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An *in vivo* investigation into the use of resin-modified glass poly(alkenoate) cements as orthodontic bonding agents

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SUMMARY The aim of this study was to investigate the *in vivo* bonding of orthodontic brackets using two resin-modified glass poly(alkenoate) cements and to compare them with a conventional light-cured diacrylate bonding agent.

Twenty consecutive patients attending for bond up appointments took part in this randomized cross-mouth control study. Alternate quadrants were bonded with either Fuji Ortho LC or 3M Multi-Cure. Transbond [Adhesive Pre-Coated Brackets (APC™)] acted as the control in the other quadrants. Failed brackets were rebonded with the same material. Bond failure rates were collected over a 1-year period.

The bond failure rates over 1 year were 7.2 per cent for Transbond (APC), 5.9 per cent for 3M Multi-Cure, and 5.8 per cent for Fuji Ortho LC. Statistically, there was no significant difference between the bond failure rates of the materials and there was no effect of time.

This clinical investigation confirmed the suitability of the resin-modified glass poly(alkenoate) cements under test as orthodontic bonding agents.

Introduction

Resin-modified glass poly(alkenoate) cements have recently been the subject of a number of investigations as orthodontic bonding agents. They were developed from the glass poly(alkenoate) cements formed by the setting reaction of aluminosilicate glass and aqueous poly(acrylic acid) (Wilson and Kent, 1972) or co-polymers of carboxylic acid such as itaconic acid or poly(maleic acid) (Mount, 1990). Possible advantages of their use include an ability to adhere to base metal alloys, plastics, and enamel. As well as fluoride release from the contained glasses they are also thought to demonstrate an ability to adsorb or absorb exogenous fluoride from saliva, toothpaste, and topical fluoride gels, which is subsequently released (Ashcraft *et al.*, 1997). The material can therefore act as a rechargeable slow release fluoride device (Hatibovic-Kofman and Koch, 1991), which may lead to less enamel decalcification. Certainly, less decalcification has been reported when conventional glass poly(alkenoate) cements have been used for band cementation (Copenhover, 1986), although it is less clear whether this is the case when resin-modified glass poly(alkenoate) cements are used as orthodontic bonding agents (Millett *et al.*, 1999).

Ex vivo studies have shown the glass poly(alkenoate) cements used for direct bonding to have significantly lower bond strengths than composite resins (Fajen *et al.*, 1990; Øen *et al.*, 1991). Indeed, Cook (1990), in an *in vivo* investigation, reported a bond failure rate of 12.4 per cent when used to bond upper anterior teeth, leading to the suggestion that the adhesive was not suited to orthodontic bonding. More recently, resin-modified glass poly(alkenoate) cements have been introduced with the addition of up to 10 per cent hydroxyethylmethacrylate (HEMA). These materials share the acid-base reaction of conventional glass poly(alkenoate) cements, whilst the HEMA component can undergo free radical addition polymerization following either chemical or light activation.

In vivo studies on orthodontic direct bonding with resin-modified glass poly(alkenoate) cements have found wide ranging bond failure rates of between 3.2 per cent (Silverman *et al*., 1995) and 34.5 per cent (Cacciafesta *et al*., 1999). The low bond failure rate of 3.2 per cent is particularly impressive when teeth as far back in the mouth as the second molars were included. However, this study lasted only 8 months and there was no cross-mouth control group utilizing a conventional diacrylate bonding agent. Fricker (1994), in a 12-month study, also quoted a low *in vivo* bond failure rate of 3.3 per cent, but only teeth from canine to canine were included. In the case of conventional diacrylic bonding agents, it is well known that premolar teeth suffer a greater number of in-service bond failures than the incisors and canines (Zachrisson, 1977). Hence, the bond failure rates in the latter study (Fricker, 1994) may be greater in everyday clinical use from premolar to premolar in both arches.

The aim of this current *in vivo* study was to investigate the use of two light-cured resin-modified glass poly(alkenoate) cements as orthodontic bonding agents. The measurement parameter was the *in vivo* bond failure rate over two time periods.

Materials and methods

Twenty consecutive full upper and lower fixed appliance patients were chosen for this study, both non-extraction and premolar extraction cases. The inclusion criteria included cases requiring metal brackets and where bands were only to be placed on molar teeth. Hence, patients requiring banded upper premolars for a Hyrax screw appliance or those who requested upper anterior ceramic brackets were excluded. Local research ethics committee approval was granted and all the patients gave their consent to participation in the study. They were treated by one operator (SC) at the University of Bristol Dental Hospital.

A split-mouth technique was used in which the quadrants to be bonded with either the test or control material were allocated randomly using a random number table (Altman, 1991). Allocation of patients to each of the poly(alkenoate) groups was carried out using a second random number table. Control quadrants were bonded with a conventional light-cured diacrylate bonding agent.

At the bond up appointment, the brackets were bonded to the teeth as follows:

1. In the control quadrants the light-cured diacrylate Transbond (3M, Monrovia, USA) was used. Instead of being applied to the bracket bases by the operator from a syringe, Dyna-Lock™ 0.022 × 0.028-inch pre-adjusted Adhesive Pre-Coated Brackets (APC™) and 3M brackets were used. These brackets were supplied with the Transbond adhesive already present on the bracket base. The enamel in the control quadrants was first polished with a slurry of pumice using a rubber cup, rinsed with water, and then etched using 37 per cent *o*-phosphoric acid for 30 seconds. Following further rinsing and thorough air drying using an oil-free air supply, Transbond™ XT Light Cure Adhesive Primer was applied to the etched enamel before placing the brackets into position. Excess adhesive was removed from around the margins using a dental probe. The adhesive was light cured using a 3M halogen curing light (Ortholux™ XT curing lamp, 3M, St Paul, USA) for 10 seconds per interspace (20 seconds per tooth).
2. In the case of Fuji Ortho LC (GC Corp, Japan) quadrants, the teeth were pumiced, washed, and isolated, before 10 per cent poly(acrylic) acid (GC Ortho Conditioner) was placed onto the enamel for 10–20 seconds. The teeth were then washed and the enamel surfaces left moist. Fuji Ortho LC was mixed according to the manufacturers' instructions and loaded onto Dyna-Lock™ 0.022 × 0.028-inch pre-adjusted brackets before placement on the tooth. Excess adhesive was removed from around the margins using a dental probe. The brackets were light cured for 20 seconds per interspace (40 seconds per tooth).

3. For the 3M Unitek™ Multi-Cure Glass Ionomer/Orthodontic Band Cement (3M) quadrants, the teeth were pumiced, etched with 37 per cent *o*-phosphoric acid for 30 seconds, rinsed with water, and again left moist. The manufacturers' instructions for mixing the cement were followed and the mixed cement loaded onto Dyna-Lock™ 0.022 × 0.028-inch pre-adjusted brackets. Once the brackets were placed onto the teeth, excess cement was removed from around the margins and the brackets were light cured for 20 seconds per interspace (40 seconds per tooth).

Molar separating elastics were also placed following bond placement. One week later, bands were placed and 0.010-inch stainless steel ligature wires were tied as figure of eight lacebacks around the first molars, premolars, and canines in all quadrants. Nickel titanium archwires (0.012-inch) were then placed and tied in using elastomeric modules. The patients were subsequently seen every 6 weeks for the remainder of their orthodontic treatment, with the usual archwire progression being 0.016-inch nickel titanium, through round stainless steel, up to the working archwire size of 0.019 × 0.025-inch stainless steel.

Bond failure data were collected over a period of at least 1 year, differentiating the first (0–6 months) and second (6–12 months) halves of the year in order to determine the effect of time on bond failure. If a bracket failed and, provided the bracket was still present, the same test material was used to rebond the same bracket on the tooth in order to determine the success of rebonding. In each case, the remnant adhesive was removed from the enamel surface using a spiral fluted tungsten carbide bur. Excess adhesive was removed from the back of the brackets with a green stone in a slow speed contra-angle handpiece.

Results

Summary bond failure data for 0–6 months are shown in Table 1 and 6–12 months in Table 2. The data from this *in vivo* cross-mouth control trial is a binary response series, namely 'fail' or 'no fail'. As an observational case control study, the data were analysed using the logistic regression technique (Stata Version 6.0, Stata Corporation, College Station, Texas, USA). Significance was pre-determined at $\alpha = 0.05$. For each material/time combination an Odds Ratio and 95 per cent confidence interval was determined. If the 95 per cent confidence interval encompasses the value 1, there is effectively no difference between the groups. Tables 3(a–d) demonstrate that there was little difference in the bond failure rates between any of the groups under investigation. There was therefore no effective difference in the bond failure rates between Transbond (APC), Fuji Ortho LC and 3M Multi-Cure. Considering the effect of time on bond failure rates, the logistic regression analysis once again suggests that there was no difference in the bond failure rates between 0–6 months and 6–12 months after initial bond placement. Rebond data were not analysed due to a low number of rebond failures, only 11 in total.

Table 1 0–6 months *in vivo* bond failures. Transbond was used as the control for both groups of patients.

Material	No fail	Fail	Total teeth
3M Multi-Cure	82	3	85
Transbond (APC)	81	5	86
Fuji Ortho	81	3	84
Transbond (APC)	76	5	81
Total	320	16	336

Table 2 6–12 months *in vivo* bond failures. Transbond was used as the control for both groups of patients.

Material	No fail	Fail	Total teeth
3M Multi-Cure	80	2	82
Transbond (APC)	79	2	81
Fuji Ortho	79	2	81
Transbond (APC)	76	0	76
Total	314	6	320

Table 3 Logistic regression analyses for the *in vivo* cross-mouth control trial investigating the effect of material and time on bond failure rates.

(a) 3M Multi-Cure versus Transbond (APC).

	OR	SE	*z*	*P* > [*z*]	95% CI
Material	1.419	0.847	0.558	0.558	0.440–4.572
Time	0.488	0.304	0.249	0.249	0.144–1.652

Sample size: 344. OR: Odds ratio. 95 per cent CI lower and upper 95 per cent CI about OR. $P > z$ probability.

(b) Fuji Ortho LC versus Transbond (APC).

	OR	SE	*z*	*P* > [*z*]	95% CI
Material	2.145	1.200	1.365	0.172	0.717–6.420
Time	0.869	0.462	–0.265	0.791	0.307–2.461

Sample size: 330. OR: Odds ratio. 95 per cent CI lower and upper 95 per cent CI about OR. $P > z$ probability.

(c) Transbond (APC) versus Transbond (APC) in the two experimental groups.

	OR	SE	*z*	*P* > [*z*]	95% CI
Material	1.246	0.315	0.869	0.385	0.759–2.045
Time	0.686	0.347	–0.744	0.457	0.255–1.850

Sample size: 334. OR: Odds ratio. 95 per cent CI lower and upper 95 per cent CI about OR. $P > z$ probability.

(d) 3M Multi-Cure versus Fuji Ortho LC versus Transbond (APC).

	OR	SE	*z*	*P* > [*z*]	95% CI
Material	1.253	0.225	1.259	0.208	0.882–1.782
Time	0.676	0.270	–0.978	0.328	0.309–1.481

Sample size: 674. OR: Odds ratio. 95 per cent CI lower and upper 95 per cent CI about OR. $P > z$ probability.

Discussion

The overall bond failure rates over the 1-year test period were 7.2 per cent for Transbond (APC), 5.9 per cent for 3M Multi-Cure, and 5.8 per cent for Fuji Ortho LC. This bond failure rate for the diacrylate control of 7.2 per cent falls within the acceptable levels for *in vivo* use discussed by Zachrisson (1977) of 4–10 per cent. The failure rates for the two resin-modified glass poly(alkenoate) cements not only compare favourably with this 4–10 per cent level, but also with the *in vivo* work of Cook (1990) at 12.4 per cent and Fricker (1992) at 20 per cent, where conventional glass poly(alkenoate) cements were used only on anterior teeth. Latterly, Fricker (1994) achieved a much lower bond failure rate of only 3.3 per cent when using the resin-modified glass poly(alkenoate) Fuji II LC. However, this material was again only used for bonding from canine to canine in each arch. An unusually high bond failure rate of 34.5 per cent was reported by Cacciafesta *et al.* (1999), but in this case the enamel was dried prior to bonding with the resin-modified glass poly(alkenoate). When the enamel was moist prior to bonding the reported bond failure rate was 7.9 per cent (Cacciafesta *et al.*, 1998). The lowest reported bond failure rates for the *in vivo* use of a resin-modified glass poly(alkenoate) cement of 3.2 per cent, were those of Silverman *et al.* (1995). Although that study included bonding teeth as far back as the second molars, it ran only for a period of 8 months.

In this present investigation, although there was no significant effect of time on observed bond failure rates, the Transbond (APC) bracket bonding system demonstrated the highest bond failure rate during the first week, with six out of the total 12 failures occurring during this short time period. Four of these were on premolar teeth and the other two on lower canines. For the premolar teeth, the locus of bond failure was mainly at the enamel resin interface. This suggests that the failure was most probably due to moisture contamination during the bonding procedure. Certainly, when using diacrylate bonding agents, it is essential to maintain a dry field after enamel etching and prior to bond placement. On posterior teeth this can be difficult, especially if the tooth has a short clinical crown with the increased risk of contamination from crevicular fluid (Zachrisson, 1977). The presence of aprismatic enamel on premolar teeth can also lead to a higher incidence of bond failure (Lovius *et al.*, 1987). The bond failures on the lower canines may have been due to problems with moisture contamination or possibly occlusal interference, although no particular note was made of this at the time of initial bonding.

The bond failures observed with both Fuji Ortho LC and 3M Multi-Cure were more evenly spread over the 1-year observation period, with three failures occurring in the first 6 months and two failures in the second 6 months for each of the two materials. This may be related to the bonding technique, which in the case of these materials is less moisture sensitive. Indeed, it was part of the bonding technique to leave the enamel moist after acid conditioning or etching and prior to placement of the brackets. Seven of the 10 bond failures were in the lower canine or premolar regions.

Although no formal statistical analysis was performed on the rebonded bracket data, it was interesting to study the data individually. The four original brackets rebonded using Fuji Ortho LC lasted for 1, 5, and 12.5 months, and until completion of treatment (20.5 months). With the Transbond rebond specimens, six out of the eight rebonded brackets lasted for more than 12 months or until the end of the patient's orthodontic treatment, whilst with 3M Multi-Cure, the rebonded brackets had a tendency to debond within a very short period of time, often within the first day (as in three out of the five rebonded brackets). The maximum time interval a rebonded bracket stayed in place with this material was 3.5 months.

From this experiment it would seem that resin-modified glass poly(alkenoate) cements are suitable for use as orthodontic bonding agents, confirming the findings of earlier *ex vivo* work (Choo *et al.*, 2001). However, in both cases the enamel was acid etched, either with poly(acrylic acid) for the Fuji Ortho LC specimens or 37 per cent *o*-phosphoric acid for the 3M Multi-Cure specimens. Although prior etching was recommended by Messersmith *et al.* (1997), Cook and Youngson (1988) with conventional glass poly(alkenoate) cements found that acid etching is not only unnecessary, but also reduced the measured *ex vivo* bond strength. Silverman *et al.* (1995) pumiced the enamel, did not perform any acid conditioning, and yet still observed an in service bond failure rate of only 3.2 per cent when using Fuji Ortho LC. More time could certainly be saved if conditioning was not performed. However, the experience of using 3M Multi-Cure on one patient without any form of acid conditioning/etching of the enamel surface, in which all the brackets debonded within a day, prompted the use of acid etching in this current trial. If less reliance could be placed on conditioning/etching the enamel surface to gain a mechanical bond, Fuji Ortho LC in particular may be useful in cases where conventional etching is likely to be less successful, such as in subjects with enamel fluorosis and amelogenesis imperfecta.

The disadvantages of resin-modified glass poly(alkenoate) cements are primarily in the time taken in their use. In this work, the powder and liquid components were mixed by hand, which is time consuming and can lead to errors in the ratio of each material used compared with an encapsulated system (Wong and Bryant, 1985). Also, the enamel was prepared according to the manufacturers' instructions, which included prior pumicing of the enamel and acid conditioning/etching according to the material used.

Conclusions

The results of this *in vivo* cross-mouth control study showed no difference in the bond failure rates of the diacrylate and resin-modified glass poly(alkenoate) cements under test, over the time periods 0–6 and 6–12 months. Resin modified glass poly(alkenoate) cements, after acid conditioning/etching, can be used for successful orthodontic bonding *in vivo* and may, indeed, offer significant advantages over conventional diacrylate bonding agents.

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