Journal of Orthodontics/Vol. 27/2000/249–254

The Influence of Bracket Base Design on the Strength of the Bracket–Cement Interface

JEREMY KNOX*, B.D.S., M.SC.D., PH.D., M.ORTH., R.C.S., F.D.S. (ORTH.),

PIERRE HUBSCH†, DIPL.-LNG., PH.D.,

MALCOLM L. JONES*, B.D.S., M.SC.D., PH.D., F.D.S., D.ORTH. R.C.S. AND

JOHN MIDDLETON†, B.SC., M.SC., F.R.S.A.

Departments of *Dental Health and Development and †Basic Dental Science, University of Wales College of Medicine, Dental School, Heath Park, Cardiff CF4 4XY, UK

Abstract. *The objectives of the study were to isolate the bracket–cement interface, and to determine the influence of bracket base morphology and orthodontic bonding agent chosen on strength of adhesion.*

The bracket bases evaluated included 60, 80, and 100 single mesh bases, a double mesh base, and the Dynalock™, and Mini Twin™ bases. The strength of interface provided by each of these bases with Concise™, Transbond™, Right On™, and non-encapsulated Fuji Ortho LC™ cements, was measured in tension and recorded in Mega Pascals.

The single-mesh bases performed well with either Concise or Right On (11·88–22·72 MPa) and, other than the 80-mesh bracket, relatively poorly with Transbond (2·18–5·15 MPa). With Fuji Ortho LC, the single mesh bases performed well (6·05–12·19 MPa). The double mesh base performed well with Right On (13·75 MPa), and reasonably well with Concise, Transbond, and Fuji Ortho LC (6·00–9·20 MPa). The Dynalock and Mini Twin Bases performed fairly well with all cements (8·87–17·16 MPa).

It was concluded that the orthodontic bonding agent selected would appear to largely determine the bond strength achieved with a particular bracket base design. A definite trend was difficult to identify in this study, and it appeared that certain combinations of bracket base and bonding agent performed optimally. Particular base designs may allow improved adhesive penetration or improved penetration of curing light. Alternatively, the dimension and distribution of resin/cement tags prescribed by one base could promote a stress distribution that is better resisted by a particular adhesive.

Index words: Orthodontic Bracket, Bonding Agent, Bond Strength.

Introduction

To achieve the complex tooth movements demanded during comprehensive orthodontic therapy, the orthodontic clinician requires a reliable method of attachment to tooth tissue. The method of attachment must allow the delivery of orthodontic forces and must be sufficiently robust to withstand masticatory loads. In addition, the attachment must be aesthetic, easily removed at the end of treatment, and result in minimal hard and soft tissue damage during application, service and removal.

However, the variables introduced in current *ex vivo* methods of bond strength testing and the large distribution of results, often prevents confident conclusions from being drawn when materials and techniques are compared (Fox *et al*., 1994; Millett and McCabe, 1996). In addition, current methods of bond strength evaluation test the cohesive strength of the cement and the strength of bracket-cement and cement–enamel interfaces recording only the weakest element of this system. The plane of failure is commonly determined by adhesive remnant measurements (Artun and Bergland, 1984) and a general mode of failure reported.

Adhesion at the bracket cement interface is achieved, most commonly, by the provision of mechanical undercut into which the orthodontic adhesive extends before polymerization. The undercut on most metal brackets is provided by a brazed fine mesh (Matasa, 1992). However, other bracket bases carry milled undercuts or are sandblasted, chemically-etched, or sintered with porous metal powder (Hanson *et al*., 1983). An attempt has been made in this study to isolate the bracket–cement interface and to determine the strength of interface offered by six different bases with a range of orthodontic cements.

There is no difference between the mean interface strength offered by the bracket bases and orthodontic adhesives studied. Null hypothesis.

Materials and Methods

The strength of the bracket-cement interface was determined by aligning and opposing identical bracket bases and 'sandwiching' a given cement between the two bracket bases at a prescribed lute dimension (0·2–0·35 mm). In most instances, incisor brackets were opposed due to the relative flatness of their bases. For each bracket type evaluated [Master Series™ (American Orthodontics, Shaboygan); Mini Twin™, Dynalock™ and Omni™ (3M Unitek, Monrovia, CA)], 80 brackets were selected. The tie wing of each bracket were sandblasted (25 μm grit) for 20 seconds and 'degreased' in acetone for 1 minute. A 5-mm washer was then attached between the mesial and distal tie wings of the bracket (Figure 1a), using a metal adhesive (Permabond ESP110 Permabond UK, Eastleigh, Hants), and the sample cured in an oven for 1 hour at 140°C. However, for 60- and 100-mesh bases, the bracket base material was only available in 15 × 1-cm strips. To evaluate the strength of the bracket cement interface achieved with 60- and 100-mesh base mesh designs, 3-mm diameter discs of each mesh type were prepared and attached to 8-mm diameter, 5-mm thick steel discs. Each mesh sample was attached centrally to one milled end of the disc that had been sandblasted and degreased, using the metal adhesive. To the opposing surface of the steel disc, a 5-mm washer was soldered (Figure 1b). To determine that the differing models of evaluation did not introduce an additional variable, the 80-mesh base was represented as a mesh disc and as a bracket base (Master Series™).

The method of evaluating bracket cement interface strength was similar for bracket and mesh disc samples. A pair of samples was aligned in the Lloyds Universal testing apparatus (Materials Sciences Ltd., North West House, Poulton-le-Flyde, Lancs, UK) with their bases opposing (Figure 1). Care was taken to ensure that the bracket bases/mesh discs were well aligned, parallel, and in gentle contact. The digital display of the Lloyds testing machine was then zeroed and the opposing pair of brackets separated to allow cement application to their bases.

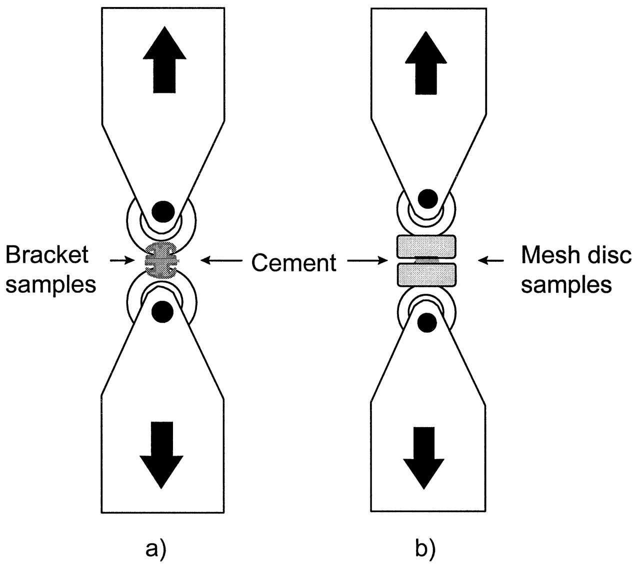

FIG. 1 Tensile evaluation of the bracket cement interface; a) bracket model; b) mesh disc model.

Ten sample pairs were employed to evaluate each of the orthodontic bonding agents. Each cement was prepared according to manufacturers instructions. However, it was found that the customary method of applying Right On, i.e. by coating the bracket base with activator and applying the paste directly, resulted in an incomplete cement cure with the lute dimensions prescribed in this study (0·2–0·35 mm). To ensure complete cement cure, the Right On paste and activator were mixed (5:1 ratio by volume) before application to the bracket base. Following cement application, the cross-head of the Lloyds machine was lowered to a prescribed bracket separation (range 0·2–0·35 mm) and the chemically-cured cements [(Concise™ Concise 'Restorative', 3M Unitek, St Pauls, Mn), Right On™ (TP Orthodontics, Inc., Lo Parte, In)] allowed to set. The light activated materials [Transbond (3M Unitek), Fuji Ortho LC (GC Corporation, Japan)] were cured using a blue light (Luxor light—ICI Dental Division, Macclesfield, Cheshire) for 60 seconds. When fully set, the samples were removed from the Lloyds machine and stored in a water bath at 37°C for 1 hour.

After 1 hour, the samples were transferred to the testing jig (Figure 1) that engaged both washers, but allowed a degree of sample rotation during tensile testing and limited the generation of 'peel' forces. To avoid the moments induced during shear testing all samples were tested in tension with a cross-head speed of 0·5 mm/min. The bond strength was recorded in Newtons and the plane of failure recorded, ensuring that failure was at the bracket cement interface, rather than cohesively within the cement. To permit the valid presentation and comparison of results the area of each bracket base design employed was measured using a Seescan Television Image Analysis System (Seescan, Level 3, Poseidon House, Castle Park, Cambridge). This allowed the calculation of tensile bond strength in Mega Pascals.

Results

Mean interface strengths are presented for each bracket base with all four cements in Table 1 and Figure 2. Analysis of variance (ANOVA) and Tukey's HSD *post-hoc* tests were employed to analyse the data. The two-way ANOVA demonstrated significant differences between the cements and the brackets evaluated, and a significant interaction between them ($P = 0{\cdot}000$). Table 2 demonstrates and quantifies significant differences in bracket cement inter-

TABLE 1 *Mean strength of the bracket cement interface (MPa)*

Bracket base	Cement							
	Concise		Transbond		Right ON		Fuji Ortho LC	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
60-mesh	12·79	3·50	5·15	2·85	16·27	4·61	12·19	3·03
80-mesh	13·22	3·22	2·72	0·78	11·88	1·38	6·05	1·36
100-mesh	22·72	7·81	2·18	0·52	16·15	5·74	8·96	2·83
Double mesh	9·20	2·74	6·00	2·28	13·75	2·52	8·30	2·07
Master Series	15·31	5·31	7·85	1·78	13·98	2·21	10·45	2·35
Dynalock	17·16	3·49	10·04	2·32	9·47	1·21	9·26	1·71
Mini Twin	14·91	4·46	11·71	2·59	10·80	1·63	8·87	1·04

TABLE 2 *Mean bracket cement interface strengths compared*

Bracket base comparison		Concise	Transbond	Right On	Fuji Ortho LC
		Cement			
60-mesh	80-mesh	1·000	0·132	0·047*	0·000***
	100-mesh	0·000***	0·031*	1·000	0·024*
	Double mesh	0·603	0·967	0·575	0·003**
	Master Series	0·889	0·065	0·679	0·559
	Dynalock	0·368	0·000***	0·000***	0·054
	Mini Twin	0·948	0·000***	0·005**	0·018*
80-mesh	60-mesh	1·000	0·132	0·047*	0·000***
	100-mesh	0·000***	0·997	0·059	0·056
	Double mesh	0·468	0·012*	0·849	0·251
	Master Series	0·952	0·000***	0·766	0·001**
	Dynalock	0·495	0·000***	0·627	0·024*
	Mini Twin	0·983	0·000***	0·988	0·070
100-mesh	60-mesh	0·000***	0·031*	1·000	0·024*
	80-mesh	0·000***	0·997	0·059	0·056
	Double mesh	0·000***	0·002**	0·630	0·993
	Master Series	0·012*	0·000***	0·731	0·723
	Dynalock	0·012*	0·000***	0·000***	1·000
	Mini Twin	0·007**	0·000***	0·007**	1·000
Double mesh	60-mesh	0·603	0·967	0·575	0·003**
	80-mesh	0·469	0·012*	0·849	0·251
	100-mesh	0·000***	0·002**	0·630	0·993
	Master Series	0·067	0·415	1·000	0·301
	Dynalock	0·005**	0·001**	0·058	0·953
	Mini Twin	0·104	0·000***	0·387	0·997
Master series	60-mesh	0·889	0·065	0·679	0·559
	80-mesh	0·952	0·000***	0·766	0·001**
	100-mesh	0·012*	0·000***	0·731	0·723
	Double mesh	0·067	0·415	1·000	0·301
	Dynalock	0·973	0·225	0·038*	0·883
	Mini Twin	1·000	0·002*	0·298	0·665
Dynalock	60-mesh	0·368	0·000***	0·000***	0·054
	80-mesh	0·495	0·000***	0·627	0·024*
	100-mesh	0·123	0·000***	0·000***	1·000
	Double mesh	0·005**	0·001**	0·058	0·953
	Master Series	0·973	0·225	0·038*	0·883
	Mini Twin	0·932	0·543	0·967	1·000
Mini Twin	60-mesh	0·948	0·000***	0·005**	0·018*
	80-mesh	0·983	0·000***	0·988	0·070
	100-mesh	0·007**	0·000***	0·007**	1·000
	Double mesh	0·104	0·000***	0·387	0·997
	Master Series	1·000	0·002**	0·298	0·665
	Dynalock	0·932	0·543	0·967	1·000

The mean difference is significant at $^{*}P < 0{\cdot}05$; $^{**}P < 0{\cdot}01$; $^{***}P < 0{\cdot}001$ levels.

face with all bracket bases and cements studied as determined by Tukey's HSD *post-hoc* test.

Discussion

The bracket-cement interface has been isolated and the influence of bracket base morphology and cement type on the strength of interface evaluated in tension. Interface strength has been tested at 1 hour after initial set, rather than at 24 hours to replicate more closely the clinical situation, where loading would begin within the first few hours after 'bond-up'. In addition, Chamda and Stein (1996) have demonstrated that the bond strengths recorded with chemically cured resins peak within the first 60 minutes and that no significant differences occur in the bond strengths provided by light-cured materials between 10 minutes and 14 hours after initial set.

Bracket base morphology can influence the strength of the bracket cement interface by determining the geometry (depth, size, and distribution) of the cement tags and stress distribution within the cement bracket interface. In addition, the penetration of light, and polymerization of light activated materials could be influenced by base morphology.

Figure 2 presents mean interface strength and 95 per cent confidence intervals for each of the bracket base morphologies evaluated with each of the cements. The strength of interface provided by each bracket base would appear to be strongly influenced by the cement chosen. However, a particular cement would appear to perform differently with the various bracket bases. There would appear to be, therefore, certain combinations of cement and bracket base that perform optimally.

The 60-, 80-, and 100-mesh bases all have significantly different mesh spacing (Figure 3). When compared to the other single mesh bases, the strength of interface provided by the 60-mesh base with Concise (12·79 ± 3·5 MPa) was similar to that provided by the 80-mesh bases (mesh disc and Master Series) with no significant difference recorded at the 5 per cent level. The 60-mesh base provided a significantly weaker interface with Concise than the 100-mesh base (P = 0·000). With Transbond, the 60-mesh base provided a significantly stronger interface than the 100-mesh disc base (P = 0·03). The pattern was similar with the other light cured cement, Fuji Ortho LC, where 60-mesh again provided a stronger attachment (P = 0·02). With Right On the 60- and 100-mesh disc bases provided a similar interface strength. The performance of the 60-mesh base with the light-cured cements could reflect the improved penetration of the curing light within the larger mesh spaces. However, the 60-mesh base may provide a size and distribution of resin tags, which promotes improved stress distribution with these cements. Alternatively, the 60-mesh base may allow a more favourable penetration of these cements.

An interesting feature of this study is the differing performance of 80-mesh disc, and Master Series bases. Both of

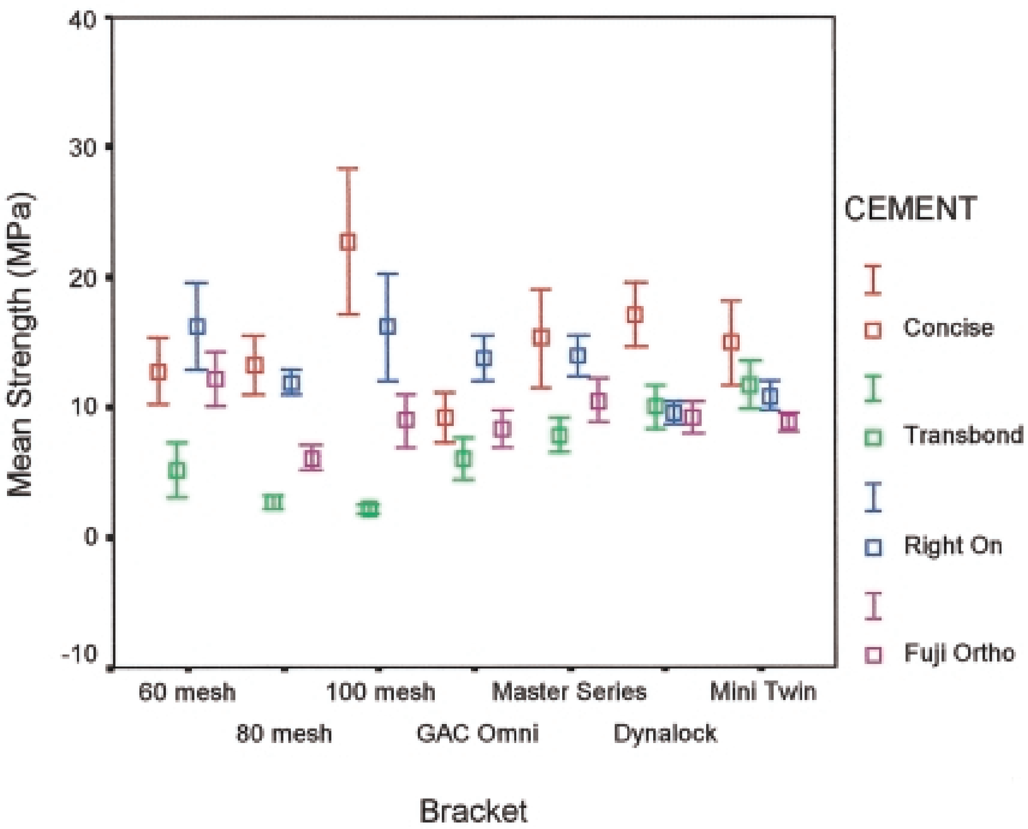

FIG. 2 Mean bracket cement interface strength (showing 95% confidence intervals).

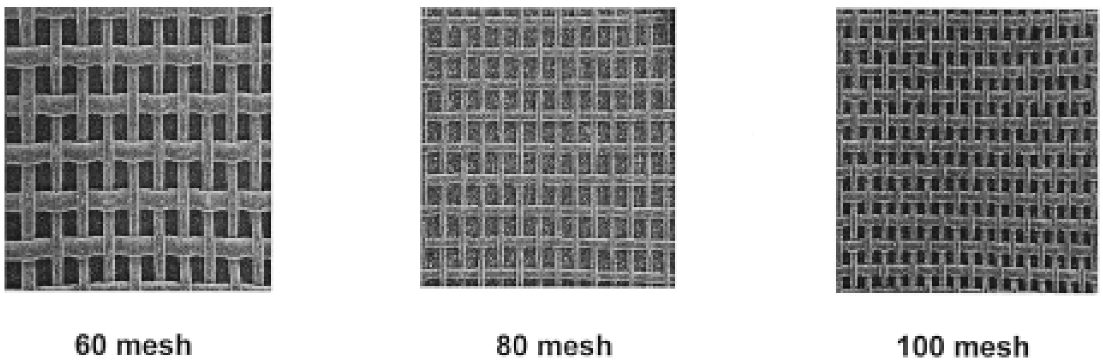

FIG. 3 Wire mesh bracket base designs (SEM × 40).

these bases are theoretically identical and should, therefore, provide a similar quality of attachment. Although this held true when Concise and Right On cements were considered, the same could not be said when Transbond and Fuji Ortho cements were selected. With Transbond and Fuji Ortho LC cements, the 80-mesh disc base provided a significantly weaker interface than Master Series ($P \leqslant 0{\cdot}001$). The differences in strength of attachment achieved with the 80-mesh bases could reflect the influence of other bracket components on the stress distribution within the interface when subjected to tensile stresses. For example, the dimensions and physical properties of the bracket stem and foil, to which the base mesh is attached, could significantly influence the stresses generated at the cement/mesh interface. Alternatively, the relatively poor performance of the 80-mesh disc samples with Transbond and Fuji Ortho LC could reflect the impaired light access afforded by the mesh disc model, incomplete polymerization, and compromised adhesion. Both the 60- and 100-mesh samples, which were evaluated using a similar model, also performed relatively poorly with Transbond and, to a lesser extent, with Fuji Ortho LC (which is dual cured).

When the performance of the 100-mesh base is compared to the other single mesh disc bases the 100-mesh/Concise interface was significantly stronger (22·72 ± 7·8 MPa) than that provided by the 60- and 80-mesh disc samples with Concise ($P = 0{\cdot}000$). With Transbond, 100-mesh base provided an interface strength (2·18 MPa), which was similar to the 80-mesh base, but significantly weaker ($P = 0{\cdot}03$) than the 60-mesh interface strength. The null hypothesis could not be rejected for the strength of interface provided by the 80-mesh (11·88–13·98 MPa) and 100-mesh (16·15 MPa) bases with Right On ($P > 0{\cdot}059$) and for the 60 (16·27 MPa) and 100-mesh bases with the same cement ($P = 1{\cdot}000$). With Fuji Ortho LC the 100-mesh base provided an interface (8·96 MPa) that was stronger than the 80-mesh base ($P = 0{\cdot}056$), but significantly weaker than the 60-mesh base ($P = 0{\cdot}024$).

If the finer 100-mesh resulted in a reduced light penetration during the initiation of the light-cured cement's setting reaction, then the strength of interface provided by the 100-mesh base with Transbond and Fuji Ortho LC should be weaker than that provided by 60- and 80-mesh bases. The 60-mesh base certainly offers a stronger interface than the 100-mesh base with both of these cements. The differences in interface strength between 80- and 100-mesh bases are less clear.

The double meshed base offers a significantly different bracket base pattern (Figure 4). A highly complex arrangements of undercuts is provided, with a more widely spaced outer mesh and a finer deeper mesh, into which orthodontic adhesive can flow. With Concise the double mesh base provided an interface (9·20 MPa), which was similar to that provided by the single 60- and 80-mesh bases, but weaker

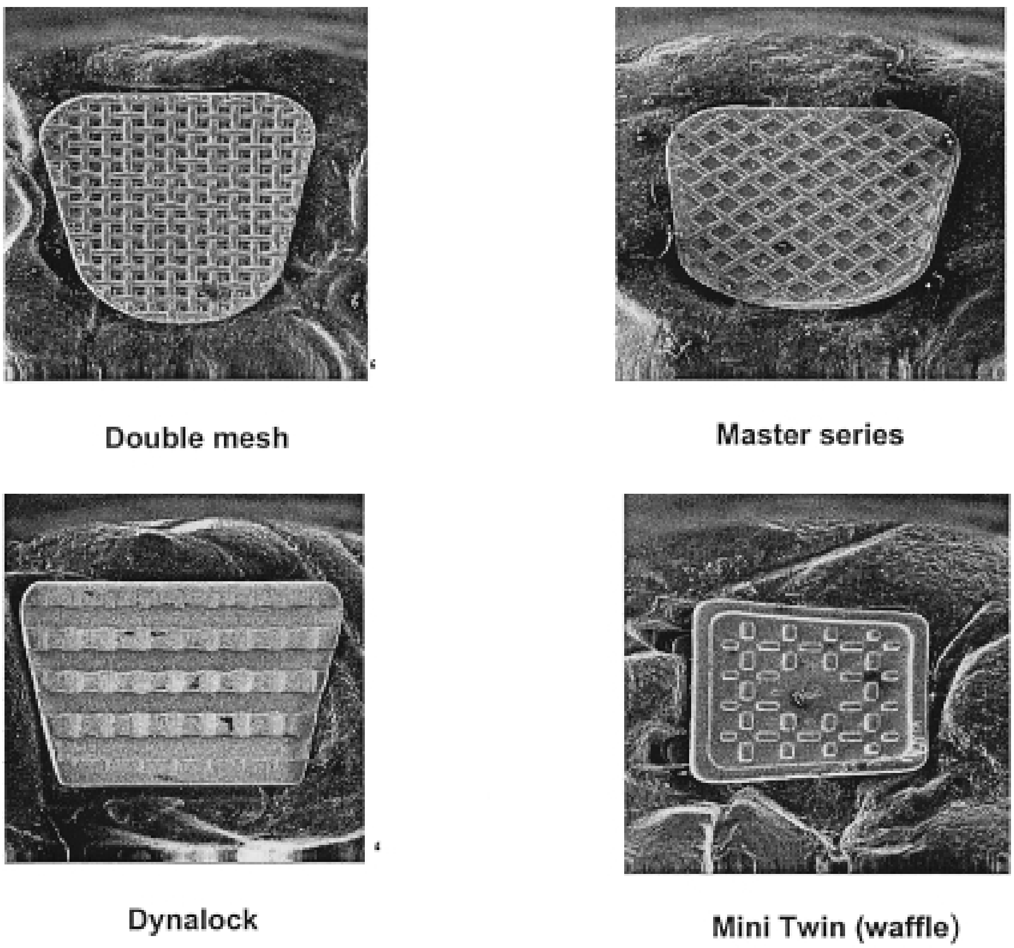

FIG. 4 Bracket base designs (SEM).

than that afforded by the 100-mesh base ($P = 0{\cdot}000$). With Transbond, the double mesh base provided an interface (6·00 MPa) which was, again, similar to that provided by the single 60-mesh base, but stronger than that afforded by the 80-mesh disc ($P = 0{\cdot}012$) and 100-mesh bases ($P = 0{\cdot}002$). With Right On, the strength of interface produced by the double mesh base (13·75 MPa) was not significantly different, at the 5 per cent level, to that provided by the three single mesh bases. With Fuji Ortho LC the double mesh base provided an interface (8·30 MPa), which was similar to that provided by the single 80- and 100-mesh bases, but weaker than that afforded by the 60-mesh base ($P = 0{\cdot}003$).

When the strength of interface offered by the double mesh base with each of the individual cements is considered the double mesh base performed reasonably well with the light cured cements (Transbond, Fuji) and Right On, but not as well as other bases with Concise. It might be suggested that the relatively coarse outer layer of the double mesh allows improved light penetration and cement set for the light-activated materials. However, the complexity of the double mesh structure offers no significant advantage for Concise. This could reflect the poorer penetration characteristics of this material with areas of incomplete penetration resulting in stress concentration when loaded in tension.

The Dynalock and Mini Twin brackets have fundamentally different base designs (Figure 4). Undercuts for resin penetration are provided by milled or case irregularities, rather than by a brazed mesh. When each cement is considered individually, the interface provided by Dynalock and Concise (17·16 MPa) was significantly stronger ($P = 0{\cdot}005$) than that provided by the double mesh base and Concise (9·20 MPa). The strength of interface offered by Dynalock and the single mesh bases with Concise was not significantly different at the 5 or 10 per cent levels. With Transbond, Dynalock provided a relatively strong interface (10·04 MPa). This interface was significantly stronger than that provided by 60-mesh, 80-mesh disc, 100-mesh or double mesh bases ($P \leqslant 0{\cdot}001$), but not statistically different from the Master Series 80 mesh base. With Right On, Dynalock provided an interface (9·47 MPa) that was weaker than that offered by the Master Series base ($P = 0038$), 60- and 100-mesh bases ($P = 0{\cdot}000$). The null hypothesis could not be rejected at the 5 per cent level for the strength of interface provided by Dynalock (9·26 MPa), double mesh, Master Series, 60- and 100- mesh bases with Fuji Ortho LC. However, the strength of interface provided by the 80-mesh disc with Fuji Ortho LC was significantly weaker ($P = 0{\cdot}024$).

The performance of the Dynalock base appears to compare well with the best of the single mesh bases with all cements studied, other than Right On. The coarse nature of the Dynalock base undercuts could be predicted to allow good cement and light penetration. Dynalock performed relatively well with the light cured cements (Transbond and Fuji) and provided a good interface strength with Concise. It is only with Right On that the Dynalock performed relatively poorly. The reason for this is unclear at present.

Finally, if the four cements are considered together in combination with the Mini Twin bracket, the strength of interface provided by this base is remarkably similar to that provide by the Dynalock base. In fact, when each of the cements was considered in isolation the strength of interface provided by the Mini Twin and Dynalock bases were statistically indistinguishable ($P > 0{\cdot}900$) for Concise, Right On and Fuji ($P = 0{\cdot}543$ for Transbond).

Conclusions

- Single mesh bases performed well with Concise and Right On (11·88–22·72 MPa) and, other than the 80-mesh bracket, relatively poorly with Transbond (2·18–5·15 MPa). With Fuji Ortho LC, 60-mesh base and 80-mesh bracket performed well (10·45–12·19 MPa), and the 100-mesh base performed moderately well (8·96 MPa).
- The double mesh base performed well with Right On and reasonably well with Concise, Transbond and Fuji (6·00–9·20 MPa).
- The Dynalock and Mini Twin Bases performed fairly well with all cements (8·87–17·16 MPa).
- The reasons for a particular base performing differently with different cements could be entirely due to the properties of the cement. However, a definite trend was difficult to identify in this study, and it appeared that certain combinations of bracket and cements performed optimally.
- Particular base designs may allow improved cement penetration or improved penetration of curing light. Alternatively, the dimension and distribution of resin tags prescribed by one base could promote a stress distribution that was better resisted by a particular cement.
- The complexity of the problem is apparent and the need for a valid computer model, which allows a more detailed investigation of the bracket cement enamel continuum, established.

References

Artun, J. and Bergland, S. (1984)
Clinical trials with crystal growth conditioning as an alternative to acid etch enamel pre-treatment,
American Journal of Orthodontics, **85,** 333–340.

Chamda, R. A. and Stein, E. (1996)
Time related bond strength of light cured and chemically cured bonding systems: an *in vitro* study,
American Journal of Orthodontics and Dentofacial Orthopaedics, **100,** 378–382.

Fox, N. A., McCabe, J. F. and Buckley, J. G. (1994)
A critique of bond strength testing in orthodontics,
British Journal of Orthodontics, **21,** 33–43.

Hanson, G. H., Gibbon, W. M. and Shimuzu, H. (1983)
Bonding bases coated with porous metal powders,
American Journal of Orthodontics, **83,** 1–4.

Matasa, C. G. (1992)
Direct bonding metallic brackets: where are they heading?
American Journal of Orthodontics and Dentofacial Orthopaedics, **101,** 552–560.

Millett, D. T. and McCabe, J. F. (1996)
Orthodontic bonding with glass ionomer cement—a review.
European Journal of Orthodontics, **18,** 385–399.