Journal of Orthodontics, Vol. 31, 2004, 323–328

SCIENTIFIC SECTION

An *ex vivo* evaluation of resin-modified glass polyalkenoates and polyacid-modified composite resins as orthodontic band cements

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Objectives: The objective of this ex vivo study was to assess the use of resin-modified glass polyalkenoates and polyacid-modified composite resins, as orthodontic band cements.

Materials and method: Plain stainless steel bands were cemented to 350 human extracted third molar teeth using 1 of 7 different cements. Following complete cement cure, half of each sample group was exposed to mechanical stress in a ball mill. Stressed and unstressed samples were tested in tension and the stress at which initial cement failure recorded. The mode of failure was recorded using an adhesive remnant evaluation.

Results: The mean band retention stresses offered by the cements studied ranged from 0.96 to 1.56 MPa. Fuji Ortho^{TM} provided the highest mean band retention stress in 'stressed' (1.56 MPa) and 'unstressed' (1.45 MPa) states. Exposure to mechanical stress did not appear to significantly influence band retention or mode of cement failure for most cements. Fuji Ortho^{TM} cement recorded the highest Weibull modulus for all cements tested. Virtually all samples failed at either the cement/enamel or cement band interface.

Conclusions: Significant differences in band displacement stress values and mode of failure were demonstrated between the cements studied. However, generic comparisons were difficult to make.

Key words: Bands, bond strength, cements, orthodontics

Received 27th November 2003; accepted 28th April 2004

Introduction

Orthodontic bands are still routinely employed in contemporary orthodontics, particularly in areas of high occlusal stress. The materials of choice for cementation are commonly the glass polyalkenoate cements, as these materials adhere to stainless steel and enamel, and also act as a fluoride reservoir helping to prevent decalcification. Conventional glass polyalkenoate cements have been demonstrated to offer superior retention for stainless steel molar bands in laboratory and clinical trials.[1–6] However, there has been some confusion in the terminology associated with the more recently developed glass polyalkenoate materials[7] and it is often unclear whether these materials offer the same band retention characteristics as the original glass polyalkenoate material.

McLean[8] has defined a conventional glass polyalkenoate (glass ionomer) cement as 'a cement that consists of a basic glass and an acidic polymer, which sets by an acid-base reaction between these components'. A resin-modified glass polyalkenoate cement is defined as 'a hybrid material that retains a significant acid-base reaction as part of their overall reaction process'. These cements set partly by an acid-base reaction and partly by a photochemical polymerization of the resin part of the cement. These cements are never in paste form, but in powder-liquid form as water is required for the acid-base setting reaction. According to McLean[8] these cements set at a slower rate in the dark, or in the

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DOI 10.1179/146531204225020697

absence of visible light, than conventional glass-polyalkenoate. Finally, polyacid-modified composite resins 'may contain either or both of the essential components of glass-polyalkenoate cement but at levels insufficient to promote the acid-base cure reaction in the dark i.e. in the absence of visible light'. These cements contain the ingredients of a glass-polyalkenoate (acid decomposable glass and perhaps some polyacid), but in insufficient amounts to promote dark setting (acid-base reaction). The acid-base reaction will only occur once water is absorbed into the set material.

The range of glass polyalkenoate materials has been explained by Burgess[9] as a continuum with conventional glass polyalkenoate cements at one end and fluoride-releasing resins (polyacid-modified composite resins) at the other end of the continuum.

It was the objective of this study to evaluate 2 resin-modified glass polyalkenoates and 3 polyacid-modified composite resins, as orthodontic band cements with reference to a conventional glass ionomer cement and a zinc phosphate cement.

Null hypotheses

- There is no difference in the quality of orthodontic band retention offered by a zinc phosphate, a conventional glass ionomer, 2 resin-modified glass polyalkenoates and 3 polyacid-modified composite resins.
- Exposure to mechanical stress, before testing, does not influence the strength of attachment offered by these cements or mode of failure.

Materials and method

Three-hundred-and-fifty extracted human third molar teeth were stored in 70% alcohol, according to local cross infection policies. The teeth were randomly divided into 7 groups of 50 teeth. Each tooth was cleaned with a pumice slurry, washed and dried. Plain molar bands were chosen for each tooth and adapted. A strip of stainless steel band (110 × 3.5 mm) was spot welded onto each band on its lingual and buccal aspect to form a loop. These loops aided the attachment of the specimen onto a specially designed jig (Figure 1).

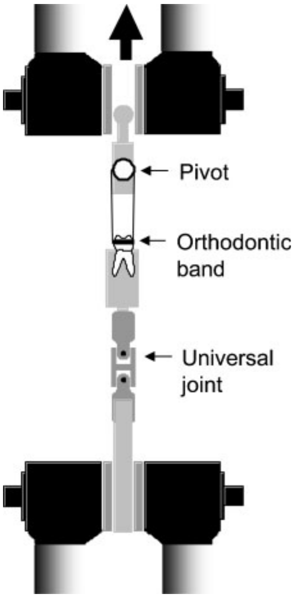

Figure 1 Test jig

The bands were then readapted and cemented with one of the cements to be evaluated (Table 1). All cements were mixed according to the manufacturers' recommendations at ambient temperature. Once the bands were loaded with cement they were then cemented onto the tooth with a band seater under hand pressure. Excess cement was removed from around the band with cotton wool roll and a Mitchell's trimmer. The light curable cements were cured with a conventional light-curing machine with the duration of exposure recommended by each manufacturer. The efficiency of the light-curing machine was tested with a Demetron Model

Table 1 Cements used in the study

Cement	Material	Manufacturer
Ormco Gold	Zinc phosphate	Ormco Orthodontics, Orange, CA
Ketac Cem	Glass polyalkenoate	3M ESPE, St Paul, MN
3M Unitek Multicure glass ionomer orthodontic band cement	Resin-modified glass polyalkenoate	3M Unitek, Monrovia CA
Fuji Ortho	Resin-modified glass polyalkenoate	GAC International Central Islip, NY
Band-Lok	Polyacid-modified composite resin	Reliance Orthodontic Products Inc. Itasca, IL
Ultra Band-Lok	Polyacid-modified composite resin	Reliance Orthodontic Products Inc. Itasca, IL
Diamond Bond VLC	Polyacid-modified composite resin	Kemdent Associated Dental Products, Swindon, UK

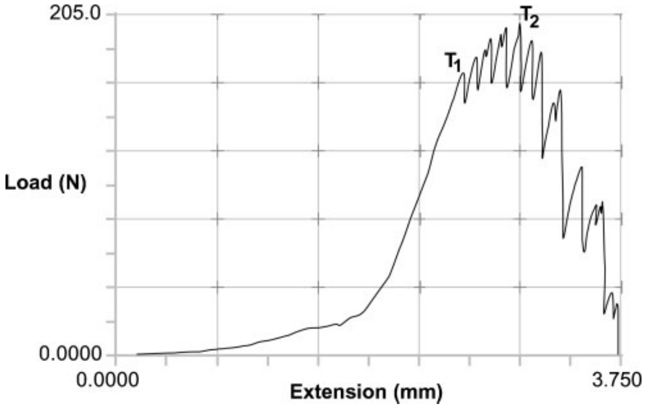

Figure 2 Load/extension graph (as printed for each specimen) (T1 point of initial failure, T2 point of complete failure)

100 curing radiometer. All specimens were then stored in distilled water at 37°C for 7 days.

Seven days after cementation, 25 samples were randomly selected from each group and subjected to mechanical stress in a ball mill machine containing 470 g of ceramic spheres of various sizes and 0.5 l of distilled water at 37°C. The ball mill machine was allowed to run at 250 rpm. Each 'stressed' sample was exposed to 1 minute of mechanical stress.

The roots of all specimens (stressed and unstressed) were invested in cold cure acrylic and tested under tensile load in a Lloyds LR-10K. A specially designed jig (Figure 1), incorporating universal joints, was used to reduce lateral and torsional stresses during testing.

The cross-head speed of the Lloyds LR-10K machine was set at 1 mm/minute. All of the specimens were tested until total dislodgement of the band from the crown of the tooth had occurred. A load-extension graph was printed for each specimen (Figure 2). The load, T1, at which point the curve initially deviated from linearity was noted as the initial point where the cement failed.

After testing, the band fitting surface and the enamel surface of all the specimens were assessed to determine the band surface area and the site of cement failure. The failure sites were graded as: 0=primarily cohesive failure within the cement, i.e. equal volumes of cement on enamel and stainless steel surfaces; 1=the majority failure is at the cement-metal junction; 2=the majority failure is at the cement-enamel junction.

Results

Band retention

The mean band displacement stress values for all unstressed and stressed cement samples are presented in Figure 3 and Table 2. Several specimens failed for reasons that were judged to be sporadic and do not imply any deficiency in the performance of the cement.

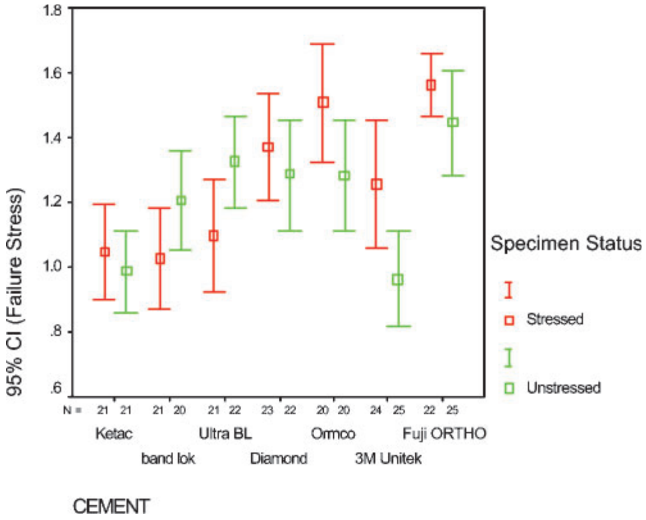

Figure 3 Band displacement stresses for stressed and unstressed cements

A one-way analysis of variance with Tukey *post hoc* tests was used to compare the mean band displacement values for unstressed and stressed samples (Tables 3 and 4).

Exposure to mechanical stress did not appear to significantly influence band retention for all cements other than Ultra Bandlok$^{\text{TM}}$ and 3M Unitek Multicure$^{\text{TM}}$ cements ($p \leqslant 0.04$). Independent *t*-tests demonstrated that Ultra Bandlok$^{\text{TM}}$ offered a significantly stronger band retention in the unstressed state, whereas 3M Unitek Multicure$^{\text{TM}}$ recorded a higher bond strength following exposure to mechanical stress.

Table 2 Mean band displacement stress values (MPa)

Cement	Label	Mean stress (MPa)	SD	95% CI		*n*
Ketac Cem	Unstressed	0.99	0.28	0.86	1.11	21
	Stressed	1.05	0.33	0.90	1.20	21
Band-Lok	Unstressed	1.21	0.33	1.05	1.36	20
	Stressed	1.02	0.35	0.87	1.18	21
Ultra BL	Unstressed	1.33	0.32	1.19	1.47	22
	Stressed	1.09	0.39	0.92	1.27	21
Diamond	Unstressed	1.29	0.39	1.11	1.46	22
	Stressed	1.37	0.38	1.20	1.54	23
Ormco	Unstressed	1.28	0.37	1.10	1.45	20
	Stressed	1.51	0.39	1.32	1.70	20
3M Unitek	Unstressed	0.96	0.35	0.82	1.10	25
	Stressed	1.25	0.47	1.06	1.45	24
Fuji Ortho	Unstressed	1.45	0.39	1.29	1.61	25
	Stressed	1.56	0.29	1.47	1.66	22

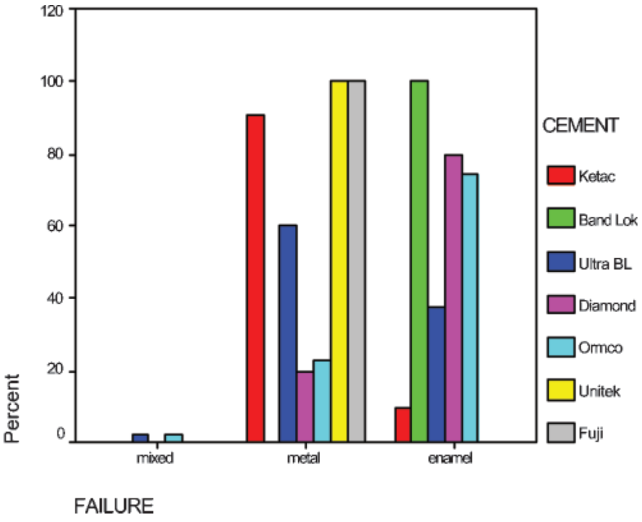

Figure 4 Mode of failure for all cements ('metal'=cement/band interface; 'enamel'=cement/enamel interface)

The Weibull probability of failure for band displacement was plotted for both the unstressed and stressed specimens. The Weibull analysis allowed the fracture probability to be calculated or predicted as a function of applied band displacement stress.[10,11] The Weibull modulus illustrates the dependability of the cement (Table 5).

Cement failure

Figure 4 demonstrates that virtually all samples failed at either the cement/enamel or cement/band interface. Very few samples in this study failed cohesively. A test for unpaired difference[12] demonstrated that the application of mechanical stress before testing did not influence the mode of failure.

Table 5 Weibull modulus of unstressed and stressed specimens

Cement	Weibull modulus Unstressed	Stressed
Ketac Cem	3.55	3.94
Band-Lok	3.19	4.18
Ultra Band-Lok	3.29	4.63
Diamond Bond VLC	4.24	3.78
Ormco Gold	4.40	3.74
3M Unitek	2.95	3.00
Fuji Ortho	8.51	4.59

Table 3 Comparison of unstressed cements (*p* values)

	Ketac Cem	Band-Lok	Ultra Band-Lok	Diamond Bond VLC	Ormco Gold	3M Unitek Multicure	Fuji Ortho
Ketac Cem		0.417	0.030*	0.084	0.108	1.000	0.000*
Band-Lok	0.417		0.926	0.990	0.994	0.238	0.261
Ultra Band-Lok	0.030*	0.926		1.000	1.000	0.009*	0.904
Diamond Bond VLC	0.084	0.990	1.000		1.000	0.030*	0.705
Ormco Gold	0.108	0.994	1.000	1.000		0.043*	0.706
3M Unitek Multicure	1.000	0.238	0.009*	0.030*	0.043*		0.000*
Fuji Ortho	0.000*	0.261	0.904	0.705	0.706	0.000*	

*The mean is significant at the 0.05 level.

Table 4 Comparison of stressed cements (*p* values)

	Ketac Cem	Band-Lok	Ultra Band-Lok	Diamond Bond VLC	Ormco Gold	3M Unitek Multicure	Fuji Ortho
Ketac Cem		1.000	1.000	0.062	0.002*	0.494	0.000*
Band-Lok	1.000		0.996	0.036*	0.001*	0.368	0.000*
Ultra Band-Lok	1.000	0.996		0.174	0.008*	0.774	0.001*
Diamond Bond VLC	0.062	0.036*	0.174		0.884	0.932	0.580
Ormco Gold	0.002*	0.001*	0.008*	0.884		0.260	0.999
3M Unitek Multicure	0.494	0.368	0.774	0.932	0.260		0.074
Fuji Ortho	0.000*	0.000*	0.001*	0.580	0.999	0.074	

*The mean is significant at the 0.05 level.

Table 6 Chi-square test for the failure mode of different cements

Cement*failure cross-tabulation				
		Failure		
Count		Metal	Enamel	Total
Cement	Ketac	38	4	42
	Band Lok		41	41
	Ultra BL	26	16	42
	Diamond	9	36	45
	Ormco	9	29	38
	Unitek	46		46
	Fuji	47		47
Total		175	126	301
Chi-square tests				
		Value	df	Asymp. Sig. (2-sided)
Pearson chi-square		187.627*	6	0.000
Likelihood ratio		240.385	6	0.000
Linear-by-linear Association		26.897	1	0.000
No. of valid cases		301		

*0 cells (.0%) have expected count less than 5. The minimum expected count is 15.91.

A Chi-squared test demonstrated a significant difference in the failure mode of the different cements (Table 6). Ketac Cem™, 3M Unitek Multicure™ and Fuji Ortho™ cements all tended to fail at the band/cement interface, whereas Band Lok™, Diamond Bond VLC™ and Ormco Gold™ tended to fail at the cement/enamel interface. Ultra Band-Lok™ failed predominantly at the band/cement interface, but a significant number of samples (38%) failed at the cement/enamel interface.

Discussion

It was the objective of this study to evaluate 2 resin-modified glass polyalkenoates and 3 polyacid-modified composite resins, as orthodontic band cements with reference to a conventional glass ionomer cement and a zinc phosphate cement. Band retention is affected by cement mechanical properties,[13] adhesion at the cement/enamel and cement/band interfaces[14–16] and, possibly, the influence of repeated mechanical stress on the cement adhesion and cohesion.[17]

The mean band retention stresses recorded in this study compare well with those published by Millett[18] who evaluated the mean band retentive strength of a modified composite, a resin-modified glass ionomer cement and a conventionally cured glass ionomer cement. Ketac Cem™ and Fuji Ortho™ were common to both studies and Millett[18] recorded a slightly higher mean retentive strength for both cements. However, Millett[18] used micro-etched bands, which have been demonstrated to offer increased bond strength,[19,20] and maximum bond strength was recorded, rather than the initial point of cement failure.

Significant differences were demonstrated between the strength of attachment offered by the materials included in this study but generic comparisons were not possible. Peutzfeldt[21] and Meyer[22] have reported an improved tensile and compressive strength of the newer glass polyalkenoate cements, resin-modified glass polyalkenoate cements and polyacid-modified composite resins. However, these physical properties only influence the cohesive strength of the cement, and not the strength of the interface of the cement with enamel and the orthodontic band, which may be more important.

For the materials tested in this study, virtually all samples failed at either the cement/enamel or cement/band interface. The zinc phosphate and polyacid modified composite materials tended to fail at the cement/enamel interface whereas the conventional and resin-modified polyalkenoate materials failed largely at the band/cement interface. These results do not concur with Millett[18] who reported failure predominantly at the cement enamel interface for Fuji Ortho™. However, Millett's study[18] evaluated micro-etched bands.

Exposure to mechanical stress did not appear to significantly influence the strength of band retention or mode of cement failure for most cements in this study. However, the strength of attachment offered by a particular cement in a laboratory study is probably less important to the orthodontic clinician than the clinical reliability of the attachment.[18] Fuji Ortho™ provided both the highest band retention stresses and highest Weibull modulus indicating that this material would provide greater bond reliability than the other cements studied. Interestingly, the Weibull moduli recorded for Ketac Cem™ and Fuji Ortho™ in this study were higher than those recorded by Millett[18] for the same materials.

This study clearly suggested that the use of Fuji Ortho™, rather than Ketac Cem™ may offer a significantly more robust method of orthodontic band cementation. Fuji Ortho™ bonds well to tooth tissue and the quality of attachment offered is not significantly influenced by exposure to mechanical stress. However, other polyacid modified glass polyalkenoate materials studied did not perform as well, and it is clear that individual materials and products need to be evaluated rather than making generic assumptions.

Conclusions

- Significant differences were demonstrated between the strength of attachment offered by the materials included in this study, but generic comparisons were not possible. Fuji Ortho^{TM} provided both the highest band retention stress and highest bond reliability of the materials studied.
- Virtually all samples failed adhesively with conventional and resin-modified polyalkenoate materials demonstrating better adhesion to enamel. The zinc phosphate and polyacid-modified composite resins studied demonstrated poor adhesion to enamel.
- Exposure to mechanical stress did not appear to significantly influence the strength of band retention or mode of cement failure for most of the cements studied.

Contributors

J. Knox and P. Durning were responsible for the concept and design of the study. K. Y. Chye was responsible for the acquisition of the data. J. Knox, P. Durning and K. Y. Chye were responsible for the analysis and interpretation of the data. J. Knox has drafted the article and all authors have approved the final version of the manuscript. J. Knox is the guarantor.

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