European Journal of Orthodontics 18 (1996) 373–384

A clinical evaluation of a glass ionomer cement as an orthodontic bonding adhesive compared with an acrylic resin

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SUMMARY Glass ionomer cement (GIC) has been suggested as an alternative to acrylic resin in bracket bonding because of its fluoride release. The aim of this clinical trial was to evaluate further the suitability of GIC as a bonding adhesive compared with an acrylic resin with regard to frequency of bracket failure, fracture modes and clean-up time after debonding. Two commercially available brackets were tested, one with a meshed foil base and the other with an integral base.

A total of 60 patients, with a mean age of 13 years 7 months (range 10 years 8 months to 19 years 1 month) were consecutively selected. Brackets were bonded with a GIC (AquaCem®, De Trey) and a no-mix diacrylate (Unite®, Unitek Corp.) according to random assignment for each jaw. One group of patients ($n=30$) was bonded with metal brackets with machine cut grooves in the base (DynaLock®, Unitek). In the second group ($n=30$) brackets with a meshed foil base (Unitwin®, Unitek) were used. Bracket failure location during treatment was recorded as were fracture modes and time required for the clean-up of enamel surfaces at debonding.

The frequency of failed brackets was higher with GIC (36 per cent) than with the diacrylate (15 per cent). Bracket failures for the cut groove base type occurred in 50 per cent with GIC and 23 per cent with the acrylic, meshed foil bases failed in 22 per cent with GIC and in 7 per cent with the acrylic, respectively. The differences in failure between bracket types were significant at $P<0.001$ for both bonding materials. Analysis of the fracture modes showed a small but noticeable difference in the strength of adhesion to the enamel surface, favouring GIC. Time required for the clean-up of enamel surfaces showed a significantly shorter debonding time for GIC. It is concluded that the use of a GIC for orthodontic bonding purposes considerably increases the risk of bond failures during treatment, especially in combination with a cut groove base type. One noticeable advantage with GIC bonding, however, is the shorter clean-up time for the enamel surfaces.

Introduction

Orthodontic bonding using the acid-etching technique combined with an acrylic or diacrylate resin was originally described by Newman (1965) and now has worldwide application. However, a considerable number of studies have shown that this technique has some undesirable effects (review by Mitchell, 1992). The major disadvantage is a risk of decalcification of the enamel surface (white spot formation) close to bonded orthodontic brackets (e.g. Zachrisson, 1977). Another unwanted effect is localized enamel fractures created during debonding due to the micromechanical retention (Diedrich, 1981). The removal of composite from the enamel with carbide burs or scalers may cause enamel loss, scratches and occasionally crack the enamel surface (Zachrisson and Årtun, 1979; Rouleau *et al.*, 1982). Furthermore, the debonding procedure has been described as time consuming (Rouleau *et al.*, 1982). Finally, allergic reaction to the acrylic resin has been reported (Altuna *et al.*, 1986; Tell *et al.*, 1988). To improve the properties of the bonding materials, numerous modifications of the original etching technique (e.g. etching time, concentration of the phosphoric acid), and various types of acrylic or diacrylate resins have been proposed. The use of light-cured resins and fluoride-releasing resins are two examples of such modifications.

Glass ionomer cements (GIC) have been proposed as alternative adhesive in direct orthodontic bracket bonding (e.g. White, 1986; Norevall *et al.*, 1990). One major advantage of GIC would be the fluoride release over a period of months when it is used as a filling material (Forsten, 1977), and a less caries-inducing microflora may develop when GIC is used as a luting agent in orthodontic bracket bonding (Hallgren *et al.*, 1992). However, several laboratory studies (Cook and Youngson, 1988; Klockowski *et al.*, 1989; Norevall *et al.*, 1990; Fox *et al.*, 1991) have reported an inferior bond strength in polyalkeonate cements compared with composite. In one of few clinical trials of bond strength for GIC, Fricker (1992) reported a higher bond failure rate compared with composite.

The adhesion of GIC to base metals and enamel has not yet been fully clarified but it has been proposed that it is physicochemical in nature (Wilson and Prosser, 1982). Fracture mode analysis provides information about the strength of adhesion. According to Matasa (1989), the strongest type of bonding is the cohesive, within the cement, leaving equal amounts of the bonding material on both the enamel and bracket base if there is a failure. Cook (1990) found that GIC bonds better to the metal base of the bracket than to the enamel, while Compton *et al.* (1992) reported the fractures to be mainly cohesive in nature. But, bracket failure has also been categorized as adhesive (at the cement/bracket interface) with most of the cement remaining on the tooth surface (Cook and Youngson, 1988; Norevall *et al.*, 1990). Standing in contrast to the need for a strong bond to the enamel is the need for brackets and cement to be easily removable from the enamel surface, thereby reducing chair-side time (Cook, 1990; Fox *et al.*, 1991).

The bracket base design is, in terms of size and morphology, the most important factor in producing optimal bond strength. The surface structure of the bracket base is also important, and bases with fine mesh and rough wires give the highest bond strength for bonding with acrylic resin in the tested brackets (Maijer and Smith, 1981). No reports are available of suitable bracket base designs for GIC as bonding material.

It was the aim of the present investigation to evaluate clinically the suitability of glass ionomer cement as an orthodontic bonding material compared with an acrylic resin. Bracket failure frequency, fracture modes and clean-up time after debonding will be described in samples of orthodontic patients. The results from tests of two commercially available brackets with marked differences in base structure, one with a meshed foil base and the other with an integral type of base, will also be reported.

Materials and methods

Patients referred to the Department of Orthodontics, Umeå University Clinic, Umeå, Sweden, were examined and therapy plans were proposed. From those patients assigned to the postgraduate programme, needing fixed appliance therapy with a straight-wire technique (the Bergen technique according to Wisth *et al.*, 1985) and with a normal number of permanent teeth, 60 were consecutively selected for the study (Table 1). The mean age of the subjects was 13 years 7 months (range 10 years 8 months to 19 years 1 month). Initially, planned extractions were undertaken, and subsequent to acquiring written consent, the patient was assigned to one of two groups. The first group of patients were bonded with stainless steel brackets with machine cut grooves in the base (DynaLock®; Unitek/3M, Unitek Corp., Monrovia, CA, 91016, USA). In the second group all patients were bonded with bracket bases with a meshed foil (Unitwin®; Unitek/3M, Unitek Corp., Monrovia, CA, 91016, USA). The final composition of the samples with regard to sex, age, and treatment time (from bonding to debonding) is given in Table 1, with girls making up about two-thirds of the patients and a mean treatment time of 1 year 9 months for all the patients.

Brackets were bonded with a glass ionomer cement (AquaCem®; De Trey Division, Dentsply Limited, Weybridge, Surrey, UK) or a no-mix diacrylate (Unite®; Unitek Corp.). For each jaw one of the two bonding materials was selected for one side according to random assignment, the other material was used for the

Table 1 Composition of the material. Mean age and mean treatment time (in decimal years) according to bracket type and sex

Bracket and sex	Observations (n)	Age at bonding (years)				Treatment time (years)			
		Mean	SD	Min	Max	Mean	SD	Min	Max
Dyna-Lock®									
Boys	13	14.10	1.46	12.08	16.75	1.86	0.40	1.40	2.38
Girls	17	12.71	1.37	10.67	16.25	1.87	0.72	0.76	3.26
Sum	30	13.31	1.55	10.67	16.75	1.86	0.59	0.76	3.26
Unitwin®									
Boys	8	13.62	1.23	11.67	15.50	1.96	0.77	0.63	2.76
Girls	22	13.87	1.69	11.83	19.08	1.63	0.54	0.90	2.60
Sum	30	13.81	1.57	11.67	19.08	1.72	0.62	0.63	2.76
Total									
Boys	21	13.91	1.37	11.67	16.75	1.90	0.55	0.63	2.76
Girls	39	13.36	1.65	10.67	19.08	1.72	0.63	0.76	3.26
Sum	60	13.56	1.57	10.67	19.08	1.79	0.60	0.63	3.26

other side. Before bonding, all tooth surfaces were gently cleaned with a fluoride-free pumice in a rubber cup, sprayed with water, and dried with an air stream for approximately 15 seconds.

The buccal surfaces of the diacrylate jaw quadrant(s) were etched for 30 seconds with 37 per cent phosphoric acid (Etching liquid®; 3M Dental Products Division, St. Paul, MN, USA), rinsed with water, and dried in an air stream for another 30 seconds. After the application of primer (Unite® No Mix Bonding Adhesive; Unitek Corp.) to the prepared enamel surface and the bracket base, the acrylic bonding material was put on the bracket. The bracket was then placed in the correct position and pressed firmly towards the enamel surface for later removal of excess bonding material with a scaler.

The glass ionomer cement chosen for the cementation was mixed according to the manufacturers' instructions and applied with a tooth pick to the bracket base. The bracket was then put in position on the dry tooth and pressed towards the enamel surface firmly as with diacrylate. Excess cement was removed.

The first aligning arch wires were applied 15–20 minutes after the end of the bonding/cementation procedure. The patients were instructed by the assisting nurse about the importance of good oral hygiene, good dietary habits, and correct tooth brushing techniques. In addition all patients were recommended to use a toothpaste containing fluoride and, in the event of bracket failure, to call immediately for a new appointment. Brackets dislodged during active treatment, in the following classified as failures, were replaced with new brackets and bonded/cemented according to the original schedule.

The debonding session involved the removal of the bracket with a Unitek® Debracketing Instrument with a pull-wire for full size brackets (Unitek Corp., Monrovia, CA, USA). Fracture modes were determined by clinical inspection of both the debonded enamel surfaces and the bracket bases and classified according to Norris *et al.* (1986), as follows:

0 = between adhesive and enamel
1 = within the body of the adhesive
2 = between adhesive and bracket base.

Removal of remaining adhesive from the enamel surfaces was accomplished with a low-speed handpiece and a 12-fluted carbide finishing bur (Jet-bur, 5LA 1172; Beavers, Morrisburg, Ontario, Canada). A new jet-bur was used for each jaw quadrant. The clean-up time was recorded in seconds for each quadrant. Finally, all teeth were polished with pumice.

Data from the bonding session and all initial bracket failures during the fixed appliance therapy, were recorded on special forms as, at a later time, were the dates when the active treatment was discontinued, fracture localization of the bonding adhesive and time for debonding.

All bonding/cementation was carried out by two of the authors (LIN, AM) to ensure a high degree of standardization throughout the study. The fracture mode evaluation and the debonding was performed by one examiner (LIN) and one chairside assistant. Intra-examiner reliability was monitored by re-examination of all debonded brackets in a stereomicroscope with ×30 magnification for confirmation of fracture mode.

Statistical analysis

The mean values for the age of the sample and the length of the active treatment period were computed. Mean values and standard deviations for frequency of initial bracket failures for each tooth distributed on type of adhesive, type of bracket, quadrant, sex and treatment time for the various groups were computed. The results from comparisons of clean-up times between DynaLock® and Unitwin® brackets cemented with GIC and diacrylate respectively were obtained in the same way. Student's t-test was used for testing of significant differences. P values ≤ 0.05 were considered significant. The adhesive fracture mode for the two adhesives and bracket types were computed in per cent.

Table 2(a) Comparisons of bracket failures for Unite® and AquaCem® according to sex, location and bracket type

	Unite®			AquaCem®			Significance of difference
	Observations (n)	Teeth (n)	Failure rate	Observations (n)	Teeth (n)	Failure rate	Spearman P value
Total							
Sum	111	493	0.15	111	492	0.36	0.0000***
Sex							
Boys	39	164	0.15	39	163	0.42	0.0002***
Girls	72	329	0.14	72	329	0.32	0.0000***
Location							
Mx right	28	126	0.11	32	142	0.34	0.0008***
Mx left	32	142	0.15	28	125	0.36	0.0008**
Md left	23	105	0.16	28	119	0.39	0.0183*
Md right	28	120	0.16	23	106	0.33	0.0091**
Bracket type							
DynaLock®	55	238	0.23	55	236	0.50	0.0000***
Unitwin®	56	255	0.07	56	256	0.22	0.0003***

Mx = maxillary arch; Md = mandibular arch.
*Statistically significant ($P < 0.05$).
**Statistically significant ($P < 0.01$).
*** Statistically significant ($P < 0.001$).

Table 2(b) Comparisons of bracket failures for short and long treatment periods according to adhesive and bracket type

	≤653 days			>653 days			Significance of difference
	Observations (n)	Teeth (n)	Failure rate	Observations (n)	Teeth (n)	Failure rate	Spearman P value
Total							
Sum	118	540	0.21	104	445	0.30	0.510^{ns}
Adhesive							
Unite®	59	270	0.14	52	223	0.15	0.3925^{ns}
AquaCem®	59	270	0.28	52	222	0.45	0.0146*
Bracket type							
DynaLock®	56	247	0.30	54	227	0.42	0 0760^{ns}
Unitwin®	62	293	0.12	50	218	0.16	0 4821^{ns}

*Statistically significant ($P < 0.05$).
**Statistically significant ($P < 0.01$).
*** Statistically significant ($P < 0.001$).
ns = not significant.

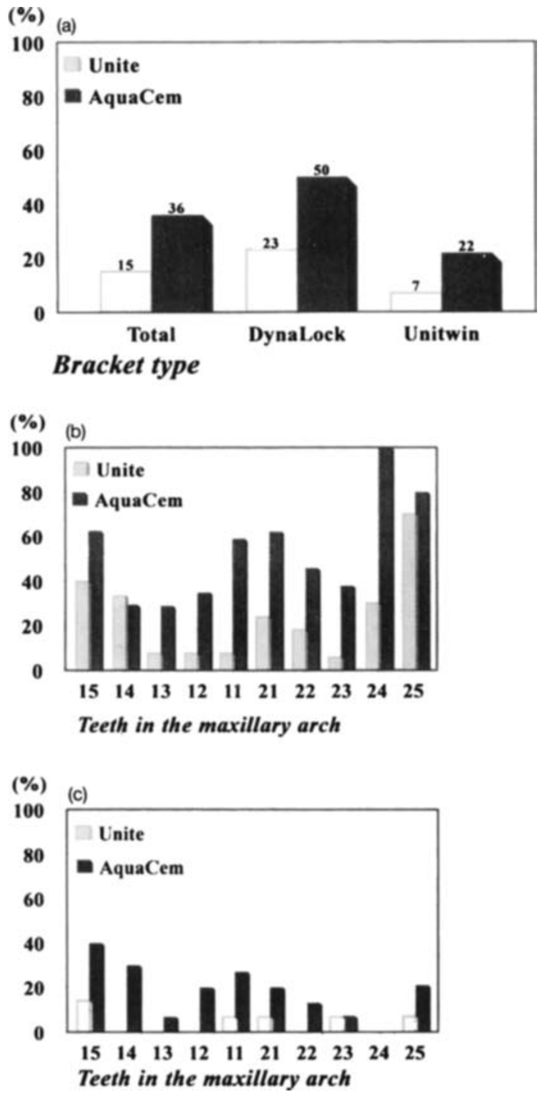

Figure 1 (a) Relative frequency of initial bracket failure (in per cent) according to bracket type; (**b**) A comparison of relative frequency of initial bracket failure (in per cent) for DynaLock® bonded with glass ionomer cement and diacrylate on individual teeth in the maxillary arch; (**c**) a comparison of relative frequency of initial bracket failure (in per cent) for Unitwin® bonded with glass ionomer cement and diacrylate on individual teeth in the maxillary arch.

Results

Comparison of failure frequencies

Comparisons of initial bonding failure rates for all brackets bonded with the glass ionomer cement (GIC) and those bonded with the diacrylate are given in Table 2a. As shown, failures were significantly more frequent for brackets bonded with the cement than with the acrylic ($P<0.001$). No differences in failure rates were apparent between upper or lower segments or between right and left sides. Nor did failure rates significantly differ between the sexes. The distribution of failures within each jaw is shown in Figure 1b,c. Marked differences were found for failures with regard to bracket type (Fig. 1a), as failures more than doubled with cement instead of acrylic agent for DynaLock® (23 compared to 50 per cent), and more than tripled for Unitwin® (7 and 22 per cent respectively).

As bracket type samples differed with respect to treatment time, an analysis of failure rates was also made after classifying the total sample into two subgroups; the first subgroup consisting of 30 individuals with a treatment time of <653 days, and the second group with the remaining 30 individuals and a treatment time >653 days (Table 2b). Only brackets cemented with GIC showed a significant time-dependent increase in failure rate ($P=0.0146$).

Comparison of fracture mode

Photographs illustrating the three types of fracture mode used in this examination are shown in Figures 2 and 3. Only 4 per cent of 479 brackets cemented with GIC fractured between adhesive and enamel as compared with 20 per cent of 480 brackets bonded with diacrylate (Table 3, Fig. 4). The major fracture location type was cohesive (within the diacrylate/cement) where 73 per cent of the GIC fractures and 44 per cent of the diacrylate fractures occurred.

Type of bracket influenced the distribution of fracture modes for the diacrylate. The DynaLock® bracket had more than twice as many fractures between adhesive and bracket base as the Unitwin® bracket (52 and 22 per cent respectively). No such difference existed for GIC. Comparison of fracture modes for upper and lower segments of the right and left sides revealed no marked differences in distribution.

Comparison of clean-up time

The total clean-up time of enamel surfaces differed significantly between the two tested adhesives ($P<0.001$). The mean clean-up time was 150 seconds for 107 bonded (Unite®)

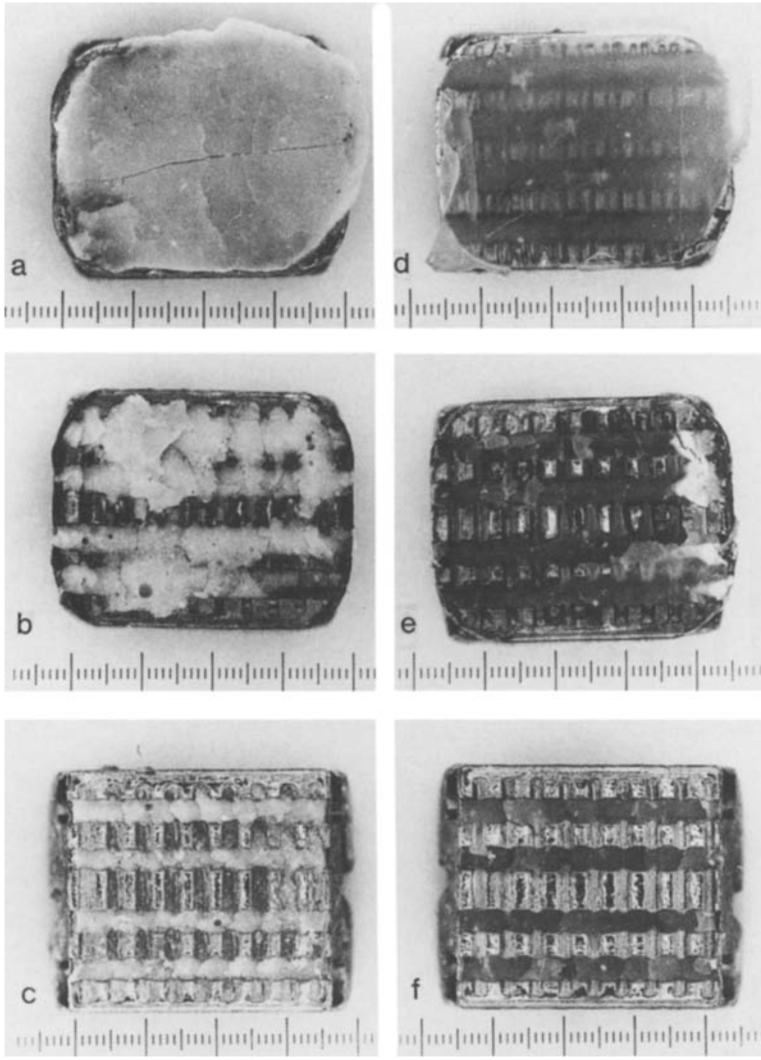

Figure 2 Bracket bases following initial debonding. (**a**) DynaLock® (mandibular canine) where fracture occurred between enamel and cement; (**b**) DynaLock® (mandibular canine), cohesive fracture; (**c**) DynaLock® (maxillary central incisor) where fracture occurred between cement and base. The retention grooves usually remained filled with adhesive; (**d**) DynaLock® (mandibular canine) where fracture occurred between enamel and diacrylate; (**e**) DynaLock® (mandibular canine), cohesive fracture; (**f**) DynaLock® (maxillary central incisor) where fracture occurred between diacrylate and base. Bar = 100 μm.

quadrants and 94 seconds for 109 cemented (AquaCem®) quadrants (Table 4). In comparing different bracket types a significantly ($P < 0.001$) shorter clean-up time was needed for the cemented DynaLock® bracket than for the cemented Unitwin® bracket (Fig. 5). No such difference was recorded for the bonded DynaLock® and Unitwin® brackets.

Discussion

Comparison of failure frequencies

The result from the present clinical comparison of a glass-ionomer cement (AquaCem®) and a diacrylate (Unite®) for orthodontic bonding shows a high bracket failure rate for both materials. A clearly higher incidence of failure

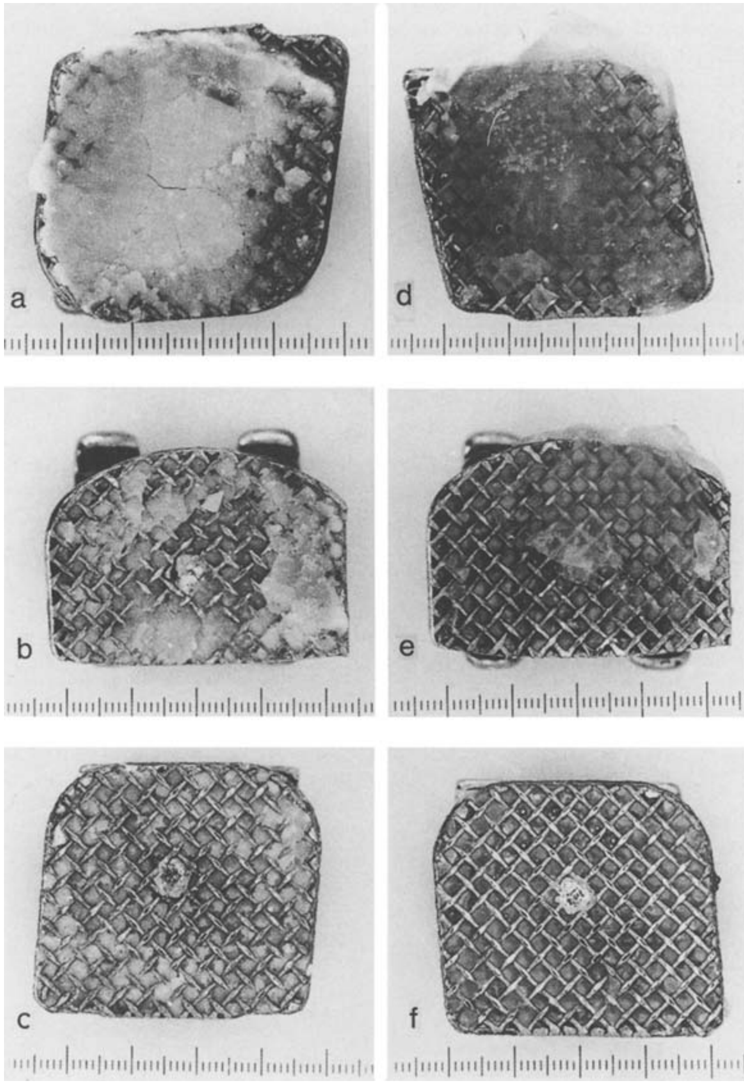

Figure 3 Bracket bases following initial debonding. (**a**) Unitwin® (maxillary canine) where fracture occurred between enamel and cement; (**b**) Unitwin® (mandibular first premolar), cohesive fracture; (**c**) Unitwin® (maxillary central incisor) where fracture occurred between cement and base. The retention grooves usually remained filled with cement; (**d**) Unitwin® (maxillary canine) where fracture occurred between enamel and diacrylate; (**e**) Unitwin® (mandibular first premolar) base, cohesive fracture; (**f**) Unitwin® (maxillary central incisor) where fracture occurred between diacrylate and base. Bar = 100 μm.

occurred for the GIC where 36 per cent of all cemented brackets loosened. The corresponding figure for the diacrylate was 15 per cent. This difference is in line with the inferior bond strength of GIC compared with diacrylate/composite reported from several laboratory studies (Cook and Youngson, 1988; Klockowski *et al.*, 1989; Norevall *et al.*, 1990; Fox *et al.*, 1991; Evans and Oliver, 1991; Øen *et al.*, 1991). The inferior bond strength of GIC can be explained by a number of clinically important material properties. Handling of GIC during and after cementation is technique-sensitive; e.g. a high powder-liquid ratio is crucial and small deviations in proportions can decrease the bond strength (Evans and Oliver, 1991). Like acrylic, it is sensitive to moisture contamination (Powis *et al.*, 1982), for 10–60 minutes after mixing during the initial setting stage of the GIC, indicating the application of a protecting varnish. Furthermore, during the late setting of the GIC, up to 24 hours after the mixing, an

Table 3. Relative frequency of adhesive fracture modes for Unite® and AquaCem® when using DynaLock® and Unitwin® brackets. All figures are percentages

	Unite® DynaLock® ($n=225$)	Unitwin® ($n=255$)	Total ($n=480$)	Aquacem® DynaLock® ($n=223$)	Unitwin® ($n=256$)	Total ($n=479$)
Mode						
0	16	23	20	6	3	4
1	32	55	44	70	74	73
2	52	22	36	24	23	23
Total	100	100	100	100	100	100

n = total number of teeth in each sample.
Mode: 0 = fracture between adhesive and enamel; 1 = fracture within the adhesive; 2 = fracture between adhesive and bracket base.

Table 4. Comparison of time requirements for clean-up of enamel surfaces following removal of two types of orthodontic brackets (DynaLock® and Unitwin®) bonded with Unite® and Aquacem®

	Unite®									Aquacem®								Significance of difference
	Dynalock®			Unitwin®				Total		Dynalock®			Unitwin®				Total		
	No.	Time Mean	SD	No.	Time Mean	SD	Student's t-test P value	No.	Time Mean	No.	Time Mean	SD	No.	Time Mean	SD	Student's t-test P value	No.	Time Mean	Student's t-test P value
Location																			
Mx right	13	148	48	15	142	54	0.7812[ns]	28	145	16	74	28	15	84	35	0.3973[ns]	31	79	0.0000***
Mx left	16	155	75	15	151	46	0.8334[ns]	31	153	13	80	29	15	120	39	0.0052**	28	101	0.0004***
Md left	10	159	71	12	145	38	0.5677[ns]	22	152	14	89	51	13	123	45	0.0771[ns]	27	105	0.0032**
Md right	14	142	86	12	165	48	0.4301[ns]	26	153	10	68	9	13	113	35	0.0008***	23	93	0.0007***
Total	53	151	70	54	150	47	0.9661[ns]	107	150	53	78	34	56	109	41	0.0000***	109	94	0.0000***

n = total number of teeth in each section.

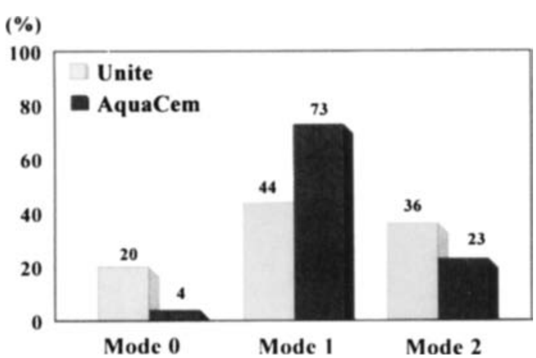

Figure 4 Distribution of fracture modes for a diacrylate (Unite®) and a glass ionomer cement (AquaCem®). Mode 0 = fracture between adhesive and enamel; 1 = fracture within the adhesive; 2 = fracture between adhesive and bracket base.

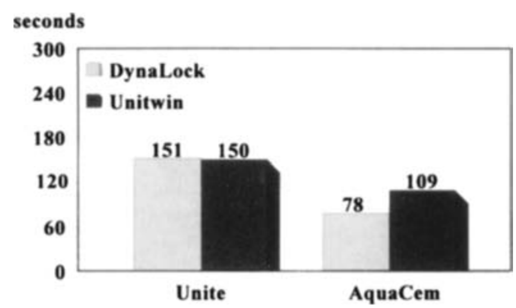

Figure 5 Comparison of time requirements for clean-up of enamel surfaces following removal of two types of orthodontic brackets (DynaLock® and Unitwin®) bonded with a diacrylate (Unite®) and a glass ionomer cement (AquaCem®).

increased sensitivity to desiccation is apparent (Powis *et al.*, 1982). On the other hand, the effects of moisture contamination on tensile strength after 24 h vary between different GICs and it is suggested to have no detrimental influence with the exception for Fuji II® (Evans and Oliver, 1991). Thus, variations in handling the GIC could contribute to the high frequency of bracket failure.

The type of bracket was shown to be an important factor explaining bracket failure in our study. The meshed foil bracket (Unitwin®) bonded with diacrylate exhibited a failure rate of 7 per cent, while cemented with GIC the failure rate increased to 22 per cent. This is in accordance with figures from the few available reports on clinical trials of bond failure rates for GIC. In a 12-month clinical evaluation of 10 subjects bonded with a composite (Right-on®) in comparison with a GIC, the failure rate for the composite was 5 per cent and for GIC 20 per cent (Fricker, 1992). Cook (1990) reported a bond failure rate of 12.4 per cent in 40 consecutive cases with 402 anterior teeth (incisor and canine brackets) cemented with GIC (Ketac-Cem®). For the second bracket type included in the study, the integral type (DynaLock®) with cut edges in the base, failure rates were extremely high; brackets bonded with diacrylate showed 23 per cent losses and cemented with GIC 50 per cent losses. In laboratory comparisons of the integral base type with foil-mesh bases, the former showed the lower mean tensile bond strength (Regan *et al.*, 1993), as well as the lower shear/peel bond strength (Ferguson *et al.*, 1984; Norevall *et al.*, 1990). In comparison with acrylic resins with a bond strength to enamel of 5–25 MPa (Delport and Grobler, 1988; Gwinnett, 1988) the GIC is a weaker adhesive with a bond strength to enamel of between 3.2–7.5 MPa (Wilson and Prosser, 1982; Voss *et al.*, 1993). This GIC quality combined with the sharp edges of the DynaLock® bracket base probably explains the high incidence of bracket failures. High failure rates for bonded brackets of this type might be explained in a similar way by the bracket base design where supposedly stress-concentrating sharp angles in the base induce a breakage in the resin (Ferguson *et al.*, 1984).

Anatomical differences between tooth surface and curvature of the bracket base may also influence the outcome in a clinical situation by producing variations in adhesive thickness. The Unitwin® bracket with its base well adapted to the tooth surface showed only a thin layer of adhesive in comparison with the DynaLock® bracket, for which differences between adhesive thickness varied both under the individual bracket and between brackets for different teeth. Increasing the thickness of the adhesive layer has been reported to decrease the tensile bond strength (Evans and Powers, 1985), decrease the shear bond strength (Pender *et al.*, 1988) and not significantly influence the shear bond strength (Mackay, 1992). Furthermore, the bucco-lingual height of the bracket may play an important role in its suitability as an attachment. The DynaLock® premolar bracket has a pronounced profile to compensate for arch form when used in a straight-wire system thereby exposing the adhesive to larger forces.

The failure rates for individual teeth bonded with Unitwin® or DynaLock® brackets showed a small percentage of failures for canines, a little higher for incisors, and the highest incidence of bracket failures for premolars (Fig. 1b,c), largely confirming earlier observations made by Zachrisson (1976, 1977). A high incidence of bracket failures in the posterior parts of the jaws has mostly been explained by the sensitivity of the acid-etching technique to moisture contamination (Zachrisson, 1976, 1977). The base area of the two tested brackets also varies, and this might, to a minor extent, contribute to the observed differences in failure frequency for individual teeth (e.g. the base area of a DynaLock® maxillary premolar bracket is 0.126 cm^2 and a Unitwin® maxillary premolar bracket 0.144 cm^2). However, tensile bond strength has been demonstrated to be independent of the nominal area of the bases (Dickinson and Powers, 1980). Furthermore, the angulation and torque in straight-wire brackets differ between individual teeth and may explain the good performance of the maxillary canine bracket where, in most cases, the apparent need for torque forces on canines was low.

The Unitwin® and DynaLock® brackets cemented with AquaCem® showed similar distribution of bracket failures for individual teeth as those when bonded with diacrylate (Fig. 1b,c), but the percentage of failures for the anterior teeth was considerably higher. This might partly be explained by the sensitivity of GIC to dehydration (Powis *et al.*, 1992), a situation more likely to occur in the upper anterior segment due to mouth breathing or incompetent lip closure in subjects with a large overjet. Considering that several subjects with large overjet participated in the study and the need to utilize heavy rectangular arch-wires for the torquing of upper anterior teeth in combination with the proven inferior bond strength of the GIC (Cook and Youngson, 1988), a high incidence of bracket failures could be anticipated for anterior brackets cemented with GIC.

Mizrahi (1988), found no sex difference in failure rates for first molar bands cemented with GIC. It is reasonable to assume that cemented brackets show the same lack of sex difference in failure rates, which the results from the present study support. However, a long treatment time did significantly increase the failure rate for GIC. This could be due to a prolonged exposure to acidic conditions in the oral cavity resulting in a loss of matrix ions from the GIC into the eroding solution (Walls, 1986), and consequently leading to a time-dependent increase of failure rates for cemented brackets.

Comparison of fracture modes

The distribution of fracture locations at debonding differed between the two materials tested. Fractures located between GIC and enamel seldom occurred (4 per cent) in comparison with fractures between the diacrylate and enamel (20 per cent). The most common (73 per cent) fracture location type for AquaCem® was cohesive which implies that the material characteristics play an important role in the rate of bracket failure rather than bond strength to enamel and bracket base. Laboratory tests on extracted teeth cemented with a chemically cured GIC (Ketac-Bond®) made by Compton *et al.* (1992) showed mainly cohesive failures (77 per cent). A high percentage of the enamel surfaces covered by the bracket base has, in fact, also been reported to contain remnants of cement after debonding (Ketac-Cem® 86 per cent, AquaCem® 62 per cent; Rezk-Lega and Øgaard, 1991). In contrast, Øen *et al.* (1991) who tested cementation/bonding of three types of GIC and Concise® to extracted premolars after 24 hours and 4 months, respectively, found that failures mainly occurred at the GIC–enamel interface.

Fracture modes for diacrylate may vary between types of adhesive, e.g. light-cured or self-cured (Wang and Meng, 1992). Furthermore, direction of force during bracket removal also influences the fracture mode, e.g. shear forces where bond failures for Concise® occurred at the enamel resin interface (Øen *et al.*, 1991), or tensile pull, with more equal distribution among various fracture modes (Rezk-Lega and Øgaard, 1991; Wang and Meng, 1992).

As expected, the type of bracket influenced the distribution of fracture modes for the diacrylate. The DynaLock® bracket had more than twice as many fractures between adhesive and bracket base as the Unitwin® bracket (52 and 22 per cent respectively). No such difference existed for GIC. These results suggest that the fracture mode and amount of residual cement/diacrylate on the enamel surface following bracket removal is governed firstly by properties of the chosen adhesive, and secondly by bracket base design. Not tested in the present study, is the possible role of direction of force during debonding procedures.

Comparison of clean-up time

The time required for removing diacrylate and GIC remnants from bonded/cemented enamel surfaces varied significantly. Comparing the mean clean-up time for the two adhesives showed that for one quadrant with diacrylate on the enamel surfaces the cleaning time was one and a half times longer than when the surfaces were cemented. This contrasts with the fracture mode analysis which indicated the fracture of GIC to occur mostly within the material. The difference might be explained by the fact that, the resin tags following acid-etching generally penetrate the enamel surface to a depth of 80 μm, sometimes reaching a depth of 100–170 μm (Diedrich, 1981). The complete removal of these resin tags cannot be achieved. However, acceptable surface cleaning might be achieved using, as here, a low-speed handpiece and a tungsten carbide bur followed by pumicing (Zachrisson and Årtun, 1979). The long-term effect of this artificial weakening of the superficial enamel structure by the acid-etching and clean-up procedure on plaque retention, caries risk and discolouration deserves further attention. The GIC, on the other hand, flakes off after the use of an air syringe and will leave only small amounts of cement on the enamel surface which is easily removed with a tungsten carbide bur (Cook, 1990). A comparative SEM study of the enamel surface after debonding brackets with either GIC or acrylic resin imply a less affected enamel surface when GIC was used as the bonding adhesive (Östman-Andersson *et al.*, 1993). Thus, it seems reasonable to assume that GIC as a material is superior to diacrylate for adhering orthodontic brackets when the appearance of the enamel surface is taken into consideration.

Conclusions

The use of a GIC for the cementation of orthodontic brackets increases the risk of bracket failure during treatment with fixed appliances. The type of bracket base considerably influences the risk of failure, particularly in the case of a combination of cut grooves in the bracket base and bonding with GIC. One advantage with GIC is the shorter clean-up time at debonding. A reduced formation of white spot with GIC will be reported in a separate study.

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Acknowledgements

We are grateful to Mrs Lisa Arvidsson and Inga Lundström for skilful technical assistance.

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