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An investigation into the use of two polyacid-modified composite resins (compomers) and a resin-modified glass poly(alkenoate) cement used to retain orthodontic bands

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SUMMARY The aim of this investigation was to determine the effectiveness of a conventional glass poly(alkenoate) cement (Intact) and newer polyacid-modified composite resin cements (Transbond™ Plus and Ultra Band-Lok™) to retain orthodontic bands.

In the *in vitro* part of this study, stainless steel bands were cemented to 240 extracted third molar teeth in three test groups comprising Intact, Transbond™ Plus and Ultra Band-Lok™. The force to deband (N) for all three cements was recorded using an Instron universal testing machine after the following observation periods: 20 minutes and 3, 6 and 12 months. The results indicated that all three cements increased their median force to deband after 12 months. Of the two compomers, Transbond™ Plus demonstrated the highest median force to deband at all four time intervals.

In the *in vivo* part of the study, 30 patients participated in a randomized cross-mouth clinical trial where the molar bands were cemented in place using either Intact or Transbond™ Plus. Ultra Band-Lok™ was not used in the clinical part of the study. The results showed there to be no clinically significant difference in band failure rates between the two cements. When patients were asked to score each for taste, there was a significant difference, with the glass poly(alkenoate) cement (Intact) being more acceptable than the polyacid-modified composite Transbond™ Plus ($P < 0.001$).

No significant differences were observed in the *in vitro* median force to deband or *in vivo* band failure rates between the glass poly(alkenoate) cement and the polyacid-modified composite resins. The choice of cementing agent can therefore be made on patient factors, e.g. taste, or operator factors, e.g. ease of handling, cost and shelf life.

Introduction

The latest materials developed for cementing orthodontic bands are polyacid-modified composite resins. Various other dental materials have been used as orthodontic cements over the years, but interest has now focused on the use of resin-based materials (Kvam *et al.*, 1983; Fricker, 1997; Aggarwal *et al.*, 2000). Conventional and resin-modified glass poly(alkenoate) cements can adhere to base metal alloys, as well as to unetched enamel (Yoshida *et al.*, 2000), making them attractive for use in orthodontic banding. Light-polymerized cements have been introduced in order to overcome the problems of moisture sensitivity and the low early mechanical strength typically associated with conventional glass poly(alkenoate) cements (Sidhu and Watson, 1995). Unlike conventional and resin-modified glass poly(alkenoate) cements, the adhesive mechanism of polyacid-modified composite resins is unknown. It has been hypothesized that these materials may be self-adhesive through the carboxyl groups of the monomer forming ionic bonds with calcium ions of untreated enamel (Hse*et al.*, 1999).

Polyacid-modified composite resins are composite materials composed of partially silanized ion leachable glass embedded in a light-activated polymeric matrix (Meyer *et al.*, 1998). The principal difference between the resin-modified glass poly(alkenoate) cements and the polyacid-modified composite resins is in the amount of resin found within the material. Usually, the newer polyacid-modified composite resins contain up to 20–50 per cent resin, e.g. 2 hydroxy-1,3-dimethacryloxypropane, unlike the resin-modified glass poly(alkenoate) cements where around 5 per cent of the material is resin (Sidhu and Watson, 1995; Gladys *et al.*, 1997), e.g. 2 hydroxyethyl methacrylate. The polyacid-modified composite resins cannot set by an acid–base reaction, as occurs within glass poly(alkenoate) cements, due to the absence of water. Instead the material is hardened through photo-polymerization. Later, a limited acid–base reaction may take place, but only once water present in the mouth has diffused into the polymeric matrix.

There are few reports in the literature on the *in vitro* properties of polyacid-modified composite resins. It has been claimed that these materials have better physical and mechanical properties when compared with resin-modified glass poly(alkenoate) cements. These include higher tensile and compressive strengths, lower water absorption, and an equivalent rate of fluoride release. They are said to behave more like composite resin materials than glass poly(alkenoate) cements (Meyer *et al*., 1998).

A comparative laboratory investigation between a conventional glass poly(alkenoate) cement and a polyacid-modified composite resin used to cement orthodontic bands found the force to deband in the polyacid-modified group to be significantly higher (Millett *et al*., 1998). A recent *in vitro* investigation looking at the shear-peel bond strength of zinc phosphate, resin-modified glass poly(alkenoate) and polyacid-modified composite resin found that both the resin-modified glass poly(alkenoate) cements and the polyacid-modified composite resins had significantly higher bond strengths than the zinc phosphate cements, with there being no statistically significant differences between the latter two cements (Aggarwal *et al*., 2000). This contrasts with another *in vitro* study comparing resin-modified glass poly(alkenoate) cement with polyacid-modified composite resins, which found significant differences between the cements with respect to shear bond strength, reporting that the polyacid-modified composite resins had the lowest shear bond strength (Liebmann and Jost-Brinkmann, 1999).

There are a number of possible advantages of light-polymerized materials over conventional glasspoly (alkenoate) cements, including a longer working time, a sharp set on photo-curing, the rapid development of strength, and an improved resistance to aqueous attack. Recently, a new polyacid-modified composite resin has been introduced for use as an orthodontic banding cement. This light-cured cement, Transbond™ Plus, contains hydroxy-1, 3-dimethacryloxypropane with another resin known as CDMA (carboxylate dimethacrylate), an oligomeric carboxylic acid with methacrylate groups. The presence of CDMA is thought to provide a greater ratio of methacrylate groups, thus allowing greater cross-linking within the resin matrix (Hse *et al.*, 1999) and perhaps, greater compressive and tensile strength.

The aims of this current investigation were to compare two polyacid-modified composite resins and a conventional glass poly(alkenoate) used to cement orthodontic bands, and in particular to determine:

1. whether there is a difference in the *in vitro* mean force to deband when orthodontic bands are cemented using either a conventional glass poly(alkenoate) cement or a polyacid-modified composite resin and also whether this is affected by time;
2. whether there is a difference in the observed *in vivo* band failure rates between a conventional glass poly(alkenoate) cement and a polyacid-modified composite resin, and whether there is a difference in taste as perceived by the patient at the time of band cementation.

Materials and methods

In total, 250 extracted human third molar teeth without caries, restorations or surface anomalies were collected from the Oral Surgery Department, Taunton and Somerset NHS Hospital. Although they were received in 10 per cent formalin solution, they were immediately rinsed, any adherent soft tissue removed, and then stored in distilled water at room temperature. The teeth were randomly divided into four groups of 60 teeth, which were allocated to one of the following observation periods: 20 minutes and 3, 6 or 12 months.

Each group consisted of 20 teeth for banding with a conventional glass poly(alkenoate) cement (Intact, Orthocare UK Ltd, Bradford, UK), 20 teeth for banding with polyacid-modified resin composite (Transbond™ Plus, 3M Unitek, St Paul, Minnesota, USA) and 20 teeth for banding with an additional polyacid-modified resin composite (Ultra Band-Lok™, Reliance Orthodontic Products, Itasca, Illinois, USA). This follows the recommendation of the required numbers for bond testing of Fox *et al.* (1991). The teeth were then placed in cold-cure acrylic blocks so that only the crowns of the teeth remained visible. With the use of a hand-held protractor, the teeth were carefully angled at 20 degrees from the vertical to enable easy engagement of the pre-welded buccal tubes by the sliding plate (loading strip) of the custom-made jig when in position in the Instron universal testing machine (Instron Ltd, High Wycombe, Buckinghamshire, UK) (Figure 1).

The crowns of the teeth were then cleaned with a slurry of pumice in water using a bristle brush in a slow speed handpiece. They were then washed with distilled water before being gently air-dried with oil-free compressed air from a 3-in-1 syringe. Stainless steel bands (3M Unitek) used for first permanent molars were selected and adapted to the crown of each tooth with a flat amalgam plugger. The bands were chosen for each tooth to provide the best fit possible.

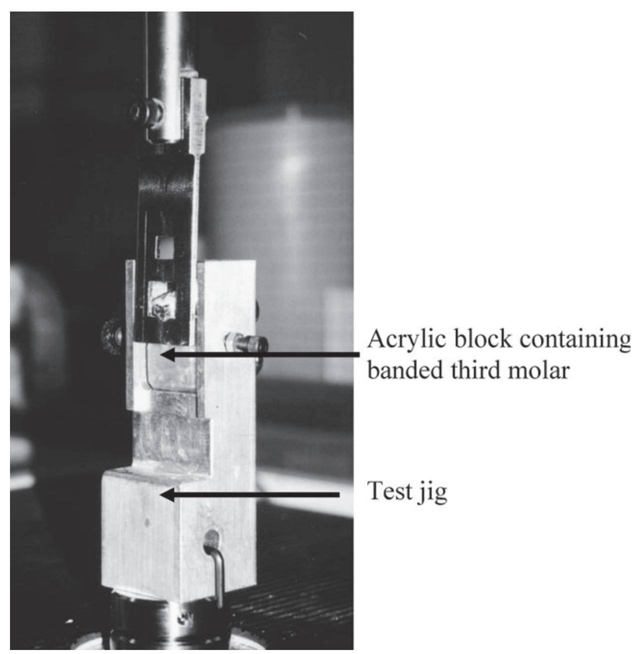


Figure 1 The customized testing jig.

All cementing agents were mixed according to the manufacturers' instructions. Only two bands were cemented with each mix of cementing material. The bands were then repositioned firmly into place before any excess cement was removed from the occlusal and cervical margins of the band with a dry cotton wool roll. All band selection and cementation was performed by one operator (PW). The conventional glass poly(alkenoate) cement, Intact, was allowed to bench cure for 5 minutes, whereas both the polyacid-modified resin cements tested, namely Transbond™ Plus and Ultra Band-Lok™, were light cured (Dentsply QHL75 halogen curing light, Dentsply, Addlestone, Surrey, UK) for 30 seconds from the occlusal surface. All specimens were then placed in a water bath (Grant Instruments, Cambridge, UK) set at 37°C for their allocated observation period of 20 minutes, and 3, 6 or 12 months. The water bath had its water changed weekly with fresh distilled and de-ionized water.

As a preliminary to the main specimen testing, 10 banded samples cemented with the glass poly(alkenoate) cement were individually tested. A specimen was positioned into the custom-made jig and secured in place by tightening adjustable screws to fix the acrylic block in position. A steel rectangular loading strip in which a square hole (7 × 7 mm) had been removed from its inferior portion was then fixed to the Instron universal testing machine in tensile testing mode. This assembly was carefully lowered and positioned so that it engaged under the pre-welded buccal tubes on the band (Figure 1). The Instron universal testing machine was then programmed to perform at a crosshead speed of 0.5 mm/minute and testing proceeded for each sample until the band was removed from the tooth. Once the band had been removed, the maximum force during debanding was measured in Newtons (N) and recorded directly using a personal computer attached to the machine. A stress/strain graph was also obtained for each sample. After each sample was tested, it was removed from the jig assembly and the Instron universal testing machine was re-calibrated before commencing with a new sample.

The preliminary samples demonstrated this to be a suitable method to assess the force required to remove cemented bands from the specimens and so all 240 banded specimens were tested in this way.

For the *in vivo* investigation, 30 patients were recruited to take part in a cross-mouth study. Ethics committee approval was obtained and consent forms were signed by the patient and/or their parents. The patients were selected for inclusion in the trial if stainless steel bands were to be used on the first permanent molars as part of the fixed appliance treatment. The selection criteria were:

1. the first molars were healthy and were neither hypoplastic nor heavily restored;
2. upper and lower fixed appliances were to be fitted;
3. no additional banded appliance was required, e.g. quadhelix.

It was calculated that a sample size of 30 patients would be required to have 80 per cent power to detect a statistical significance of proportions assuming a difference of 25 per cent between the two different cementing agents Transbond™ Plus and Intact. The method of analysis was a McNemar's test of equality of paired proportions with a $P < 0.05$ significance level.

One week prior to band placement, elastic separators were placed mesially and distally to the first molars and brackets were bonded to the anterior teeth. At the following visit the separators were removed and the molars cleaned with a slurry of water and pumice using a rubber cup in a slow speed handpiece. The teeth were then rinsed to remove any excess pumice. Optimum fit molar bands were selected for the first molars by one operator (PW). Two cementing agents were to be tested in the *in vivo* experiment, namely Intact, the glass poly(alkenoate) cement, and the newer polyacid-modified composite, Transbond™ Plus. The higher median force to deband values of Transbond™ Plus meant that this was the polyacid-modified composite of choice for use in the *in vivo* experiment. In diagonally opposite quadrants, the bands were cemented with one cement and the other cement was used in the other two quadrants. Quadrant and cement allocation was determined using sealed envelopes containing odd and even numbers generated using a random number table. The patient was asked to choose an envelope in each case. The bands were chosen and cemented into position by one operator (PW). The cementation was obviously not carried out blind, but allocation of the cements to their respective quadrants was randomized. In each case the cements were mixed according to the manufacturers' instructions. Those cemented with Transbond™ Plus were light cured from the occlusal for 30 seconds. Once the bands were cemented into position the patient was asked to describe the taste of each and to score the taste on a scale of 0 to 10, with 0 being tasteless and 10 being awful. The order in which the cements were used was also randomized in order to reduce bias prior to asking the patients to comment on the taste.

Once the cements had set, 0.012 inch nickel titanium archwires were placed. The patients were reviewed at 6 weekly intervals. The archwire sequence was 0.016 inch nickel titanium, 0.016 × 0.022 inch stainless steel and, finally, 0.019 × 0.025 inch stainless steel. If a band failed it was recorded and then recemented using the original cement. The observation period was 12 months.

Results

The data were analysed using Stata 7 (StataCorp 2001, Stata Statistical Software Release 7.0, College Station, Texas, USA) and the significance was predetermined at $\alpha = 0.05$. Summary statistics are presented in Table 1. The data were tested for normality using the Shapiro–Francia *W'* test and were found not to be normally distributed.

Table 1 Summary statistics of the *in vitro* results for force to deband (N) of the three cements over the four time periods.

Cement	Time period	Median	Interquartile range	95% confidence intervals of the median
Intact	20 minutes	34.02	24.53 – 56.78	24.94 – 48.53
Transbond™ Plus	20 minutes	61.10	33.15 – 78.04	34.73 – 75.99
Ultra Band-Lok™	20 minutes	51.70	32.74 – 70.29	33.08 – 66.92
Intact	3 months	25.29	15.46 – 82.13	15.76 – 78.48
Transbond™ Plus	3 months	56.03	33.42 – 74.70	35.71 – 68.86
Ultra Band-Lok™	3 months	49.45	33.39 – 71.63	34.01 – 69.06
Intact	6 months	46.00	28.21 – 71.17	28.99 – 69.05
Transbond™ Plus	6 months	58.79	36.76 – 87.26	37.05 – 84.24
Ultra Band-Lok™	6 months	53.04	37.48 – 78.98	37.72 – 78.07
Intact	12 months	92.52	62.25 – 128.92	64.85 – 128.06
Transbond™ Plus	12 months	78.99	60.71 – 122.84	61.10 – 117.67
Ultra Band-Lok™	12 months	57.65	41.50 – 93.06	57.65 – 42.83

The *in vitro* data summarized in Table 1 show overall that the median force to deband increased with time with large interquartile ranges for all of the results. At all four time intervals, except 12 months, Transbond™ Plus demonstrated a consistently higher median force to deband (N) compared with the other two cements. At all but the 12 month time interval, Intact demonstrated the lowest median and mean force to debond. The Kaplan–Meier survival plots and logranks of the glass poly(alkenoate) and the polyacid-modified composite resins over the different observation periods are shown in Figure 2A–D. Significant differences in the survival probabilities were noted at 20 minutes and 12 months, and in all cases, except 12 months, the survival probability was greatest for Transbond™ Plus. No significant difference was observed at 3 and 6 months.

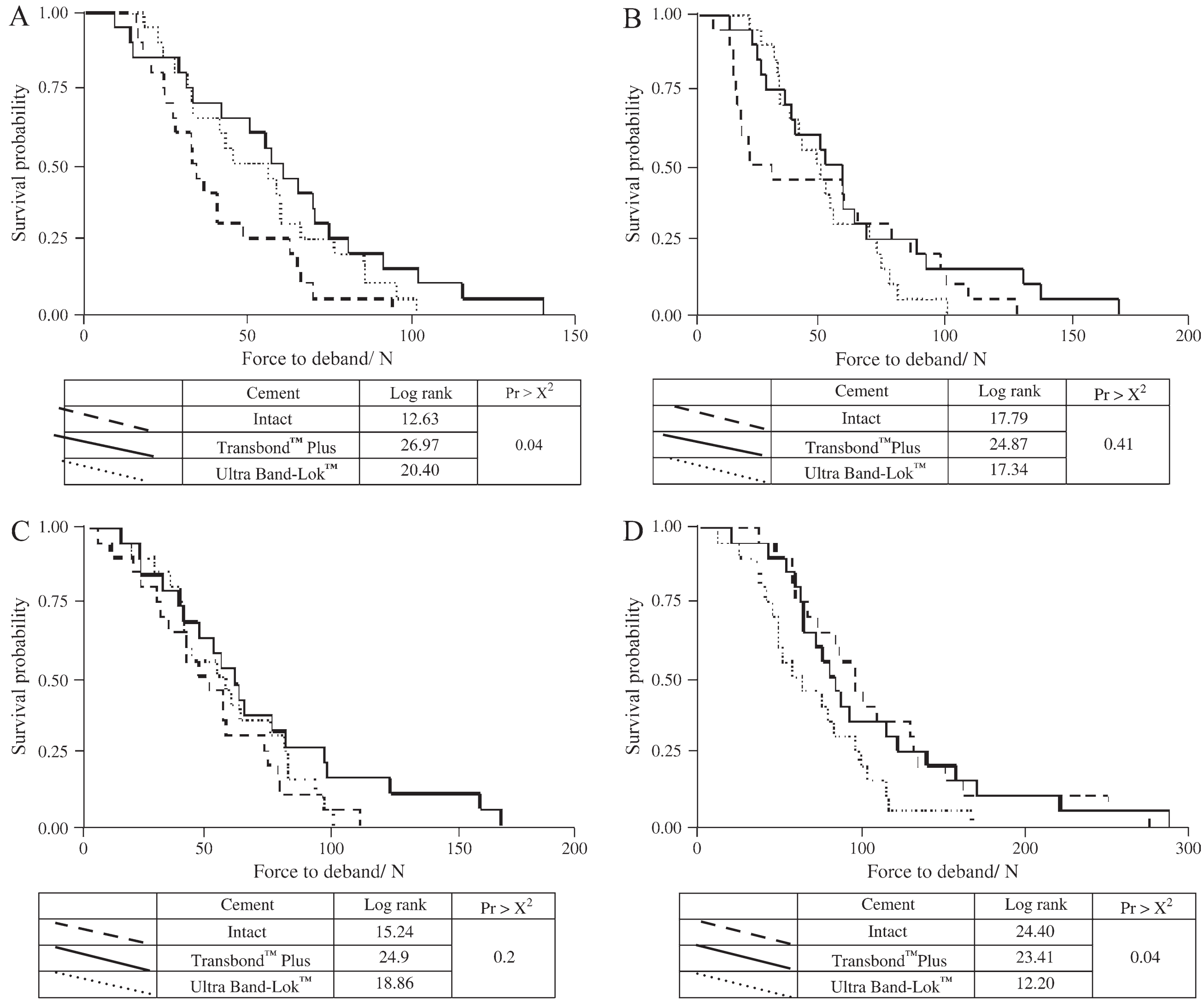
The *in vivo* results showed the very low number of band failures over the initial 12 months, namely two in the Intact group and one in the Transbond™ Plus group, out of 120 bands placed, which precluded statistical analysis. It would seem that there was little difference in the band failure rates between the two cements.

The taste data were analysed using the Wilcoxon signed-rank test (Table 2), which demonstrated a significant difference in taste between Intact and Transbond™ Plus, with the latter judged to have the worst taste.

Discussion

From the summary statistics of the *in vitro* results for the force to deband (N) of the three cements (Table 1), it can be seen that there was an overall increase in the median force to deband with increasing time. Concerns regarding the ability of the light-cured cements, namely Transbond™ Plus and Ultra Band-Lok™, to achieve an acceptable degree of cure, because of the limited area of cement available to the light source (Sargison *et al*., 1995), were not confirmed in this present *in vitro* study. If this were to be a problem, then it would be expected to be demonstrated at the all-important 20 minute observation period. It was the chemically-cured glass poly(alkenoate) cement, Intact, that demonstrated the lowest median force to deband at 20 minutes. A possible explanation for the increase in the observed median force to deband with time of the polyacid-modified composite resins could be the continuation of the free radical addition polymerization process initiated by light curing accompanied by the limited acid–base reaction as water moves into the material from the surrounding environment (Small *et al*., 1998).

Intact, the conventional glass poly(alkenoate) cement, demonstrated a slight increase in the median force to deband with time from 3 to 12 months, which was perhaps surprising given the findings of other workers who have found the opposite (Akashi *et al*., 1999). This may also be the result of a continuing acid–base setting reaction between the glass and the poly(acrylic acid), although whether this is likely to occur over such a prolonged period of 12 months is not known. Another theory is that glass poly(alkenoate) cements may possess the ability to 'heal' themselves if a crack appears, which prevents further propagation (Davidson, 1994). As water absorption occurs, an acid–base reaction may take place in parts of the cement that were embedded within the set matrix and that were not originally involved in the initial setting reaction. Therefore, unreacted material may become available, giving the glass poly(alkenoate) cement the ability to repair itself. Another proposed theory is that hydroscopic expansion or even plasticization of the material takes place as water uptake occurs (Oysaed and Ruyter, 1986; Koike *et al*., 1990). This may relieve or minimize stresses within the material and in turn reduce the likelihood of crack propagation. This might not only occur within the material, but also at the adhesive interface with the enamel surface or metal band, further modifying the stress field and affecting bond durability and strength. Earlier work has demonstrated that masticatory loads are most likely to induce crack propagation within the adhesive layer (Knox *et al*., 2000). This process, which can limit or reduce the effects of crack propagation within a material, is likely to reduce the incidence of its 'in service' failure. In both the *in vivo* and *in vitro* situation the surface



(A)

Cement	Log rank	Pr > X^2
Intact	12.63	0.04
Transbond™ Plus	26.97	
Ultra Band-Lok™	20.40	

(B)

Cement	Log rank	Pr > X^2
Intact	17.79	0.41
Transbond™Plus	24.87	
Ultra Band-Lok™	17.34	

(C)

Cement	Log rank	Pr > X^2
Intact	15.24	0.2
Transbond™ Plus	24.9	
Ultra Band-Lok™	18.86	

(D)

Cement	Log rank	Pr > X^2
Intact	24.40	0.04
Transbond™Plus	23.41	
Ultra Band-Lok™	12.20	

Figure 2 Kaplan–Meier survival probabilities and log rank tests for the three cements at the observation periods of (A) 20 minutes, (B) 3 months, (C) 6 months and (D) 12 months.

Table 2 Wilcoxon signed-rank test for the *in vivo* taste data.

Sign	Observations	Sum of ranks	Expected sum
Positive	1	12	227.5
Negative	25	443	227.5
Zero	30	10	10

$P = 0.001$.

area of the cement exposed to the aqueous environment is limited, with the orthodontic band offering some protection against the possible detrimental or perhaps beneficial effects of water absorption (Nicholson *et al*., 1992; Akashi *et al*., 1999; Cattani-Lorente *et al*., 1999).

Comparison of the Kaplan–Meier survival probability plots and logranks over the four time periods (Figure 2) shows there to be a statistical difference between the cements after 20 minutes and 12 months. After 20 minutes it would appear that Intact is the weaker of the three cements and it may be inferred that the glass poly(alkenoate) cements would be expected to fail earlier in clinical use compared with the polyacid-modified composite resins. On the other hand, after 12 months it would appear that Ultra Band-Lok™ would be expected to fail in clinical use compared with Transbond™ Plus and Intact.

With the use of third permanent molars in this *in vitro* investigation it is likely that each tooth will have a variable cement thickness around the circumference of the band. Therefore, it is probable that each band may fail by a combination of adhesive and cohesive failure depending on the cement thickness. The optimum film thickness of a glass poly(alkenoate) cement or a polyacid-modified composite resin when used to retain orthodontic bands is not known. Not only is the film thickness important, but also the uniformity of the film. Variations in film thickness can lead to the development of areas of stress concentration from which crack initiation and propagation can arise. When a composite resin cement layer is thick, shear stress concentrations are thought to occur at the periphery of the adhesive interface (Alster *et al*., 1995). If a load were to be applied, for example occlusal forces, it is liable to demonstrate adhesive or partial adhesive failure at the periphery. If the film thickness is uniform, then failure is usually more likely to occur as film thickness increases. This is because there is an increased risk of other stress factors, such as voids, being present within the material (Dukes and Byrant, 1969). This is particularly important for materials that are mixed by hand, such as in the case of conventional glass poly(alkenoate) cements, e.g. Intact. During the mixing process, air may become incorporated into the mixture forming voids, which may potentially reduce the cohesive and tensile strengths of the cement. Increasing the film thickness can also lead to the formation of higher internal stresses due to a greater polymerization/setting shrinkage (Wake, 1959).

Some studies investigating the tensile strength of thin resin composite layers as a function of layer thickness found that tensile strength gradually decreased with increasing layer thickness (Alster *et al*., 1995), but when tooth substance was used as a bonding substrate the influence of the cement layer thickness was found to be insignificant (Aksu *et al*., 1987). Although in the present study there was little difference between the measured force to debond between the cements, the range of the results was high, which might be explained by the variability in the shape and size of the third molar teeth used as substitutes for the first molar.

During the 12 month observation period in the *in vivo* study there was little difference in clinical performance between the two cements, with only two bands failing in the Intact group and only one in the Transbond™ Plus group, out of a total of 120 bands. There was, however, a significant difference in the taste scores between the two cements, with Transbond™ Plus being judged to have the least pleasant taste. The choice of which band cement to use would therefore depend on operator preference, e.g. ease of handling, cost, and patient factors, e.g. taste.

Conclusions

The following conclusions can be drawn from this investigation:

1. The highest median force to deband was seen at 12 months with all three band cements.
2. At each *in vitro* time interval, except 12 months, the highest median force to deband was demonstrated by Transbond™ Plus and the lowest by the glass poly(alkenoate) cement, Intact.
3. There was little difference in the *in vivo* band failure rates between Intact and Transbond™ Plus. Two bands failed in the Intact group and only one in the Transbond™ Plus group, out of a total of 120 bands.
4. The patients in this study rated the taste of the polyacid-modified cement, Transbond™ Plus, to be worse than that of the glass poly(alkenoate) cement, Intact.
5. With there being little difference in clinical failure rates between the two cements, the choice of which band cement to use may come down to patient preference, and taste is one factor to consider.

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