Journal of Orthodontics/Vol. 27/2000/255–260

The Use of a Cyanoacrylate Adhesive for Bonding Orthodontic Brackets: an *ex-vivo* study

M. KUSAI AL-MUNAJED*, D.D.S., DIP. ORTH.

P. H. GORDON*, PH.D., B.D.S., F.D.S., M.ORTH.

J. F. MCCABE†, D.SC.

Departments of *Child Dental Health and †Dental Materials Science Unit, Framlington Place, University of Newcastle upon Tyne, NE2 4BW, U.K.

Abstract. *The purpose of this study was to evaluate the performance of a cyanoacrylate orthodontic adhesive with regard to tensile bond strength and bond failure location in comparison with a conventional no-mix orthodontic composite adhesive using stainless steel and ceramic brackets.*

One-hundred-and-twenty caries-free extracted premolar teeth were used in this study. There were 30 specimens for each tooth, adhesive, and bracket combination, and of these half were tested at 24 hours and half at 3 months. Hence, there were 15 samples in each test group. Bond strengths were assessed using an Instron Universal Testing Machine after storage for 24 hours and for 3 months at 37°C in distilled water.

Analysis of variance showed the mean bond strength of specimens bonded with cyanoacrylate was significantly lower than for those bonded with Right-on ($P < 0{\cdot}001$). Weibull analysis showed that at a given stress the probability of failure significantly increased after 3 months for brackets bonded with cyanoacrylate. A Chi-square test of the ARI scores revealed no significant difference among the groups tested.

This study showed that cyanoacrylate adhesives are unsuitable for use as a bonding agent in routine orthodontic practice.

Index words: Adhesion, Cyanoacrylate, Dental Materials, Orthodontic Brackets.

Introduction

Bonding orthodontic brackets to tooth surfaces, instead of banding the teeth, has some distinct advantages: it improves the aesthetic aspect of orthodontic appliances, minimizes the treatment time and allows a better standard of oral hygiene to be achieved.

The use of acid etch techniques in the direct bonding of orthodontic attachments was first reported by Newman (1965). The process involves etching the enamel surface with phosphoric acid to increase porosity and enhance retention. Since that time, different materials have been utilized as bonding agents. Mitchell (1967) utilized the acid etching technique using zinc phosphate cement to bond metal-based attachments with micromechanical interlocks into their bases, while zinc polyacrylate cement was used for direct bonding of orthodontic attachments by Mizrahi and Smith in 1969.

BIS-GMA (bis-phenol A glycidyl methacrylate) resins were introduced successfully as dental adhesives in the 1960s and later applied in clinical orthodontic practice as adhesives (Silverman *et al*., 1972). The acid etched composite technique has become the most widely adopted bonding system in contemporary orthodontic practice, but such a system still has a number of shortcomings, such as loss of enamel after acid etching (Pus and Way, 1980), enamel damage caused by post-debonding clean up procedures (Zachrisson and Årtun, 1979), and enamel fracture, which may take place while debonding, particularly with ceramic brackets (Redd and Shivapuja, 1991).

Practitioners have searched for adhesives that could overcome the shortcomings of composites and simplify the procedures involved in bonding, with reliable bond strength and easy debond at the end of treatment. In an attempt to satisfy such requirements, different techniques and different materials have been introduced and tested.

Moin and Dogan (1978) reported the use of acrylic resin systems in bonding orthodontic attachments, but the materials did not achieve sufficient bond strength. Wilson and Kent (1972) developed glass ionomer cement, which was primarily used as a direct restorative material, and then applied for cementing orthodontic bands and brackets. This material releases fluoride (Tay and Braden, 1988) and, thus, may reduce enamel decalcification around brackets (Marcusson *et al.*, 1997). Cyanoacrylate adhesives have been utilized in different fields of medicine and dentistry, and have been applied as an orthodontic adhesive. One of the significant advantages of cyanoacrylate adhesives is their ability to polymerize as a thin film at room temperature, without a catalyst, when pressure is applied in a moist environment.

The bond strength characteristics of cyanoacrylates as an orthodontic adhesive were investigated in previous studies. Crabb and Wilson (1971) reported that cyanoacrylate adhesive showed poor performance and unstable bond strength in comparison with carboxylate cement, and they concluded that this adhesive is an unsuitable material for clinical orthodontic use.

0301-228X/00/030000+00$02.00

Howells and Jones (1989) assessed the bond strength of a (powder/liquid) cyanoacrylate adhesive system in bonding orthodontic brackets. The adhesive showed poor performance after storage in saline for a week. On the other hand, Krishnan *et al.* (1994) found that cyanoacrylate adhesives produce similar bond strength to BIS-GMA control adhesive material when specimens were kept in a 37°C water bath for 24 hours. All the previous studies were carried out utilizing stainless steel orthodontic brackets and without acid etching of the enamel prior to bonding.

The aim of this study is to evaluate *ex vivo* the tensile bond strength of a newly developed cyanoacrylate adhesive system using two kinds of orthodontic brackets (stainless steel and ceramic) with a conventional orthodontic bonding system used as a control.

Materials and Methods

Two kinds of adhesives were evaluated in this study: SmartBond® (Gestenco International Ab., Gothenburg, Sweden). The bonding agent in this material is cyanoacrylate. Right-on® (T.P. Orthodontics, Indiana, U.S.A.), a no-mix chemically activated BIS-GMA-based composite adhesive system was used in this study as a control adhesive material.

Two kinds of brackets were utilized in this investigation: stainless steel brackets (Mesh pad bases, 0·022-inch slot, 13·25-mm^2 base area, Andrews prescription-A company), and ceramic brackets (Allure III, 0·022-inch slot, 12·25-mm^2 base area, Roth prescription, GAC International, Inc). The retention for brackets was achieved mechanically, with an undercut groove in the bracket base, and chemically, with a silane layer applied directly to the alumina.

One-hundred-and-twenty caries-free premolar teeth extracted for orthodontic reasons were collected, cleared of tissue tags and kept in 0·5 per cent aqueous chloramine solution for at least 1 week, then transferred to distilled water and stored in a refrigerator until testing. The apex of each tooth was cut off and a small horizontal grove was cut in the root to aid fixation. Teeth were then mounted, with the long axis vertical, in polyester resin blocks. All the work was done in a humidified environment.

Mounted teeth were divided into eight groups, each of 15 teeth, with 10 upper and five lower premolars. Each group was used to evaluate bond strength at either 24 hours or 3 months for one of the following:

(1) stainless steel brackets with Right-on;
(2) stainless steel brackets with SmartBond;
(3) ceramic brackets with Right-on;
(4) ceramic brackets with SmartBond.

Specimens were stored in water for (24 hours or 3 months) at 37°C prior to testing.

Prior to bonding, the buccal surface of each tooth was cleaned with pumice, sprayed with water, and dried with compressed air.

For SmartBond, 37 per cent phosphoric acid etching gel was applied to the buccal surface of the teeth for 15 seconds and rinsed. The adhesive was dispensed on a special pad and then applied with a small rounded brush to the bracket base. A thin film is required to achieve good bond strength and the polymerization is initiated by moisture. Each bracket was positioned on the tooth surface and pressed in place until the adhesive was set. The manufacture's instructions were followed for bonding brackets using Right-on.

Because all bonding procedures were done at room temperature, 10 minutes were allowed to ensure complete curing before transferring the specimens to a bath of distilled water at 37°C.

An Instron electromechanical testing machine (Instron Limited, Coronation Road, High Wycombe, Bucks HP12 3SY) was used to assess the bond strength of each group as described by Fox *et al*. (1994). A steel loop was fitted around the gingival wings of each bracket. The steel wire and the polyester blocks were mounted on universal joints to ensure perpendicular pull to the bracket.

The crosshead of the Instron moved at a constant speed of 1 mm per minute.

The maximum force required to produce bond failure was measured in Newtons and recorded. The force per unit area required for breakage was calculated and recorded in MPa as the shear bond strength.

Attachments that fell off in the water bath prior to testing were given a zero value of bond strength. All such attachments were bonded with SmartBond.

The fracture sites were examined to determine the location of bond failure during debonding and classified according to the modified Adhesive Remnant Index (ARI) system of Årtun and Bergland (1984) in regard to the amount of adhesive remaining on the bracket base.

The results were analysed using the Minitab statistical package (Minitab, Inc, 1996).

Two-way analysis of variance was carried out to determine any significant effects of adhesives and bracket. Weibull (1951) analysis was used to calculate characteristic strength, Weibull Modulus and the probability of failure at a 50 N force applied for each material.

A Chi-square test was used to determine significant differences in the ARI scores between the different groups. Significance for all statistical tests was predetermined at $P \leq 0·05$.

Scanning electron micrographs were taken of the tooth surface and the bracket base of specimens chosen from the groups that showed the highest and the lowest mean bond strength.

Results

Summary statistics for the bond strength of the materials tested at 24 hours and 3 months after bonding are listed in Tables 1 and 2, respectively.

Right-on adhesive showed a higher mean bond strength than the SmartBond with both kinds of brackets. The bond strength of SmartBond noticeably decreased when testing was carried out after storage in a water bath at 37°C for 3 months.

Two-way analysis of variance revealed that both the choice of adhesive and the type of bracket have a significant effect on bond strength. Right-on produced significantly greater mean bond strength at both 24 hours and 3 months. There was a tendency for stainless steel brackets to give higher bond strength than ceramic brackets, but only the difference between adhesives was significant. These results are shown in Tables 3 and 4.

The Weibull modulus and the characteristic force values of the materials tested are listed in Tables 5 and 6. The Weibull equation was used to calculate the probability of failure at a given force (50 N). It revealed that the Right-on adhesive shows a lower probability of failure than SmartBond with both kinds of brackets.

Both kinds of adhesive gave a greater probability of failure with ceramic brackets than with stainless steel brackets, and the combination of SmartBond and ceramic brackets produced the greatest probability of failure at a load of 50 N after 24 hours ($P < 0{\cdot}05$). Probability of failure at 50 N for Right-on decreased at 3 months compared with 24 hours. For SmartBond the opposite was true and 86–97 per cent failure at 50 N was experienced for this material after immersion in water at 37°C for 3 months.

Figures 1 and 2 show the probability of failure at increasing force levels using the Weibull equation. The curves illustrate that at any level of force brackets bonded with Right-on have a lower probability of failure than those bonded with SmartBond.

Figures 3–6 show scanning electron micrographs of both tooth surface and the bracket base of specimens in the groups that showed the highest (stainless steel brackets bonded with Right-on and tested at 24 hours) and the lowest (ceramic brackets bonded with SmartBond and tested at 3 months) mean bond strength. In this example, Right-on showed a higher incidence of retained adhesive on the tooth surface (two-thirds of the specimens showed an ARI score of 0 or 1), whereas in this example of SmartBond, the majority of the adhesive was remained on the bracket base (two-thirds of the specimens showed an ARI score of 2 or 3). The amount of adhesive remaining on the tooth was, generally, the complement of the amount remained on the bracket.

Tables 7 and 8 reveal that there no overall differences between the ARI scores of the groups tested, showing there

TABLE 1 *Bond strength of specimens at 24 hours (MPa)*

	Right-on stainless steel	Right-on ceramic	SmartBond stainless steel	SmartBond ceramic
Mean	7·24	5·75	3·58	3·01
SD	2·07	2·52	1·41	1·14
Min	4·49	2·33	1·77	1·61
Max	11·59	11·35	6·59	5·05

TABLE 2 *Bond strength of specimens at 3 months (MPa)*

	Right-on stainless steel	Right-on ceramic	SmartBond stainless steel	SmartBond ceramic
Mean	5·83	5·73	1·72	1·28
SD	0·86	1·31	1·09	1·44
Min	3·46	3·35	0·34	0
Max	6·61	8·21	3·78	4·28

TABLE 3 *Two-way ANOVA analysis of bond strength at 24 hours*

Source of variance	d.f.	Sum of squares	Mean squares	*F* ratio	*P*
Adhesive	1	154·49	154·49	154	<0·001
Bracket	1	16·08	16·08	16·1	<0·001
Interaction	1	3·14	3·14	3·14	>0·05
Error	56	195·23	3·49		

TABLE 4 *Two-way ANOVA analysis of bond strength at 3 months*

Source of variance	d.f.	Sum of squares	Mean squares	*F* ratio	*P*
Adhesive	1	291·42	291·42	209·65	<0·001
Bracket	1	2·4	2·4	1·73	>0·05
Interaction	1	1·32	1·32	0·95	>0·05
Error	56	77·66	1·39		

TABLE 7 *ARI Scores 24 hours post-cure*

Score	Right-on SS&Cer	SmartBond SS&Cer
0/1	16	11
2/3	14	19

Chi-square = 1·68.
d.f. = 1, *P*-value = 0·194.

TABLE 8 *ARI Scores 3 months post-cure*

Score	Right-on SS&Cer	SmartBond SS&Cer
0/1	11	14
2/3	19	16

Chi-square = 0·617.
d.f. = 1, *P*-value = 0·432.

TABLE 5 *Weibull analysis of materials tested at 24 hours*

Material	Mean force (N)	Mean stress (MPa)	Characteristic force (N)	Weibull modulus	Probability of failure at 50N
Right-on/SS	96·01	7·25	106·14	3·69	0·06
Right-on/Cer	70·53	5·75	79·72	2·53	0·27
SmartBond/SS	47·47	3·58	53·38	2·82	0·56
SmartBond/Cer	36·79	3·01	41·35	2·92	0·82

TABLE 6 *Weibull analysis of materials tested at 3 months*

Material	Mean force (N)	Mean stress (MPa)	Characteristic force (N)	Weibull modulus	Probability of failure at 50 N
Right-on/SS	77·41	5·81	81·56	10·69	0·01
Right-on/Cer	70·21	5·72	76·46	4·86	0·12
SmartBond/SS	23·87	1·72	25·79	1·75	0·96
SmartBond/Cer	16·47	1·28	4·43	0·31	0·87

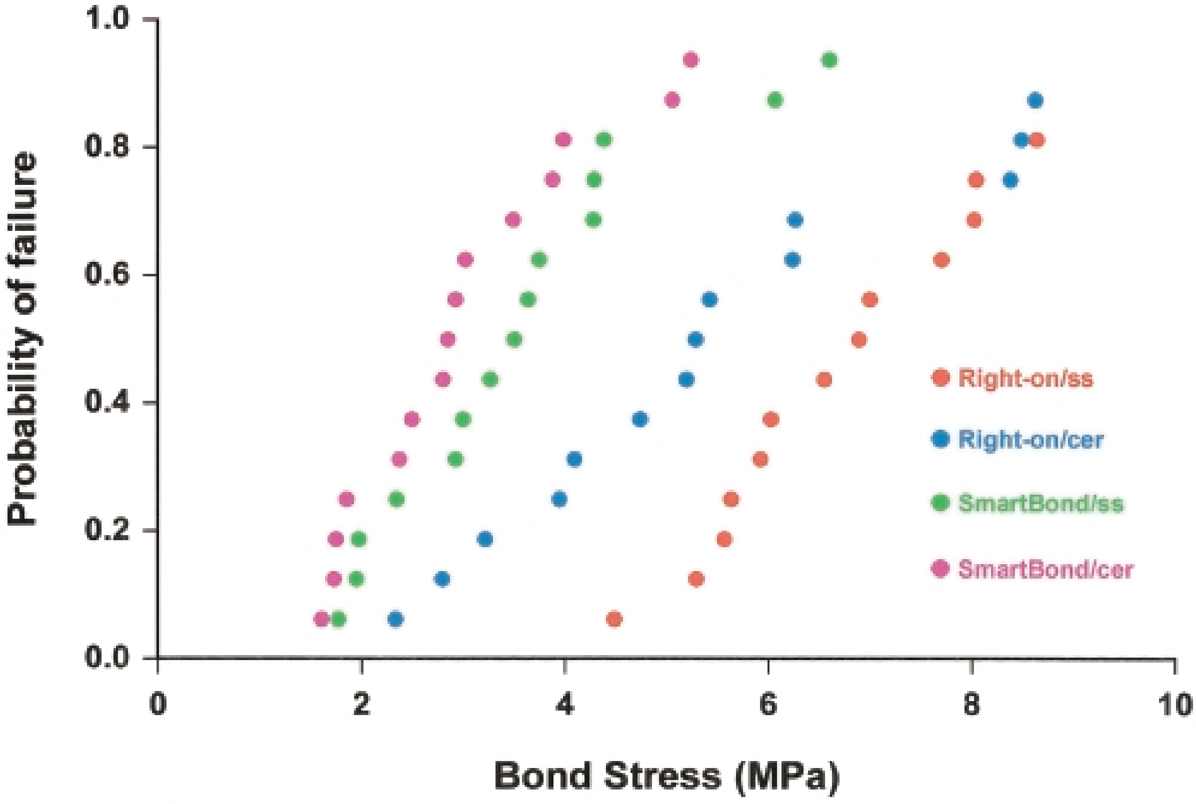

FIG. 1 Weibull curve for materials tested 24 hours post-cure.

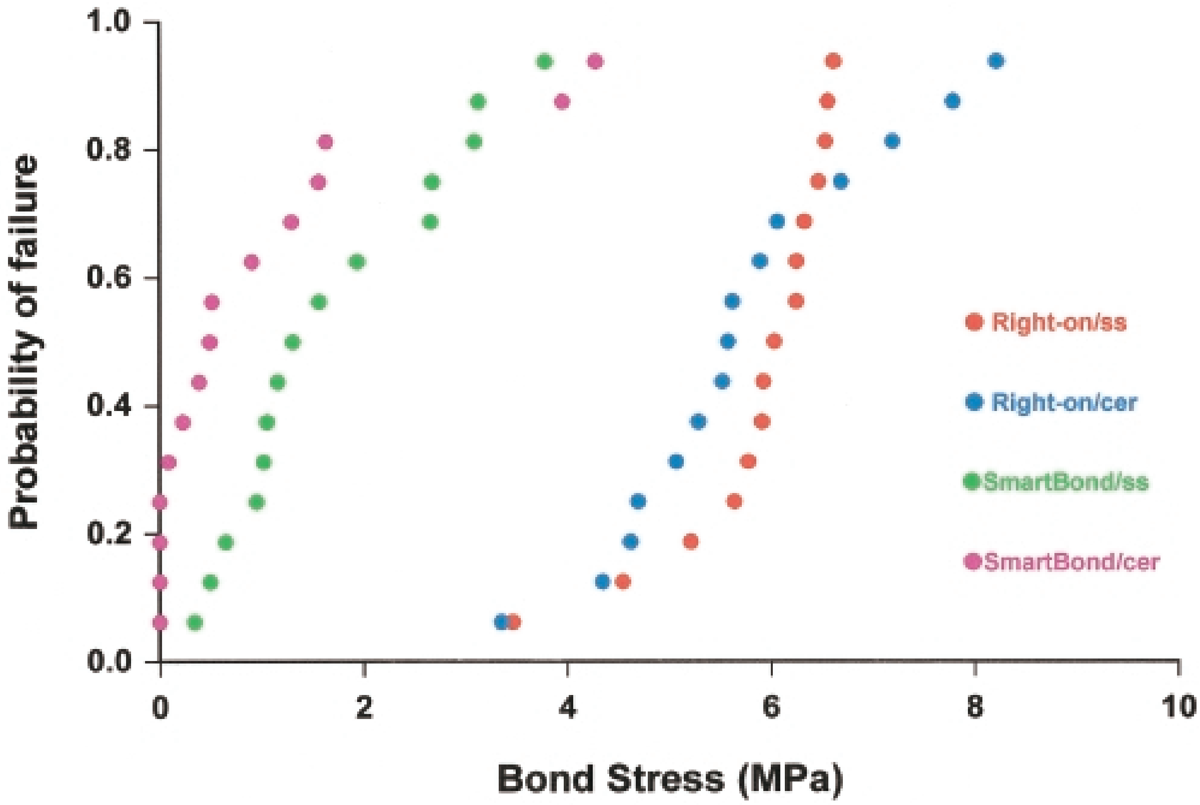

FIG. 2 Weibull curve for materials tested 3 months post-cure.

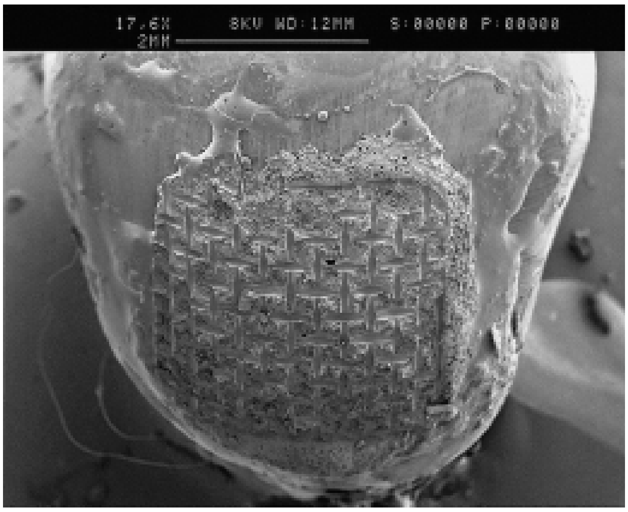

FIG. 3 Scanning electron micrograph of a buccal tooth surface on which a stainless steel bracket was bonded with Right-on. Most of the adhesive retained on the tooth surface.

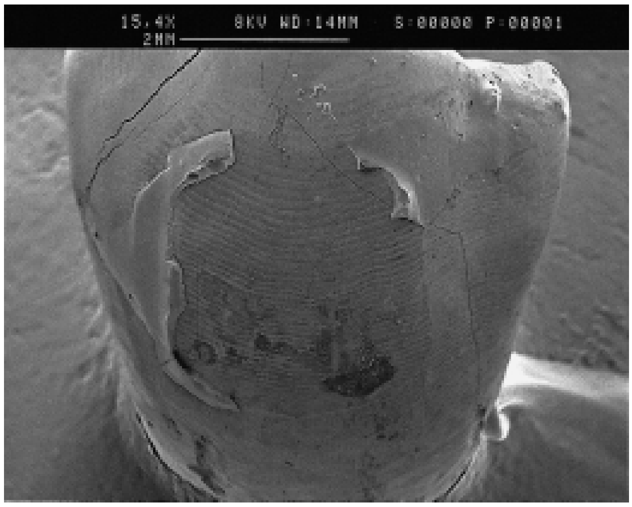

FIG. 5 Scanning electron micrograph of a buccal tooth surface on which a ceramic bracket was bonded with SmartBond. Very little adhesive was retained on the tooth surface.

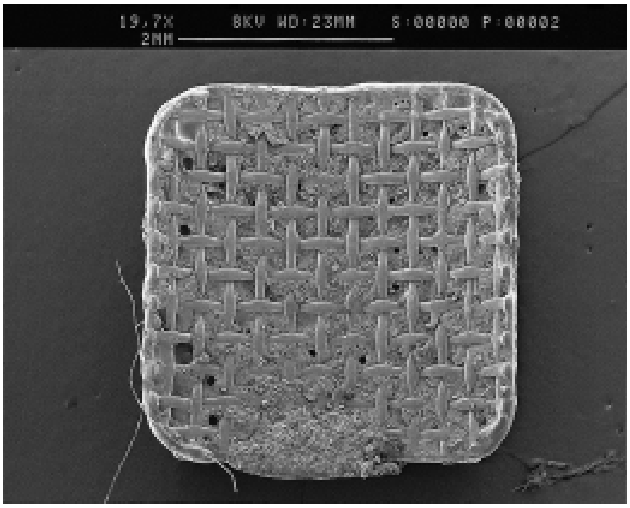

FIG. 4 Scanning electron micrograph of a stainless steel bracket base bonded with Right-on.

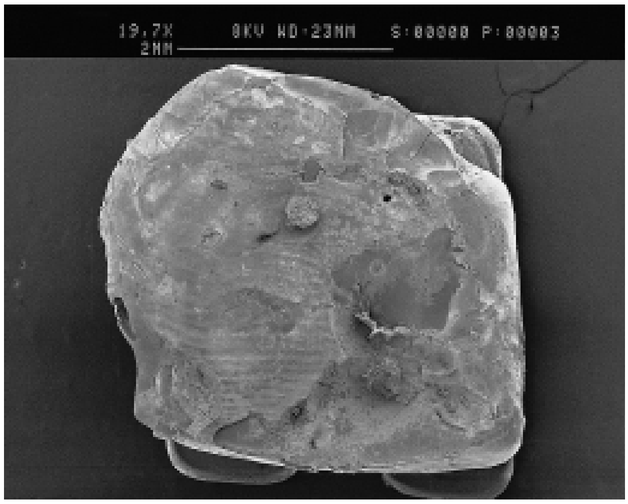

FIG. 6 Scanning electron micrograph of a ceramic bracket base bonded with SmartBond. The majority of the adhesive remained on the bracket base.

was little difference between the materials with regard to the mode of failure.

Discussion

Although, in this study, cyanoacrylate adhesive was used to bond brackets after acid etching of the tooth surface, the technique did not seem to offer any significant advantage when compared with the findings of previous studies. These include those of Howells and Jones (1989), and Crabb and Wilson (1971), in which no acid-etching procedure was used.

The hydrolytic instability of the material suggests that it may be unsuitable for clinical use. Moreover, the fluid nature of the adhesive and its tendency to cling to instruments make it difficult to use. These findings are disappointing as the cyanoacrylates may be considered as conceptually appealing in some respects. They offer the possibility of 'instant bonding' and the hydrolytic degradation allows easy and safe debonding with little or no 'clean-up' required.

The mean values shown in Tables 6 and 7 are presented both in terms of stress (MPa), where the bracket base area is taken into consideration, and as force (N). The force is probably more significant, since it is a more direct indication of the load applied to the bracket and is independent of bracket base area.

Keizer *et al.* (1976) have reported 2·7 MPa as an adequate bond strength for orthodontic attachments. The probability of failure at this stress decreased for stainless steel brackets bonded with Right-on from less than 0·02 for at 24 hours post-cure to less than 0·01 for the group tested after 3 months. For SmartBond, the probability of failure at this stress with stainless steel brackets increased from more than 0·2 after 24 hours to more than 0·7 after 3 months in water, and it doubled with ceramic brackets from more than 0·4 to more than 0·8.

Accordingly, since we would predict at least 40–80 per cent failure within 3 months, cyanoacrylate does not seem suitable for use as an orthodontic adhesive for more than a few weeks. However, it may be useful for short period of time in certain clinical situations, particularly under wet conditions, such as bonding attachments on impacted teeth, where control of moisture is difficult to achieve and no strong forces are likely to be exerted. Materials such as glass ionomer cements have been introduced in orthodontic practice as alternative bonding agents to composites, but with disappointing results. Bond strengths of these materials are reported to be lower than that obtained with composites (Fricker 1992; Miguel *et al*., 1995). However, some investigations have reported on attempts to improve the bonding characteristic of these materials (Millet *et al*., 1993). Resin-modified glass ionomer cement systems have been introduced recently and found to give greater bond strength than conventional glass ionomer cement (McCarthy and Hondrum, 1994). Further investigations of these and other adhesive materials currently being investigated as dentine bonding agents may help in attaining the ideal characteristics sought by orthodontists.

Conclusions

Cyanoacrylate adhesives are unsuitable for use as a bonding agent in routine orthodontic practice. However, the ability of this adhesive to adhere to wet surfaces could enable practitioners to bond attachments in wet conditions where the use of other materials has proved difficult.

References

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

Crabb, J. J. and Wilson, H. J. (1971)
Use of some adhesives in orthodontics,
Dental Practitioner, **22,** 111–112.

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.

Fricker, J. P. (1992)
A 12 month clinical evaluation of a glass ionomer polyalkenoate cement for the direct bonding of orthodontic brackets,
American Journal of Orthodontics and Dentofacial Orthopedics, **101,** 381–384.

Howells, D. J. and Jones, P. (1989)
In vitro evaluation of a cyanoacrylate bonding agent,
British Journal of Orthodontics, **16,** 75–78.

Krishnan, P. H., Gupta, D. S. and Sharma, V. P. (1994)
Application of cyanoacrylate in orthodontics,
Journal of Polymer Materials, **11**, 299–300.

Marcusson, A., Norvall, L. I. and Persson, M. (1997)
White spot reduction when using glass ionomer cement for bonding in orthodontics: a longitudinal and comparative study,
European Journal of Orthodontics, **19,** 233–242.

McCarthy, M. F. and Hondrum, S. O. (1994)
Mechanical and bond strength properties of light cured and chemically cured glass ionomer cements,
American Journal of Orthodontics and Dentofacial Orthopedics, **105,** 135–141.

Miguel, J. A. M., Almeida, M. A and Chevitarese, O. (1995)
Clinical comparison between a glass ionomer cement and a composite for direct bonding of orthodontic brackets,
American Journal of Orthodontics and Dentofacial Orthopedics, **107,** 484–487.

Millet, D. T., McCabe, J. F. and Gordon, P. H. (1993)
The role of sandblasting on the retention of metallic brackets applied with glass ionomer cement,
British Journal of Orthodontics, **20,** 117–122.

Minitab Inc. (1996)
3081 Enterprise Drive, State College, PA 16801–3008.

Mitchell, D. L. (1967)
Bandless orthodontic bracket,
Journal of the American Dental Association, **74,** 103–110.

Mizrahi, E. and Smith, D.C. (1969)
Direct cementation of orthodontic brackets to dental enamel,
British Dental Journal, **127,** 371–375.

Moin, K. and Dogan, I. L. (1978)
An evaluation of shear bond strength, measurements of unfilled and filled combinations,
American Journal of Orthodontics, **74,** 531–535.

Newman, G. V. (1965)
Epoxy adhesives for orthodontic attachments: progress report,
American Journal of Orthodontics, **51,** 901–912.

Pus, M. D. and Way, D. C. (1980)
Enamel loss due to orthodontic bonding with filled and unfilled resins using various clean-up techniques,
American Journal of Orthodontics, **77,** 269–283.

Redd, T. B. and Shivapuja, P. K. (1991)
Debonding ceramic brackets: effects on enamel,
Journal of Clinical Orthodontics, **25,** 475–481.

Silverman, E., Cohen, M., Anthony, G. and Dietz, V. (1972)
A universal direct bonding system for both metal and plastic brackets,
American Journal of Orthodontics, **62,** 236–244.

Tay, W. M. and Braden, M. (1988)
Fluoride diffusion from polyalkenoate (glass ionomer) cements,
Biomaterials, **9**, 454–456.

Weibull, W. (1951)
A statistical distribution function of wide applicability,
Journal of Applied Mechanics, **18**, 293–297.

Wilson, A. D. and Kent, B. E. (1972)
A new translucent cement for dentistry,
British Dental Journal, **132**, 133–135.

Zachrisson, B. U. and Årtun, J. (1979)
Enamel surface appearance after various debonding techniques,
American Journal of Orthodontics, **75,** 121–137.