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The influence of different bracket base surfaces on tensile and shear bond strength

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SUMMARY Fracture of the bracket–cement–enamel system usually takes place between the bracket and the cement. Especially for glass ionomer-based materials, it is helpful if this part of the system can be improved. The aim of this *in vitro* study was to investigate the influence of different bracket base pre-treatments in relation to three different cements, Transbond XT, a resin composite, Fuji Ortho LC, a resin-modified glass ionomer cement (GIC), and Fuji IX Fast, a conventional glass ionomer cement, on shear as well as on the tensile bond strength. Upper incisor brackets with three types of base treatment, sandblasted, silicoated, and tin-plated, were bonded to bovine enamel. Untreated brackets were used as the controls. Ten specimens were tested for each group. The brackets were stored for 24 hours after bonding and tested in shear as well as in tensile mode. After fracture the remaining adhesive was scored using the adhesive remnant index (ARI). Analysis of variance was used to detect statistical differences between the bond strengths at a level of $P < 0.05$.

Although some of the bracket pre-treatments had a statistically significant effect on bond strength, no clear improvement was measured. The ARI scores of the test groups did not show a change when compared with the control groups. The investigated base pre-treatments did not have such a beneficial influence on bond strength that improved clinical results can be expected. Improvement of the bond between bracket and cement might be found in other variables of the bracket–cement–enamel system such as the elasticity of the materials.

Introduction

In the early days of bracket adhesion research, the aim was to achieve a strong and reliable bond between the bracket and the enamel. With the use of the current mesh-based brackets and resin composites, these initial problems have mostly been resolved. Now the focus is more on details such as faster bonding, harmless removal procedures, and antibacterial effects of the bonding materials to help oral hygiene.

For these reasons, the popularity of using resin-modified glass ionomer cements (RMGIC) for bracket bonding is increasing. Their bonding properties are acceptable and they have the advantages of fluoride release. Although the influence of the type and amount of fluoride is still not clear, a beneficial effect is assumed (Corry *et al.*, 2003; Benson *et al.*, 2005).

A second type of material that also releases a substantial amount of fluoride is conventional glass ionomer cement (GIC). Another advantage of this material is the chemical bonding to enamel. COO− groups of the GIC bind to Ca^{2+} ions of the enamel. This results in a non-invasive, superficial bonding. Separation of the bracket at the end of treatment is therefore not within the enamel, but at the surface. This minimizes the risk of enamel damage and reduces the cleaning time. The main disadvantages of this type of material are the low bond strength properties, the slow curing reaction, and the high failure rate (Miguel *et al.*, 1995; Algera *et al.*, 2006).

In contrast with the non-invasive chemical bonding of GIC is the hybrid layer which is formed when resin composite is used as the bonding material. Resin composite needs a micromechanical bonding to adhere to enamel. After treatment, the hybrid layer has to be removed. This results in damage while on the other hand not all material is removed.

In vitro as well as *in vivo* debonding usually takes place between the cement and the bracket. It is therefore logical that this part of the bracket–cement–enamel system has to be improved if a lower failure rate is demanded. Several suggestions such as different base geometries (Lopez, 1980), mesh sizes (Reynolds and von Fraunhofer, 1976; MacColl *et al.*, 1998; Knox *et al.*, 2000), mesh numbers (Knox *et al.*, 2001; Bishara *et al.*, 2004), and surface treatment of the mesh (Kern and Thompson, 1993; Ozer and Arici, 2005; Arici *et al.*, 2006) have been proposed for enhancement of this part of the system. The literature does not, however, give a clear answer to the question as to which combination of materials provides the best bonding. Surface enlargement as a result of microabrasion is an advantage when plane surfaces, such as crowns, are bonded to a tooth structure (Tiller *et al.*, 1985a,b). For bracket bonding with composite or glass ionomer-based materials, this benefit is not clear. Chung *et al.* (2001) reported an improvement of the bond as a result of sandblasting the bracket base when composite resin was used as the cement. When GIC (Ketac Cem) was used as the bonding material in combination with a sandblasted bracket, a significant improvement of 22 per cent in bond strength was found (Millett *et al.*, 1993). No difference was observed when a RMGIC was used (Ozer and Arici, 2005). Tavares *et al.* (2006) and Sonis (1996) did not find a difference in bond strength between sandblasted brackets and control groups. Willems *et al.* (1997) concluded that the influence of sandblasting on bond strength is dependent on the bracket base type. Arici *et al.* (2006) reported that the particle size of the aluminium oxide, the blasting time, and the distance to the object seems to be of importance.

Microabrasion in combination with silicoating is another technique successfully used in prosthetic dentistry (Swartz *et al.*, 2000). With this technique, a SiOx layer is burned on the metal surface and the layer is subsequently silanized using Silicoup. This enables a chemical bonding with the oxides of the cement. Newman *et al.* (1995) stated that silicoating the bracket base can be of benefit if resin composite is used as the cement. No data are available concerning bonding silicoated brackets with GIC.

Swartz *et al.* (2000) evaluated the influence of surface treatment of high-noble alloys, used for porcelain fused to metal crowns. A benefit of tin-plating in combination with RMGIC was found when tensile tests were performed. An explanation for the results was an improved chemical bonding of the cement to the oxides formed at the tin surface.

In view of the doubts and contradiction in previous research, the aim of this *in vitro* study was to investigate the influence of different bracket base pre-treatments, e.g. sandblasting, silicoating, and tin-plating, in relation to three different cements. The bonding properties were evaluated with shear as well as tensile bond strength testing.

Materials and methods

Specimen preparation

The brackets used in this research were stainless steel, mesh based (Mini Twin, 'A' Company Orthodontics, San Diego, California, USA), bonded to bovine enamel. Enamel from 240 freshly extracted bovine teeth, randomly collected from 2-year-old cattle, was used as the substrate. The crowns were sectioned from the roots and embedded in cylindrical polymethyl methacrylate moulds. The vestibular enamel surface was ground on wet silicon carbide paper up to grit 1200 to create a flat standard bonding surface.

The cements investigated are shown in Table 1. All cements were handled according to the manufacturers' prescriptions with the exception of Fuji IX Fast. For this cement, the conditioning step was not performed. Prior to the use of Fuji Ortho LC the enamel was conditioned with a polyacrylic acid gel (GC Dentin Conditioner, GC Corp., Tokyo, Japan) for 20 seconds following which extensive rinsing and air drying of the enamel took place. Before bonding with Transbond XT, 35 per cent phosphoric acid (Ultradent Products, South Jordan, Utah, USA) was applied on the enamel for 30 seconds, followed by rinsing, air drying, and application of adhesive primer (3M-Unitek, Monrovia, California, USA).

If light curing was required, the Elipar Trilight curing unit (3M-Espe Dental Products, Seefeld, Germany) was used in the standard mode at 750 mW/cm^2.

Bracket pre-treatment

Brackets with a bonding area size of 2.9 × 4.2 mm, intended for use on central upper incisors, were cemented to the enamel substrates. The brackets were bonded in the same way: the cement was applied to the bracket, the bracket was placed and firmly pressed with a probe at the bonding area. Excess material was removed prior to curing. The specimens were stored for 24 hours at 37°C in tap water.

Prior to bonding, four groups were created: sandblasted, silicoated, tin-plated, and a control. The bases of the brackets from the sandblasted group were roughened with aluminium oxide particles <50 μm for 3 seconds. The brackets used in the silicoated group were also sandblasted followed by the application of a silicon oxide layer using a Siliflame coater (Heraeus-Kulzer GmbH, Wehrheim, Germany). Subsequently, a silane layer was applied using Silicoup (Heraeus-Kulzer GmbH). The brackets of the third group were electrolytically plated with a layer of tin less than 10 μm thick.

Tensile and shear strength determination

For tensile testing, the set-up used has been described previously (Algera *et al.*, 2005). A round stainless steel

Table 1 Materials used in this study.

Material	Manufacturer	Cement type	Batch number	Expiry. date
Fuji IX Fast	GC Corporation	Conventional glass ionomer cement	0506083	2007–2006
Fuji Ortho LC	GC Corporation	Resin-modified glass ionomer cement	0309253	2005–2009
Transbond XT	3M-Unitek	Resin composite	3 JF	2006–2010

wire, with a diameter of 1 mm, was bent in a U-form and tied with a harness ligature to the bracket. The free ends of the wire were clamped in the connecting piece of the cross-head. A hinge in the connecting piece, together with the round wire, made vertical alignment of the specimen in the pre-test phase possible. Vertical alignment is necessary for homogeneous stress distribution during the test over the specimen. For shear testing, the specimens were placed in a brass block so that the bracket base was located exactly at the edge of this holder (Figure 1). A metal plate, intended to guide the specimen, was placed parallel to the specimen, but without touching it. An extension connected to the cross-head was placed at the top of the specimen, performing a compressive force in line with it. In this way, the enamel is sheared of the bracket.

Twenty-four hours after the start of the bonding procedure, the specimens were measured in a universal testing machine (Hounsfield Ltd, Redhill, Surrey, UK). Each group consisted of 10 specimens. The cross head speed during testing was 0.5 mm/minute. The loads at fracture were recorded in Newtons and converted to megapascals. After testing, the type of fracture was scored using the adhesive remnant index (ARI; Årtun and Bergland, 1984) to identify the weakest point in the bracket–adhesive–enamel system. The scores were determined with a stereomicroscope at a magnification of ×25.

Statistical analysis

Two-way analysis of variance (ANOVA) was used to test the effect of the different bracket base pre-treatment methods in combination with different cements on the debonding force. Furthermore, one-way ANOVA was used to determine differences in debonding force between the base pre-treatments within the materials; $P < 0.05$ was considered significant. Tukey's *post hoc* test was performed to show individual differences. The software used was SigmaStat Version 3.0 (SPSS Inc., Chicago, Illinois, USA).

Results

Bond strength

Table 2 shows the results of the shear and tensile bond strengths. ANOVA demonstrated statistical differences between Transbond XT, Fuji Ortho LC, and Fuji IX Fast ($P < 0.001$). Transbond XT showed the highest results, while Fuji IX Fast gave the lowest results. There was also a clear difference between the shear and tensile strength results, with the shear strength results being significantly higher ($P < 0.05$). No clear difference in bond strength was found between the four different bracket base pre-treatment methods. Regarding the shear test results, the control group of Transbond XT showed significantly higher values compared with the tin-plated group. For Fuji Ortho LC, the tin-plated group gave the highest results. Tensile testing showed less variation.

ARI scores

The ARI scores for the shear and tensile measurements are presented in Table 3. The average ARI scores for Transbond XT and Fuji Ortho LC were between 2.1 and 3.0. This means that fracture occurred mainly between the bracket and the cement. Combined with the bond strength results, no improvement with the pre-treatment procedure was observed. Fuji IX Fast showed, for most of the tests, a low ARI score.

Discussion

The use of glass ionomer-based cements for bracket bonding is gaining popularity because of the believed cariostatic

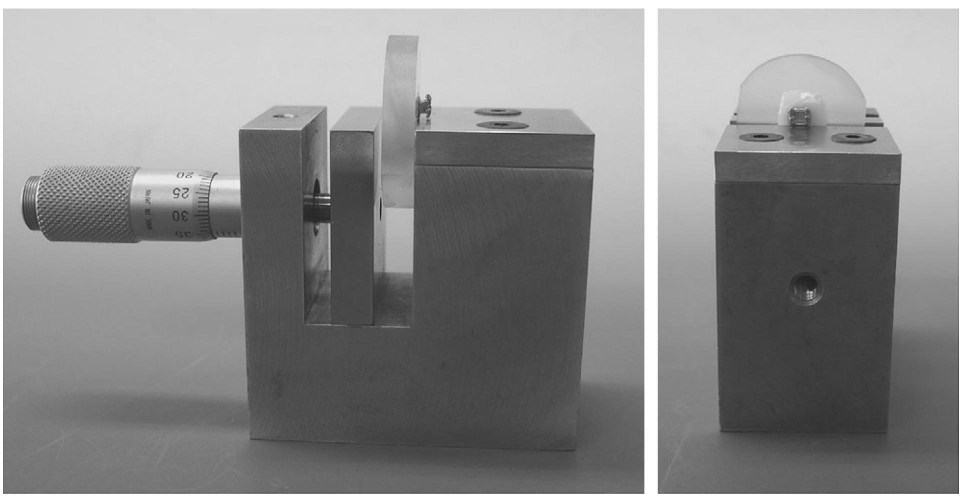

Figure 1 Photographs showing the set-up for the shear stress determinations. A lateral view (left) and a frontal view (right) of the specimen and the specimen container.

effect. It is not, however, a commonly used material for bracket bonding because of the assumed inferior bonding properties compared with resin composite. This assumption is supported in the present study. The specimens bonded with resin composite demonstrated the strongest bond, while the brackets bonded with conventional GIC gave the lowest results.

The main purpose of the present study was to evaluate the influence of modifying the mesh base on bond strength. The different cements were evaluated in relation to different bases. The results show that only tin-plating had a positive effect on the shear strength of Fuji Ortho LC. This is partly in line with results of Swartz *et al.* (2000) who found an improvement in tensile strength when tin-plating in combination with a RMGIC was used. The tensile strength of the RMGIC bonded to the tin-plated bases in the present study did not improve.

Table 2 Shear and tensile bond strengths (in megapascals) together with the standard deviations for the different variables.

	Control	Sandblasted	Silicoated	Tin-plated
Shear bond strength				
Transbond XT	18.3^{Aa} (4.3)	16.3^{ABa} (5.1)	14.0^{ABa} (5.3)	12.4^{Ba} (3.8)
Fuji Ortho LC	8.5^{Bb} (3.4)	11.1^{ABb} (7.8)	9.8^{Bab} (5.6)	15.1^{Aa} (3.1)
Fuji IX Fast	3.7^{Ac} (2.5)	2.6^{Ac} (1.6)	4.3^{Ab} (1.4)	4.3^{Ab} (2.6)
Tensile bond strength				
Transbond XT	5.6^{Aa} (1.0)	6.7^{Ba} (0.5)	6.1^{Aa} (0.9)	6.2^{Aa} (0.4)
Fuji Ortho LC	4.5^{ABb} (0.5)	4.9^{Ab} (0.6)	4.0^{BCb} (1.0)	3.2^{Cb} (0.5)
Fuji IX Fast	1.5^{Ac} (0.4)	1.6^{Ac} (0.6)	1.6^{Ac} (0.5)	1.9^{Ac} (0.5)

Equal capital characters indicate statistical equality within the material (horizontal). Equal small characters indicate statistical equality within the pre-treatment (vertical).

Except for the RMGIC group bonded with tin-plated brackets, neither the shear nor the tensile strength changed dramatically. Therefore, no clinically significant influence of any of the modification procedures can be expected.

Regarding the ARI scores, most specimens fractured at the bracket–cement interface. This was more pronounced in the tensile than in the shear tests. One explanation may be that the stress distribution over the specimens was different in both tests. The bracket–cement interface is more resistant to compressive then to tensile stress. The ARI scores did not change as a result of the base pre-treatments when they were compared with the control group.

The type of material is of influence bonding in bracket. In the shear groups, the GIC showed more breakage inside the cement or at the enamel interface compared with the RMGIC or composite groups.

The bond strength results, as well as the ARI scores found in this study, support the earlier proposed theory (Algera *et al.*, 2008) that not only the internal strength of the cement plays a role in the bracket–cement bonding but also the elasticity of the cement and the other components of the bracket–cement–enamel system. To find bond strength improvements, the scope of research might be fucussed on this property of the bracket–cement–enamel system.

Table 3 Frequency distribution together with the averages of the adhesive remnant index (ARI) scores of the shear and tensile measurements.

	ARI score									
	Shear tests					Tensile tests				
	0	1	2	3	Average	0	1	2	3	Average
Transbond XT										
Control	0	2	5	3	2.1	0	1	1	8	2.7
Sandblasted	0	5	0	5	2.5	0	1	0	9	2.8
Silicoated	1	0	7	2	2.1	1	7	1	1	1.2
Tin-plated	2	1	5	2	1.7	1	1	1	7	2.4
Fuji Ortho LC										
Control	1	0	3	6	2.4	0	0	2	8	2.8
Sandblasted	0	1	6	3	2.2	0	0	1	9	2.9
Silicoated	0	0	6	4	2.4	0	0	2	8	2.8
Tin-plated	0	0	2	8	2.6	0	0	0	10	3
Fuji IX Fast										
Control	1	2	4	3	1.9	0	0	1	9	2.9
Sandblasted	6	4	0	0	0.4	1	1	8	0	1.7
Silicoated	3	4	1	2	1.2	1	1	1	7	2.4
Tin-plated	4	0	0	6	1.8	0	0	1	9	2.9

A score of 0 indicates that no adhesive was left on the enamel, 1 less than half of the adhesive remained, 2 more than half remained, and 3 all the adhesive remained on the enamel surface.

Conclusions

No clear improvement was found in relation to the pre-treatments of the bracket bases. This means that surface enlargement by means of sandblasting or establishing a chemical bond between the bracket and the cement was not successful. It is likely that other factors are responsible for the resistance to fracture.

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References

Algera T J, Kleverlaan C J, de Gee A J, Prahl-Andersen B, Feilzer A J 2005 The influence of accelerating the setting rate by ultrasound or heat on the bond strength of glass ionomers used as orthodontic bracket cements. European Journal Orthodontics 27: 472–476

Algera T J, Kleverlaan C J, Prahl-Andersen B, Feilzer A J 2006 The influence of environmental conditions on the material properties of setting glass-ionomer cements. Dental Materials 22: 852–856

Algera T J, Kleverlaan C J, Prahl-Andersen B, Feilzer A J 2008 The influence of dynamic fatigue loading on the separate components of the bracket-cement-enamel system. American Journal of Dentistry (in press)

Arici S, Ozer M, Arici N, Gencer Y 2006 Effects of sandblasting metal bracket base on the bond strength of a resin-modified glass ionomer cement: an *in vitro* study. Journal of Materials Science: Materials in Medicine 17: 253–258

Årtun J, Bergland S 1984 Clinical trials with crystal growth conditioning as an alternative to acid-etch enamel pretreatment. American Journal of Orthodontics 85: 333–340

Benson P E, Shah A A, Millett D T, Dyer F, Parkin N, Vine R S 2005 Fluorides, orthodontics and demineralization: a systematic review. Journal of Orthodontics 32: 102–114

Bishara S E, Soliman M M, Oonsombat C, Laffoon J F, Ajlouni R 2004 The effect of variation in mesh-base design on the shear bond strength of orthodontic brackets. Angle Orthodontist 74: 400–404

Chung K, Hsu B, Berry T, Hsieh T 2001 Effect of sandblasting on the bond strength of the bondable molar tube bracket. Journal of Oral Rehabilitation 28: 418–424

Corry A, Millett D T, Creanor S L, Foye R H, Gilmour W H 2003 Effect of fluoride exposure on cariostatic potential of orthodontic bonding agents: an *in vitro* evaluation. Journal of Orthodontics 30: 323–329

Kern M, Thompson V P 1993 Sandblasting and silica-coating of dental alloys: volume loss, morphology and changes in the surface composition. Dental Materials 9: 151–161

Knox J, Hubsch P, Jones M L, Middleton J 2000 The influence of bracket base design on the strength of the bracket-cement interface. Journal of Orthodontics 27: 249–254

Knox J, Kralj B, Hubsch P, Middleton J, Jones M L 2001 An evaluation of the quality of orthodontic attachment offered by single- and double-mesh bracket bases using the finite element method of stress analysis. Angle Orthodontist 71: 149–155

Lopez J I 1980 Retentive shear strengths of various bonding attachment bases. American Journal of Orthodontics 77: 669–678

MacColl G A, Rossouw P E, Titley K C, Yamin C 1998 The relationship between bond strength and orthodontic bracket base surface area with conventional and microetched foil-mesh bases. American Journal of Orthodontics and Dentofacial Orthopedics 113: 276–281

Miguel J A, Almeida M A, 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

Millett D, McCabe J F, 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

Newman G V, Newman R A, Sun B I, Ha J L, Ozsoylu S A 1995 Adhesion promoters, their effect on the bond strength of metal brackets. American Journal of Orthodontics and Dentofacial Orthopedics 108: 237–241

Ozer M, Arici S 2005 Sandblasted metal brackets bonded with resin-modified glass ionomer cement *in vivo*. Angle Orthodontist 75: 406–409

Reynolds I R, von Fraunhofer J A 1976 Direct bonding of orthodontic attachments to teeth: the relation of adhesive bond strength to gauze mesh size. British Journal of Orthodontics 3: 91–95

Sonis A L 1996 Air abrasion of failed bonded metal brackets: a study of shear bond strength and surface characteristics as determined by scanning electron microscopy. American Journal of Orthodontics and Dentofacial Orthopedics 110: 96–98

Swartz J M, Davis R D, Overton J D 2000 Tensile bond strength of resin-modified glass-ionomer cement to microabraded and silica-coated or tin-plated high noble ceramic alloy. Journal of Prosthodontics 9: 195–200

Tavares S W, Consani S, Nouer D F, Magnani M B, Nouer P R, Martins L M 2006 Shear bond strength of new and recycled brackets to enamel. Brazilian Dental Journal 17: 44–48

Tiller H J, Magnus B, Gobel R, Musil R, Garschke A 1985a Sand-blasting process and its use in surface conditioning of dental alloys (I). Quintessenz 36: 1927–1934

Tiller H J *et al.* 1985b Sand blasting procedures and its effect on the surface properties of dental alloys (II). Quintessenz 36: 2151–2158

Willems G, Carels C E, Verbeke G 1997 *In vitro* peel/shear bond strength evaluation of orthodontic bracket base design. Journal of Dentistry 25: 271–278

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