentistry. One of them is the bonding of orthodontic brackets, either direct or indirect. Because of the immense search for aesthetics in the field of orthodontics, manufacturers have marketed brackets made of various types of plastic (Miura *et al.*, 1969, 1971; Newman, 1969, 1971). Although these brackets received initial acceptance by many clinicians, they were soon abandoned because of slot dimension distortion and staining (Dobrin *et al.*, 1975).

In late 1986 the first bracket made of ceramic material became widely available. Subsequently, anecdotal reports of bracket failure and tooth damage associated with the use of ceramic brackets have been published (Schwartz 1980; Birnie 1990; Joseph and Rossouw 1990).

The most recent aesthetic brackets have been constructed of a glass-filled plastic material to prevent slot-dimension distortion and to reduce staining. These brackets employ a chemically retentive mechanism for adhesion to enamel. Plastic brackets have been used principally with acrylic adhesives. Diacrylate cements used with the plastic brackets were found not to bond well (Moser *et al.*, 1979; Pulido and Powers, 1983). Bracket primers were developed to improve bonding of diacrylate adhesives to plas-

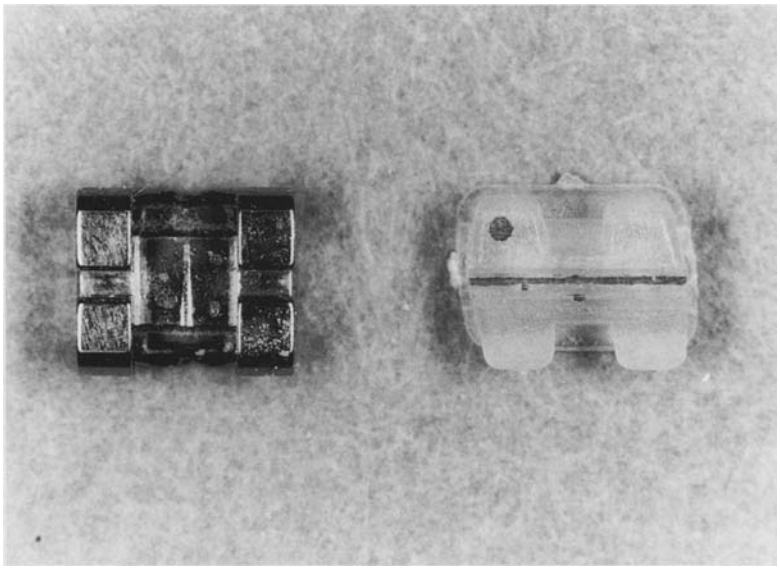

Figure 1 The different types of brackets used. Left, ULTRATRIMM® metal brackets with a mesh base; right, ÄSTHETIK-LINE® glass-filled and reinforced polycarbonate brackets with a plain base.

tic brackets; however, some of these primers were not sufficiently effective.

The purpose of this study was:

(1) to test the shear bond strength of a new plastic bracket and to compare it with a metal bracket with a mesh base;
(2) to compare the shear bond strength of different commercially available adhesives used with plastic brackets and to evaluate the effectiveness of commercial bracket primers;
(3) to determine the fracture sites of the various specimens after debonding.

Materials and methods

Altogether 280 brackets of two different materials from two manufacturers and with different base designs were used. ULTRATRIMM® metal brackets with a mesh base were compared with ÄSTHETIK-LINE® glass-filled and reinforced polycarbonate brackets with a plain base (Fig. 1). The nominal base area of the metal and the plastic brackets was measured from photographic enlargements by use of a digitizer coupled to a computer. Three measurements were taken of each type of bracket base and the mean was used in the calculations. The code and the name of each product, the manufacturer, the design and the nominal area of the brackets bases are shown in Table 1.

Using 14 different adhesives, 10 brackets of each type (plastic and metal brackets) were bonded *in vitro* to freshly extracted human maxillary incisors. Table 2 gives the code and name of each product, the system, and the manufacturer.

Before bonding the extracted teeth were stored at room temperature in a 0.9% NaCl-

Table 1 Product, base design, nominal area and manufacturer of the brackets used.

Type	Base design	Nominal area (mm^2)	Manufacturer
ULTRATRIMM® Metal bracket	Mesh base	13.06	Dentaurum (Pforzheim)
ÄSTHETIK-LINE® Plastic bracket	Plain	11.13	Forestadent (Pforzheim)

Table 2 Manufacturer, code and system of the direct bonding adhesives.

Adhesive	Code	System	
Twinlook (Kulzer, Wehrheim, Germany)	A	Mix (Dual)	Primer
1 To 1 (TP Orthodontics, Indiana, USA)	B	Mix (Paste/paste)	Primer
Achieve (A-Company, California, USA)	C	Mix (Paste/paste)	
Accubond (GAC, N.Y., USA)	D	Mix (Paste/paste)	
Cleanse & Bond I (Lee Pharmaceuticals, California, USA)	E	No-Mix	Primer
Rely-A-Bond (Reliance, Illinois, USA)	F	No-Mix	Primer
No-Mix:30 Silkon (American Orthodontics, St. Phila, USA)	G	No-Mix	Primer
Lee Insta-Bond (Lee Pharmaceuticals, Calif., USA)	H	No-Mix	
Achieve (A-Company, California, USA)	I	No-Mix	
Ortho-Loc (GAC, N.Y., USA)	J	No-Mix	
Super-C Ortho (Amco, St. Phila, USA)	K	Mix (Powder/liquid)	
Genie (Lee Pharmaceuticals, California, USA)	L	Mix (Powder/liquid)	
Bond-Eze (Unitek, California, USA)	M	Mix (Powder/liquid)	
Quasar (Rocky Mountain, Colorado, USA)	N	Mix (Powder/liquid)	

solution. The teeth were then mounted in cold-cured acrylic, leaving only the buccal surface exposed (Fig. 2). After mounting, the test pieces were randomly separated into 14 groups (two for each bonding material) and stored in 0.9% NaCl-solution at 37°C.

Before bonding, the enamel surfaces were polished with a mixture of water and fluoride-free pumice using a rubber polishing cup. Thereafter, the enamel surfaces were etched for 30 seconds with the recommended etching liquid supplied by the manufacturer (37% ortho-phosphoric acid). The teeth were rinsed thoroughly with water and dried with an oil-free air source. The adhesives were mixed in accordance with the manufacturers' instructions. After mixing, the adhesive was applied to the bracket base with a mixing stick, the bracket was then placed on the etched enamel surface with a bracket plier and pressed against the tooth. With the plastic brackets, primers were used according to the manufacturers' instruction for adhesives 1 To 1, Cleanse & Bond I, Rely-A-Bond, and No-Mix:30 Silkon. For adhesive, Twinlook, 'Dentacolor Connector' (Kulzer, Wehrheim) was used as a primer. After bonding each bracket was optically examined and adhesive overlapping the bracket was removed. Ten minutes after bonding the teeth were moved to a 0.9% NaCl-solution for storage and thermocycled at 5–55°C for 2000 cycles.

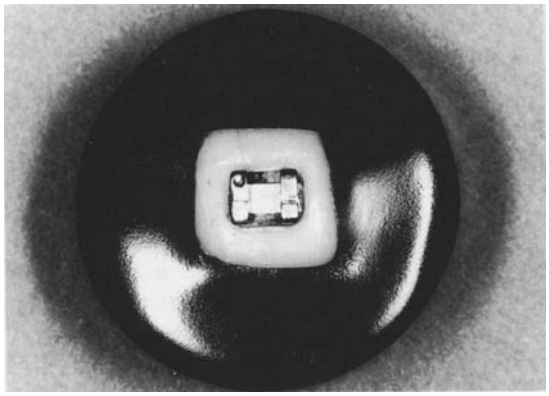

Figure 2 Tooth mounted in cold-cured acrylic with the bonded bracket ready to be tested.

The shear bond strength was tested using an Instron® (Canton, Mass., USA) testing machine. The circular acrylic test pieces were mounted in a jig with the brackets orientated in a vertical position (Fig. 3). A plate with a square opening of 5 by 4 mm made of stainless steel was fixed to the crosshead, with the lower edge of the opening hooked underneath the wings of the brackets (Fig. 2). The load was put underneath the occlusal wings of the bracket. The speed of the crosshead was 1 mm/minute. The force required to break the bond was recorded and the bond strength, expressed in N/mm^2 was calculated. Tooth and bracket were optically inspected to determine the predominant site of bond failure, defined as bracket/adhesive, enamel/adhesive or within the adhesive (Table 3).

Means and standard deviations of the shear bond strength within each test group of bracket type and adhesive were calculated (Table 4). The difference in shear bond strength between the two types of bracket base (metal versus plastic) was tested with Mann–Whitney *U* test,

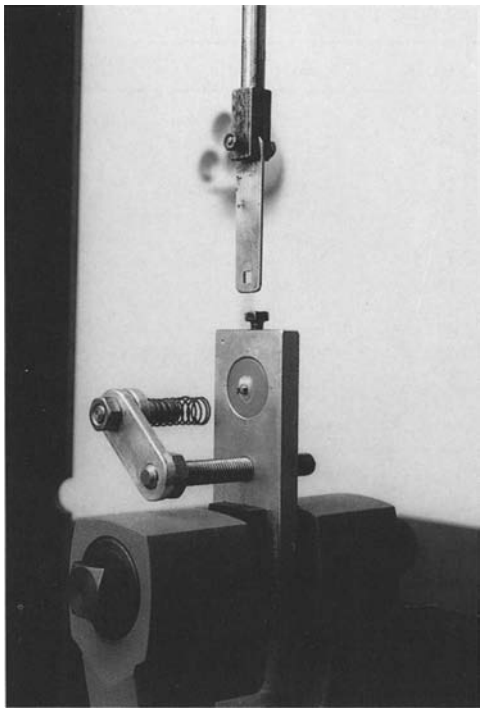

Figure 3 The Instron testing machine with the circular acrylic test pieces mounted in a jig.

Table 3 Failure site for the metal and plastic brackets with different adhesives.

	Failure site	
Code	Metal brackets	Plastic brackets
A	Bracket/adhesive	In adhesive
B	Bracket/adhesive	In adhesive
C	Bracket/adhesive	Bracket/adhesive
D	Bracket/adhesive	Bracket/adhesive
E	In adhesive	In adhesive
F	In adhesive	In adhesive
G	In adhesive	In adhesive
H	In adhesive	Bracket/adhesive
I	In adhesive	Bracket/adhesive
J	In adhesive	Bracket/adhesive
K	Enamel/adhesive	Enamel/adhesive
L	Enamel/adhesive	Enamel/adhesive
M	Enamel/adhesive	Enamel/adhesive
N	Bracket/adhesive	Enamel fracture

and a One-way Analysis of Variance Test according to Scheffe was used to test the effect of plastic bracket primer on the shear bond strength of the plastic bracket-cement adhesion.

Results

Shear bond strength

The comparison between plastic and metal bases within 14 groups of different adhesives is shown in Table 4.

For the plastic brackets the adhesive Quasar showed the highest bond strength with 19 N/mm^2 and the adhesive Achieve Mix the lowest with 3 N/mm^2. For the metal brackets the corresponding combination was Accubond with 11.6 N/mm^2 and No-Mix: Silkon 30 with 5.2 N/mm^2.

The plastic brackets showed significantly higher bond strength than the metal brackets together with the adhesives Twinlook and Quasar ($P<0.001$), and for 1 To 1 the bond strength was slightly higher ($P<0.05$). The metal brackets displayed a significantly higher shear bond strength together with the adhesives Achieve Mix ($P<0.001$), Lee Insta-Bond, Achieve No-Mix and Bond-Eze ($P<0.01$).

For the remaining adhesive groups, no difference in bond strength was found between plastic and metal brackets.

For the plastic brackets the One-way Analysis of Variance according to Scheffe showed a statistically significant difference between groups with the one-step diacrylate adhesives ($P<0.01$) (Fig. 4) and the two-paste diacrylate adhesives with and without primers ($P<0.001$) (Fig. 5). Brackets bonded with primer showed a higher bond strength.

For the metal brackets the mix adhesives (paste/paste) 1 To 1, Achieve Mix, and Accubond showed higher bond strength than the other adhesives.

Site of bonding failure

The sites of bonding failure are shown in Table 3. The site of bonding failure for the plastic brackets, bonded with two-paste and one-step adhesives, and using primers, was found within the adhesives. For the same adhesives, but without primers, the bonding failures were situated on the bracket surface. For the metal brackets, bonded with the two-paste (dual and paste/paste) and one-step adhesives, the site of bond failure was found on the bracket surface.

For plastic as well as metal brackets, bonded with powder-liquid adhesives, the bonding failures were found on the enamel surface. Enamel

Table 4 Shear bond strength of the metal and plastic brackets with different adhesives in N/mm²

Adhesive	Bracket base	*n*	*x*	SD	Min.	Max.	*P*
A	Mesh base	10	6.98	1.43	5.36	10.26	***
(Twinlook)	Plain plastic base	10	13.21	3.11	7.45	17.57	
B	Mesh base	10	11.49	3.69	6.58	19.14	*
(1 To 1)	Plain plastic base	10	14.89	4.53	9.32	23.30	
C	Mesh base	10	11.04	3.98	6.36	18.38	***
(Achieve Mix)	Plain plastic base	10	3.17	2.29	1.84	9.54	
D	Mesh base	10	11.61	3.89	6.28	19.14	NS
(Accubond)	Plain plastic base	10	8.59	2.44	4.85	12.86	
E	Mesh base	10	7.37	2.84	2.76	12.56	NS
(Cleanse & Bond I)	Plain plastic base	10	8.02	3.80	2.91	14.76	
F	Mesh base	10	8.58	3.00	2.76	13.48	NS
(Rely-A-Bond)	Plain plastic base	10	9.48	2.66	5.19	15.73	
G	Mesh base	10	5.19	3.10	1.99	10.49	NS
(No-Mix:30 Silkon)	Plain plastic base	10	5.47	0.68	4.08	6.21	
H	Mesh base	10	8.99	3.03	3.14	14.09	**
(Lee Insta-Bond)	Plain plastic base	10	3.63	4.29	0.00	15.53	
I	Mesh base	10	8.27	2.1	4.75	11.94	**
(Achieve No-Mix)	Plain plastic base	10	4.63	1.46	2.43	7.87	
J	Mesh base	10	7.44	3.29	3.06	12.25	NS
(Ortho-Loc)	Plain plastic base	10	5.35	1.80	3.30	8.93	
K	Mesh base	10	10.76	3.67	4.75	18.76	NS
(Super-C Ortho)	Plain plastic base	10	12.26	4.25	5.44	18.41	
L	Mesh base	10	7.75	1.99	5.21	11.79	NS
(Genie)	Plain plastic base	10	7.90	2.66	5.05	13.20	
M	Mesh base	10	6.13	2.40	3.37	11.03	**
(Bond-Eze)	Plain plastic base	10	3.57	1.33	2.14	6.50	
N	Mesh base	10	9.40	3.91	2.76	15.62	**
(Quasar)	Plain plastic base	10	19.07	4.96	8.79	24.27	

NS, $P>0.05$; * $P<0.05$; ** $P<0.01$; *** $P<0.001$.

fractures were observed only after debonding of plastic brackets bonded with the adhesive Quasar.

Discussion

There were significant differences between the two-paste diacrylate adhesives with bracket primer and the same group of adhesives without primer. Comparison of means with the Scheffe interval showed that the two-paste adhesives with the bracket primer had the highest values of bond strength. It appears that the two-paste diacrylate adhesives without primer polymerized without adhering to the plastic bracket. This lack of bonding between the plastic brackets and diacrylate adhesives is explained by the lack of chemical reaction between the bracket and adhesive. Because of certain advantages offered from light-cured composites over chemically activated systems such as a longer working time, Adhesive A 'Twinlook' together with the primer 'Dentacolor Connector' (Kulzer, Wehrheim) seems to be adequate for use with polycarbonate brackets (Wilson, 1988; Wang and Meng, 1992). The shear bond strength produced by the adhesive without primer was very low, which indicates that poor results may be expected in clinical applications.

The metal brackets showed the highest bond strength with the two-paste diacrylate adhesives, which is in agreement with recent studies (Buzzita *et al.*, 1982; Reynolds and von Fraunhofer, 1977; Dickinson and Powers, 1980). The only exception was with the adhesive

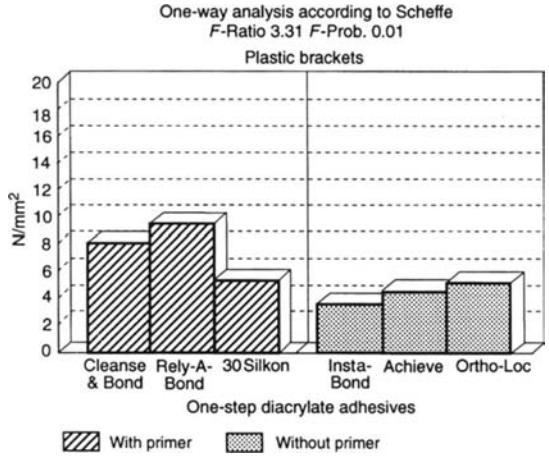

Figure 4 Two of the one-step diacrylate adhesives with primer (E and F) showed significantly higher bond strength than those without primer (H I J) ($P<0.01$).

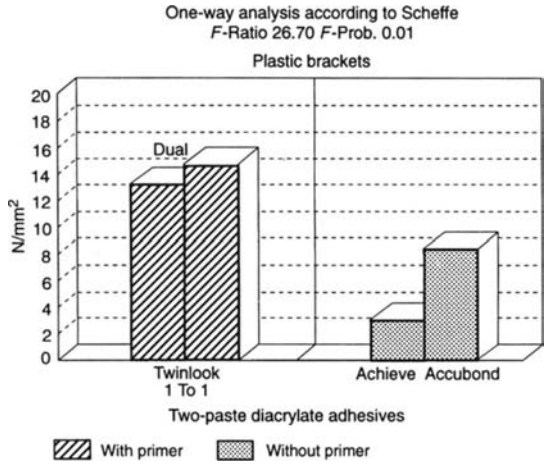

Figure 5 The two-paste diacrylate adhesives with primer (A, B) showed significantly higher bond strength than those without primer (C, D) ($P<0.001$).

Twinlook. Wang and Meng (1992) showed that there was no difference in bond strength of metal brackets bonded with light-cured and self-cured adhesives. According to the manufacturer, this adhesive offers advantages with ceramic and acrylic. The low bond strength of the mesh base with this adhesive could only be explained through the weak mechanical attachment of the adhesive in the undercuts of the bracket base.

With the one-step diacrylate adhesive all the metal brackets achieved the acceptable clinical niveau of 6–8 N/mm^2 (Reynolds and von

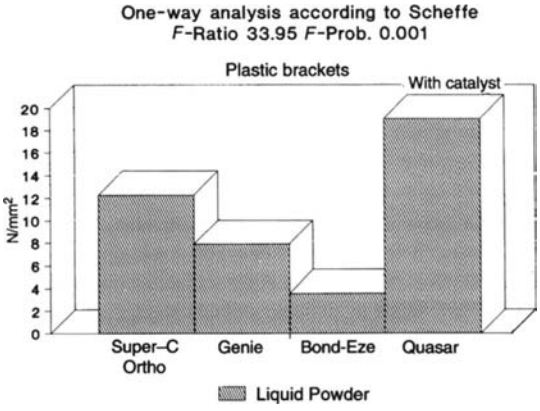

Figure 6 The liquid-powder cements (K, N) showed significantly higher bond strength than the other two (L, M) ($P<0.001$).

Fraunhofer, 1975) except for the adhesive No-Mix:30 Silkon. The plastic brackets which were bonded with plastic primer together with adhesives Cleanse & Bond I, Rely-A-Bond, and No-Mix:30 Silkon showed the same bond strength as the metal brackets (Harris *et al.*, 1992; Pulido and Powers, 1983), but there was a difference between the shear bond strength of the plastic brackets and mesh bases if no plastic primer was used (Pulido and Powers, 1983). This difference was statistically significant for the adhesives Lee Insta-Bond and Achieve No-Mix, but not for the adhesive Ortho-Loc.

The powder-liquid acrylic adhesives showed different results (Fig. 6). The adhesives Super-C Ortho and Genie showed no difference with the metal and plastic brackets, the adhesive Super-C Ortho showing higher shear bond strength (Moser *et al.*, 1979). The bond strength of the plastic brackets with adhesive Bond-Eze was insufficient. The adhesive Quasar caused enamel fracture if used with plastic brackets. The catalyst used to activate the acrylic adhesive seems to have an effect on the chemical adhesion between brackets/adhesive.

Conclusion

Reynolds and von Fraunhofer (1975) suggested that adhesives displaying a shear bond strength lower than 6–8 N/mm^2 are not suitable for clinical use. Thus, with the exception of No-Mix:30 Silkon, all 14 adhesives used in the present study seem to have been adequate for

bonding of metal brackets. For the plastic brackets however, only eight of the 14 adhesives displayed a bond strength > 6 N/mm^2.

The adhesive Quasar used with a special catalyst demonstrated the highest bond strength with plastic brackets. The catalyst used with this adhesive seems to improve the penetration of the adhesive into the enamel. The shear bond strength reached values > 20 N/mm^2 and sometimes caused enamel fractures.

The shear bond strength of the one-step adhesives was, for both types of brackets, lower than for the two-step adhesives.

This new polycarbonate bracket material should also be investigated regarding slot dimension distortion and staining.

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