Shear bond strengths of ceramic brackets bonded with different light-cured glass ionomer cements: an *in vitro* study

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SUMMARY The purpose of this study was to evaluate the shear bond strengths of four light-cured glass ionomer cements used for direct bonding of ceramic brackets, and to compare the results with a two-paste chemically-cured composite resin. Two commercially available polycrystalline ceramic brackets, with either chemically or mechanically retentive bracket bases, were evaluated. The brackets were bonded to 100 freshly extracted bovine incisors, and, after storage in tap water at room temperature for 24 hours, they were subsequently tested in a shear mode using a universal testing machine. The maximum bond strength and the site of bond failure were recorded.

With the mechanically retentive base, Fuji Ortho LC produced the highest bond strength (18.50 MPa), which was not significantly different from the values achieved with Concise (14.88 MPa) ($P > 0.1$) and Photac Bond (13.86 Mpa) ($P = 0.1$). The lowest bond strength was provided by Iocomp A20 (5.23 MPa).

With the chemically retentive base, the highest bond strength was measured with Concise (29.27 MPa), which was significantly ($P < 0.01$) higher than the values for Photac Bond (16.27 MPa) and Fuji Ortho LC (13.48 MPa). Again Iocomp A20 produced the lowest bond strength (3.21 MPa).

Three cements (Dyract Ortho, Iocomp A20 and Fuji Ortho LC) provided higher shear bond strengths with the mechanical retention system, whereas Concise and Photac Bond gave higher strengths with the silane-treated bracket bases. However, the strengths were statistically significantly different only for Iocomp A20 ($P = 0.001$) and Concise ($P = 0.001$).

With the mechanically retentive base, Dyract Ortho and Iocomp A20 failed at the enamel-adhesive interface, whereas Photac Bond and Concise debonded at the bracket-adhesive interface. Fuji Ortho LC failed at both, the bracket-adhesive (40 per cent) and the adhesive-enamel (60 per cent) interface.

With the chemically retentive base, all the adhesives failed at the enamel-adhesive interface. Only one bracket fracture occurred in this study, and no enamel damage was detected.

Introduction

Since the introduction of the acid etch technique of enamel (Buonocore, 1955), the direct bonding of orthodontic brackets has become widely used by orthodontists resulting in a considerable improvement in aesthetics and oral hygiene, as well as reduction in chair working time.

However, fixed orthodontic therapy also has its disadvantages. During the bonding procedure, surface enamel may be lost both through pumicing and acid etching. Enamel can also be lost

during bracket debonding, through the clean-up of residual resin from the tooth, as well as during rebonding procedures.

Another potential risk in orthodontic therapy, in the absence of good oral hygiene, is the development of enamel surface decalcification around bracket margins within a few weeks (Gorelick *et al.*, 1982; Øgaard *et al.*, 1988; Jost-Brinkmann *et al.*, 1996), attributed to the prolonged accumulation and retention of plaque next to the attachment (Zachrisson and Zachrisson, 1971).

A bonding material that could make the tooth structure more resistant to caries, through fluoride release, yet provide the bond strength and properties of composite resins without the usual H_3PO_4 induced loss of enamel, would clearly reduce the negative iatrogenic effects of orthodontic therapy (Klockowski *et al.*, 1989).

Glass ionomer cements were invented by Wilson and Kent (1972) as hybrids of silicate and polycarboxylate cements, and first introduced for use in clinical restorative dentistry. Unlike conventional resins, they have the ability to bond physicochemically to both enamel and dentine (Kent *et al.*, 1973), and to non-precious metals and plastics (Hotz *et al.*, 1977). They adhere to the enamel surface without the need for acid etching. The bond strengths of glass ionomer cements may be enhanced by 'conditioning' the tooth surfaces with a weak acid, such as polyacrylic, to remove contaminants and debris (Swift, 1988). Other effective conditioning solutions include tannic acid, dodicin and surface-active microbial solutions. All have functional groups capable of hydrogen bonding to tooth material, which promote effective cleaning and wetting of the substrate surface (Powis *et al.*, 1982).

Glass ionomers release fluoride over long periods into adjacent enamel. This is more effective in rendering tooth structures resistant to the caries process than application of acidulated phosphate fluoride (Valk and Davidson, 1987). In addition, glass ionomer cements are able to absorb fluoride from fluoride tooth paste, thus acting as a rechargeable slow release fluoride device (Hatibovic-Kofman and Koch, 1991).

Although *in vitro* studies have shown that the bond strengths of glass ionomer cements are significantly lower than composite resins (Murray

and Yates, 1984; Klockowski *et al.*, 1989), other studies have suggested their possible use as orthodontic bonding adhesives (Tavas and Salem, 1990; Evans and Oliver, 1991). Since they possess a number of advantageous properties over composite resins that may outweigh their relatively inferior bond strength, further research seems appropriate.

Ceramic brackets were introduced in 1986 to meet the increased demand for more aesthetic orthodontic appliances. Current ceramic attachments are composed of either monocrystalline or polycrystalline aluminium oxide. These brackets are, however, not without problems, which include enamel wear (Douglass, 1989; Viazis *et al.*, 1990), bracket fracture (Flores *et al.*, 1990; Holt *et al.*, 1991; Ghafari, 1992), tooth damage on debonding (Swartz, 1988; Maskeroni *et al.*, 1990) and high friction (Pratten *et al.*, 1990; Angolkar *et al.*, 1990; Jost-Brinkmann *et al.*, 1992; Keith *et al.*, 1993). *In vitro* studies have suggested that high bond strengths are associated with an increased incidence of enamel fracture (Viazis *et al.*, 1990; Winchester, 1991).

Two types of ceramic bracket bases are available: one type (Figure 1a,b) has undercuts or grooves that provide a mechanical interlock to the adhesive, whereas the other (Figure 2a,b) has a smooth surface and relies on a chemical coating to enhance bond strength (Swartz, 1988). The latter bracket is coated with silica (glass) and then silane treated. One end of the silane molecule is a 'silanol' group, that can be bonded tenaciously to silica and its other end bonds to the acrylic resin. The resultant chemical bond is extremely strong and may cause the enamel-adhesive interface to be stressed during either debonding or sudden occlusal force impact (Swartz, 1988), with irreversible damage to the tooth. The high bond strengths of ceramic brackets can also be related to the increased rigidity and decreased distortion, as well as resulting in difficulty of peeling the bracket from the adhesive during debonding (Constant and Ogre, 1988). The rigid, brittle nature of both the ceramic bracket and the underlying enamel results in a poor environment for absorption of stress during debonding (Swartz, 1988). If the bond between the adhesive and the enamel is stronger than the
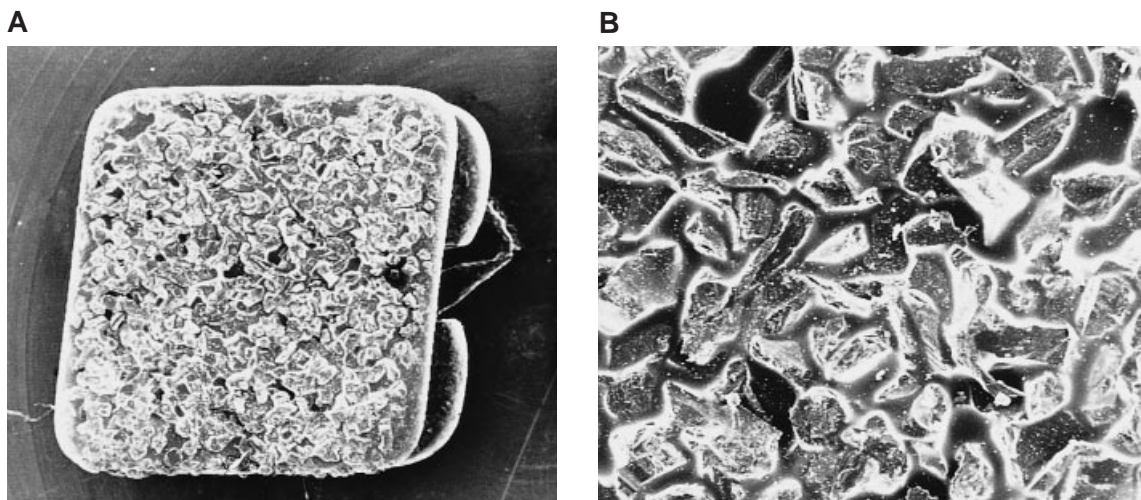
A

B

Figure 1 Scanning electron micrographs of a Transcend 6000 ceramic bracket showing the mechanically retentive base at (A) ×20.5 and (B) ×100 magnification.
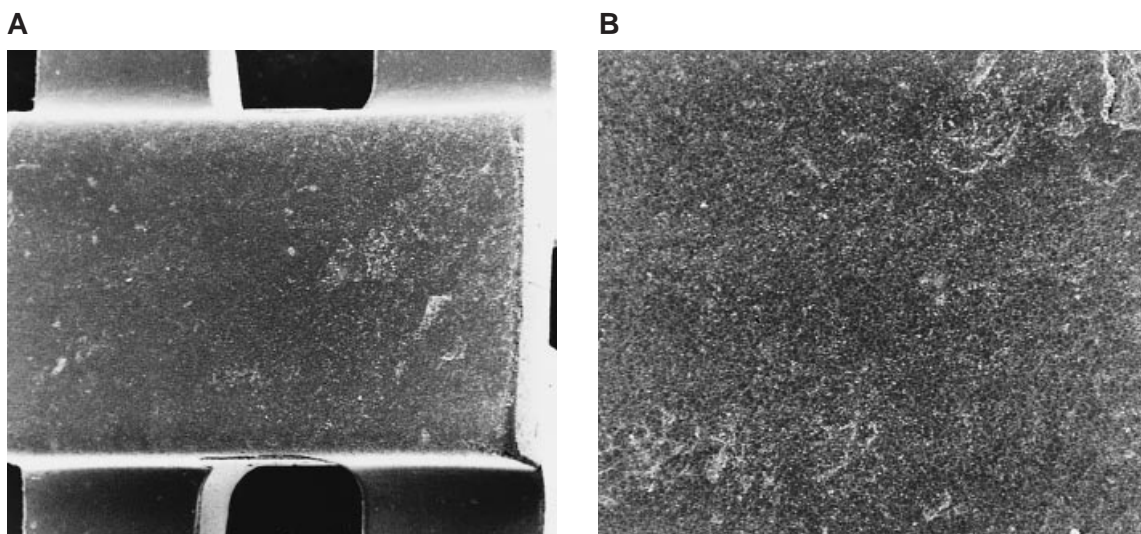
A

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Figure 2 Scanning electron micrographs of a Fascination ceramic bracket showing the chemically retentive base at (A) ×20.5 and (B) ×100 magnification.

enamel itself, the enamel will fracture during debonding. Recently, many manufacturers have employed different mechanisms to decrease the bond strength of ceramic brackets, including various retentive surfaces. The surface area is increased permitting mechanical interlocking of the bracket and the resin.

The aim of this study was to evaluate the shear bond strength of four light-cured glass ionomer cements used for direct bonding of ceramic brackets, and to compare the results with a two-paste chemically-cured composite resin. Two commercially available polycrystalline ceramic brackets, with either chemical or mechanical

retention in the bracket bases, were examined. The enamel conditioning was performed by using polyacrylic acid. In addition, the nature of the bond failure was investigated and the residual adhesive remaining after bracket debonding was recorded (Oliver, 1988).

Materials and methods

Four types of light-cured glass ionomer cements were tested in this study: (A) Dyract Ortho (DeTrey/Dentsply, Konstanz, Germany), (B) Iocomp A20 (DMG, Hamburg, Germany), (C) Photac Bond (Espe Co., Seefeld, Germany), and (D) Fuji Ortho LC (GC Corporation, Tokyo, Japan). These materials were compared with a two-paste chemically-cured orthodontic adhesive (Concise, 3M/Unitek, Monrovia, CA, USA) used as a control group (E).

Two types of commercially available maxillary left central incisor ceramic brackets with 0.018″ slots were studied. One bracket type was mechanically retained (Transcend 6000, 3M/Unitek, Monrovia, CA, USA), whereas the other bracket type was chemically retained (Fascination, Dentaurum Co., Pforzheim, Germany). Each type of bracket was placed in five groups, labelled groups A to E. Each group consisted of 10 brackets. A total of 100 brackets were tested.

One-hundred freshly extracted permanent bovine mandibular incisors were collected from a local slaughterhouse. The teeth were cleansed of soft tissue and most of the root was removed. They were embedded in cold-cured, fast setting acrylic (SG 130, Ebalta, Rothenburg/Tauber, Germany) with their labial surfaces exposed, and stored in tap water at room temperature. The teeth were randomly assigned to one of 10 groups. The facial surface of each incisor was ground wet for five minutes on a 350-grit silicone carbide paper using a DPU4 machine (Struers, Copenhagen, Denmark) and afterwards cleaned with a mixture of water and fluoride-free polishing paste (Oral-B, Frankfurt a. M., Germany) using a rubber polishing cup. The enamel surface was rinsed with water to remove the polishing paste, dried with a stream of oil-free air and conditioned with polyacrylic acid (GC Co., Tokyo, Japan) for 10 seconds. The teeth were then rinsed

Figure 3 Placement of the bracket near the centre of the facial surface of the tooth with sufficient pressure to express excess adhesive.

with water for 30 seconds and dried. The brackets were then bonded with adhesives (A) to (E) following the manufacturers' guidelines. The teeth bonded with Concise were also cleaned with polishing paste as described above, followed by etching with 37 per cent phosphoric acid for 30 seconds.

All brackets were placed by one operator near the centre of the facial surface of the tooth with sufficient pressure to express excess adhesive (Figure 3). Excess adhesive was then removed from the margins of the bracket base with an explorer before polymerization. Except the brackets bonded with Concise, each was exposed to polymerization light of 450 nm wavelength and 280 ± 5 mW/cm^2 (Heliomat H2, Vivadent, Schaan, Liechtenstein) with a 20-second burst to each of the mesial, distal, incisal, and gingival margins.

After bonding, the brackets were stored in tap water at room temperature for 24 hours and subsequently tested in a shear mode with a universal testing machine (Erichsen 469 LE4 500 N, Wuppertal, Germany), according to the draft of ISO specification TC 106/SC 2/WG 16.

For shear testing, the acrylic block was secured in the lower frame of the machine, so that the bracket base of the sample paralleled the direction of the shear force (Figure 4). The specimens were stressed in a gingivoincisal direction with a cross-head speed of 0.01 mm/second. The maximum load necessary to debond or initiate bracket fracture was recorded in Newtons.

Statistical analysis was performed using the program Jandel Sigma Plot applying the Student's *t*-test. The level of significance was set to $P = 0.01$.
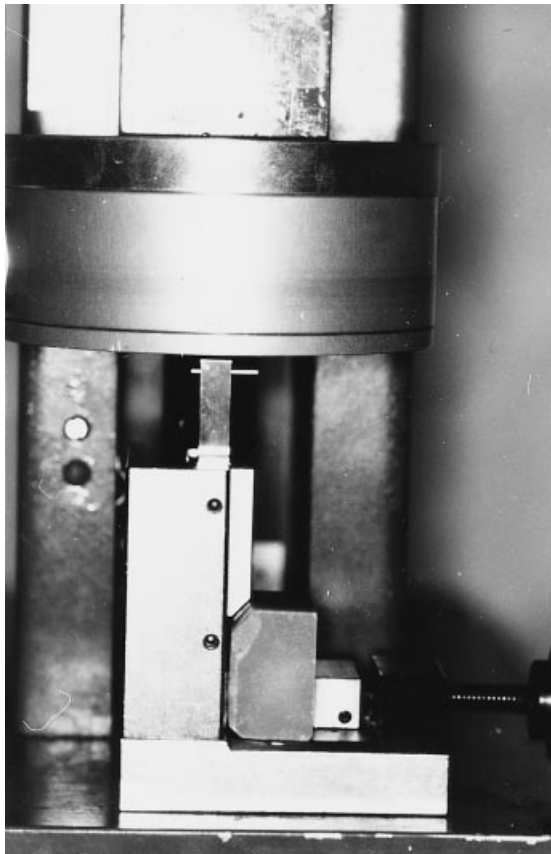
Figure 4 Securing of the acrylic block in the lower frame of the testing machine, so that the bracket base of the sample paralleled the direction of the force.

After shear mode testing, the bracket bases and the enamel surfaces were examined under a light stereomicroscope at ×20 magnification and the site of bond failure was recorded. A representative sample was further examined by scanning electron microscopy.

For determination of the location of bond failure, each sample was classified as one of the following failure types (Hyer, 1989).

Type 1

Failure at the bracket-adhesive interface. Ninety per cent or greater of the bracket pad was exposed and 10 per cent or less of the bonded enamel was free of adhesive.

Type 2

Combination failure (mixed). Less than 90 per cent, but more than 10 per cent of the bracket pad was exposed or more than 10 per cent, but less than 90 per cent of the bonded enamel surface was free of adhesive.

Type 3

Failure at the enamel-adhesive interface. Ten per cent or less of the bracket pad was exposed and 90 per cent or more of the bonded enamel was free of adhesive.

Type 4

Failure of the bracket itself. Fracture of the bracket during removal left part of the bracket still bonded to the enamel.

Type 5

Failure of the enamel itself. A portion of the enamel was removed with the bracket base without loss of more than 10 per cent of the adhesive from the bracket pad.

The amount of residual adhesive remaining on the tooth surface after debonding was recorded with a modified Adhesive Remnant Index (ARI), as suggested by Oliver (1988). The scale of this index has a range between 1 and 5, with 1 indicating that all the adhesive remained on the enamel surface and 5 indicating that no adhesive remained on the enamel.

Results

The mean loads and the standard deviations (SD) required to induce bond failure for each bracket/adhesive combination are shown in Table 1. Shear forces are given in megapascals (MPa).

With the mechanically retentive base, Fuji Ortho LC produced the highest bond strength (18.50 MPa), which, however, was not significantly ($P > 0.1$) higher than Concise (14.88 MPa). The next strongest glass ionomer cement was Photac Bond (13.86 MPa). The lowest bond strength was provided by Iocomp A20 (5.23 MPa).

Table 1 Shear bond strengths (MPa).

Bracket/adhesive combinations	N	Mean (MPa)	SD
Transcend 6000 + Dyract Ortho	9	7.17	3.80
Transcend 6000 + Iocomp A20	10	5.23	1.40
Transcend 6000 + Photac Bond	9	13.86	5.44
Transcend 6000 + Fuji Ortho LC	10	18.50	6.76
Transcend 6000 + Concise	10	14.88	9.90
Fascination + Dyract Ortho	10	4.56	1.51
Fascination + Iocomp A20	10	3.21	0.75
Fascination + Photac Bond	10	16.27	2.55
Fascination + Fuji Ortho LC	10	13.48	2.05
Fascination + Concise	10	29.27	5.94

Table 2 Bond failure sites.

Bracket/adhesive combinations	Bracket/ adhesive	Mixed	Enamel/ adhesive	Bracket	Enamel
Transcend 6000 + Dyract Ortho			9		
Transcend 6000 + Iocomp A20			10		
Transcend 6000 + Photac Bond	9				
Transcend 6000 + Fuji Ortho LC	4		6		
Transcend 6000 + Concise	9		1		
Fascination + Dyract Ortho			10		
Fascination + Iocomp A20			10		
Fascination + Photac Bond		2	8		
Fascination + Fuji Ortho LC			10		
Fascination + Concise			9	1	

With the chemically retentive base, the highest bond strength was obtained with Concise (29.27 MPa), which was significantly ($P < 0.01$) higher than Photac Bond (16.27 MPa) and Fuji Ortho LC (13.48 MPa). Again, Iocomp A20 produced the lowest bond strength (3.21 MPa).

Three adhesives (Dyract Ortho, Iocomp A20 and Fuji Ortho LC) provided higher shear bond strengths with the Transcend 6000 brackets, however, only for one adhesive (Iocomp A20) was the difference statistically significant ($P = 0.001$). On the other hand, Concise and Photac Bond had a higher strength with the Fascination brackets, but only for Concise was the difference statistically significant ($P = 0.001$) .

The types of bond failures are listed in Table 2.

With the mechanically retentive base, Dyract Ortho (Figure 5a,b) and Iocomp A20 failed at the enamel-adhesive interface, whereas Photac Bond (Figure 6a,b) and Concise (Figure 7) debonded at the bracket-adhesive interface. Fuji Ortho LC experienced failures both at the bracket-adhesive (40 per cent) and the adhesive-enamel (60 per cent) interfaces (Figure 8).

With the chemically retentive base, all the adhesives failed at the enamel-adhesive interface (Figures 9 and 10). Only one bracket fracture (Fascination/Concise) occurred in this study, whereas no enamel damage was detected. The distribution of the adhesive remnant index (ARI), according to the different variables (bracket type, adhesive type) is given in Table 3.

Discussion

Many recent studies have shown that fixed orthodontic therapy may represent a potential risk for carious white-spot lesion development adjacent
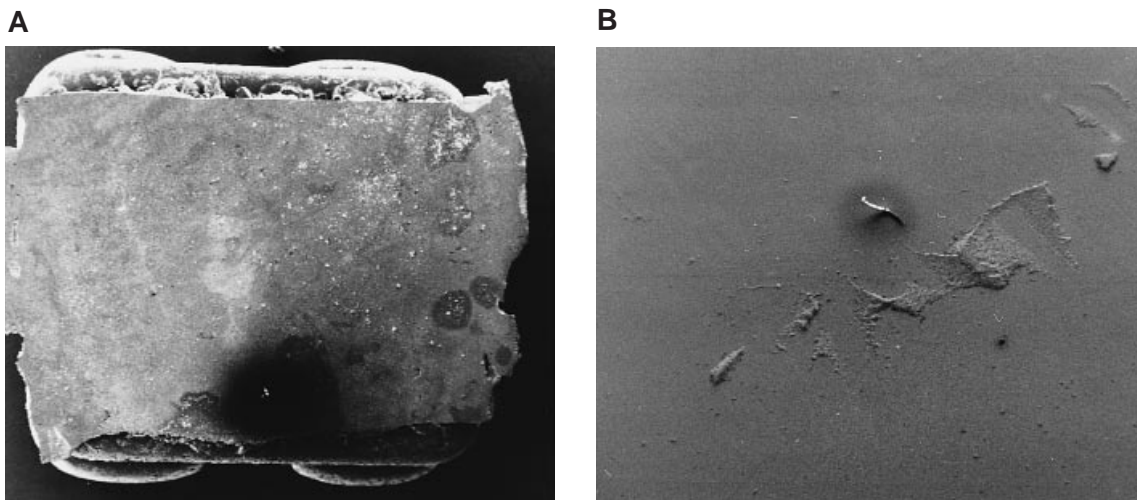
A

B

Figure 5 SEM of a Transcend 6000/Dyract Ortho combination that failed at the enamel-adhesive interface at ×20.5 magnification. (A) The majority of adhesive is attached to the bracket base. (B) SEM of the enamel surface of the same sample showing very small adhesive remnants at ×20.5.
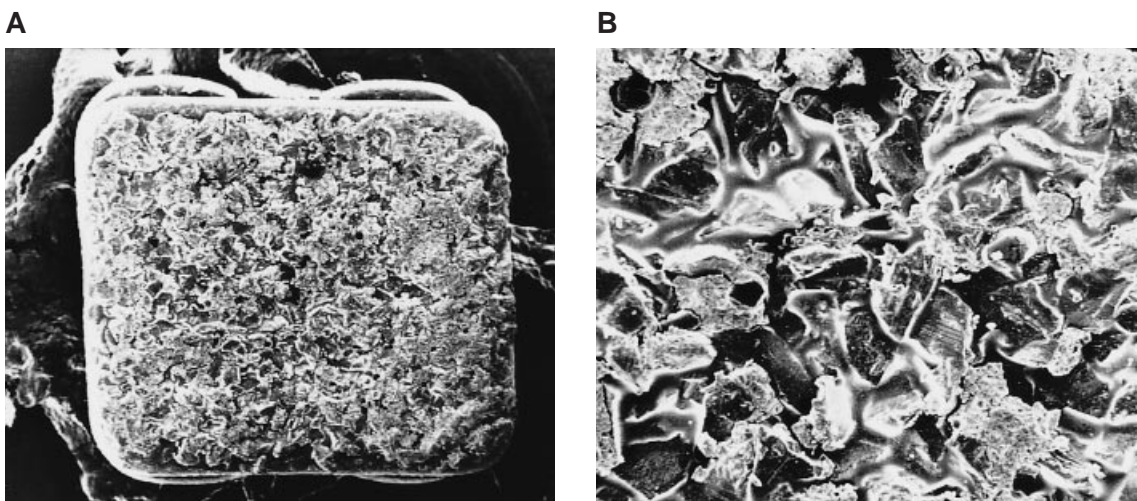
A

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Figure 6 Scanning electron micrographs of a Transcend 6000/Photac Bond combination that debonded at the bracket-adhesive interface at (A) ×20.5 and (B) ×100 magnification, showing small fragments of adhesive on the bracket base.

to bracket margins (Årtun and Brobakken, 1986; Øgaard, 1989). The use of an adhesive system, which has several properties including fluoride release, anticariogenic effects, biocompatibility, chemical adhesion to enamel, dentine, metals and plastics, as well as resistance to acid erosion (Norris *et al.*, 1986), would be considered a major advance for the bonding of orthodontic brackets.

The use of ceramic brackets in orthodontics, although providing a considerable improvement in aesthetics, sometimes results in problems during debonding, such as enamel cracks, if the bond strength is too high and thus able to approach the cohesive integrity of the enamel itself. Furthermore, since these brackets are very brittle and elongate less than 1 per cent before
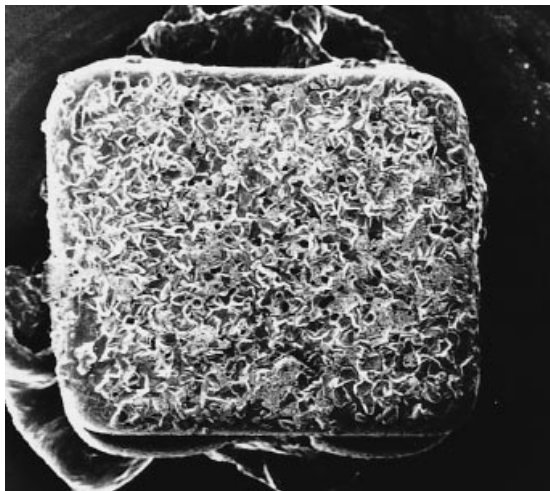
Figure 7 SEM of a Transcend 6000/Concise combination that failed at the bracket-adhesive interface, showing small fragments of adhesive on the bracket base (×20.5).

Figure 9 SEM of a Fascination/Dyract Ortho combination that debonded at the enamel-adhesive interface, showing the majority of adhesive on the bracket base (×20.5).
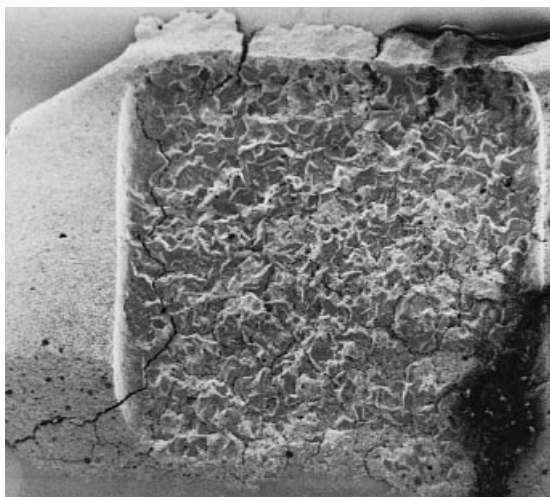

Figure 8 SEM of the enamel surface of a Transcend 6000/Fuji Ortho LC combination which failed at the bracket-adhesive interface. Most of the adhesive remained on the enamel surface (×18.5).

Figure 10 SEM of the enamel surface of a Fascination/Fuji Ortho LC combination which debonded at the enamel-adhesive interface, with more than 90 per cent of the bonded enamel free of adhesive (×20.5).

fracturing, bracket fractures can often occur during debonding, with large amounts of the bracket material remaining on the tooth, removal of which requires the use of abrasive burs that may also cause enamel surface loss.

These problems have led most manufacturers to produce ceramic brackets with decreased bond strengths between the base and the composite resin, by abandoning the chemical retention, and providing the bracket base with a mechanical

Table 3 Distribution of the adhesive remnant index (ARI).

Bracket/adhesive combinations	1	2	3	4	5
Transcend 6000 + Dyract Ortho					9
Transcend 6000 + Iocomp A20					10
Transcend 6000 + Photac Bond	7	2			
Transcend 6000 + Fuji Ortho LC		4		3	3
Transcend 6000 + Concise	7	2			1
Fascination + Dyract Ortho					10
Fascination + Iocomp A20					10
Fascination + Photac Bond			4	4	2
Fascination + Fuji Ortho LC					10
Fascination + Concise				1	8

Score:
1: All adhesive remains on the enamel.
2: More than 90 per cent of the adhesive remains on the enamel.
3: More than 10 per cent, but less than 90 per cent of the adhesive remains on the enamel.
4: Less than 10 per cent of the adhesive remains on the enamel.
5: No adhesive remains on the enamel.

retention, that allows adhesive to flow into the undercuts or grooves and thus provides micro-mechanical interlocking.

In combination with mechanically retentive ceramic brackets, Fuji Ortho LC and Photac Bond revealed statistically the same bond strength as the control composite resin, with slight advantages for Fuji Ortho LC.

Reynolds (1975) suggested that a minimum bond strength of 60 to 80 kg/cm^2 would appear adequate for most clinical orthodontic needs. He also reported successful clinical bonding with adhesives that provide an *in vitro* bond strength of approximately 50 kg/cm^2. Therefore, in the present study, all adhesives used as bonding agents for mechanically retentive ceramic brackets provided bond strengths adequate for clinical use.

With the silane-treated brackets, the control composite resin revealed the highest bond strength, which was significantly greater than all the other cements tested. Only two glass ionomer cements (Fuji Ortho LC, Photac Bond) showed a bond strength high enough to be clinically acceptable.

Therefore, in the present study all the bracket/adhesive combinations provided bond strengths adequate for the clinical use, except for the combinations Fascination/Dyract Ortho and Fascination/Iocomp A20, which had bond strengths lower than the minimum value recommended by Reynolds (1975).

Previous studies evaluating the shear bond strengths of ceramic brackets with either mechanical or chemical retention have shown conflicting results. Two studies reported higher bond strength with silane chemical retention (Iwamoto *et al*., 1987; Viazis *et al*., 1990), whereas the results of other studies showed no increase in bond strength using silane coupling agents (Guess *et al*., 1988; Gwinnett, 1988; Merrill *et al*., 1994). In this study, three glass ionomer cements (Dyract Ortho, Iocomp A20 and Fuji Ortho LC) provided higher shear bond strengths with the mechanically retentive brackets, whereas Concise and Photac Bond had a higher strength with the silane-treated brackets. However, the differences were statistically significant only for Iocomp A20 ($P = 0.001$) and Concise ($P = 0.001$).

With the chemically retentive base, all the adhesives failed at the enamel-adhesive interface and 90 per cent of the glass ionomer remained on the bracket bases, indicating a stronger adhesion to ceramic than to enamel. The glass ionomer is thus easily removed from enamel during debonding.

The use of the polyacrylic acid as enamel conditioner caused the bond failure to be located mostly at the enamel-adhesive interface, resulting

in a higher ARI score, as earlier reported by Bishara *et al.* (1993). In order to determine if the same holds true with no conditioner at all, further studies seem to be appropriate.

Finally, it seems reasonable to point out that in this study the laboratory conditions for bonding were ideal, whereas clinically, intra-oral contamination, moisture, temperature, and other variables, such as the forces of mastication, trauma and the orthodontic mechanics, have been found to influence the bond strength (Gorelick *et al.*, 1978). Therefore, an *in vitro* study has its own limitations and cannot fully reproduce the clinical conditions. *In vivo* studies are therefore needed to determine whether glass ionomer cements can provide sufficiently high bond strengths to withstand the stresses of orthodontic therapy and of the oral environment, while also providing for safe debonding of ceramic brackets, without any enamel damage or loss.

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