Rebonding performance of different ceramic brackets conditioned with a new silane coupling agent

Frank Falkensammer, Erwin Jonke, Michael Bertl, Josef Freudenthaler and Hans Peter Bantleon
Department of Orthodontics, Bernhard-Gottlieb University Dental Clinic, Medical University of Vienna, Austria

Correspondence to: Frank Falkensammer, Department of Orthodontics, Bernhard-Gottlieb University Dental Clinic, Medical University of Vienna, Sensengasse 2a, A-1090 Vienna, Austria. E-mail: frank.falkensammer@meduniwien.ac.at

SUMMARY The objective of this study was to investigate the rebonding effect of a new silane coupling agent on various ceramic brackets bonded to ceramic specimen. Different ceramic brackets (Fascination 2, Clarity SL, and In-OvationC) were assigned to three groups: rebonding with new silane coupling agent, rebonding with conventional silane coupling agent, or regular bonding as control ($n = 16$). Bracket adhesion was calculated with a shear test in a universal testing machine. The bracket–composite–ceramic interface was evaluated using the adhesive remnant index score. One-way analysis of variance was applied for inferential statistics. Rebonding with the new silane coupling agent resulted in high shear bond strengths (SBSs; mean values: 37.44–41.24 MPa) and ceramic specimen fractures. Rebonding with the conventional silane coupling agent resulted in significantly ($P < 0.001$) lower clinically adequate SBS (mean values: 20.20–29.92 MPa) with the least ceramic specimen fractures. Regularly bonded ceramic brackets resulted in clinically adequate to high SBS (mean values: 17.06–41.56 MPa) depending on their bracket base design. Rebonded ceramic brackets showed sufficient SBS to ceramic specimen surfaces. However, increased bracket adhesion was associated with a risk of ceramic specimen surface damage. Therefore, ceramic brackets rebonded with the new silane coupling should be debonded cautiously using alternative debonding methods.

Introduction

Adequate bonding of brackets to ceramic surfaces is of clinical importance as an increasing number of adults are under orthodontic treatment (Pine *et al.*, 2001; Ajlouni *et al.*, 2005). Adult patients are demanding aesthetic orthodontic treatment. Thus, orthodontists need to bond ceramic brackets to ceramic surfaces more frequently. The requirements of an ideal ceramic bracket are suitable for any given orthodontic technique, aesthetically appealing, easily debondable without tooth/restoration surface damage, and feasible for rebonding (Brantley and Eliades, 2001). Aesthetic ceramic brackets were introduced in orthodontic dentistry in 1986 (Karamouzos *et al.*, 1997). In the past, ceramic brackets were milled from single crystalline aluminium oxide providing for high aesthetic standards. One shortcoming of these brackets was brittleness with a low fracture resistance. Currently available ceramic brackets are cast in polycrystalline aluminium oxide combining aesthetic properties and adequate fracture resistance (Russell, 2005). The first generation of ceramic brackets had mechanically retentive bracket bases resulting in high shear bond strength (SBS). This strong adhesion resulted in cracks in the enamel or restorative material during debonding (Wang *et al.*, 1997; Barghi, 2000). Consequently, various bracket base designs have been

introduced to adjust the SBS to clinically adequate values without destroying the integrity of the underlying surface. Current ceramic brackets show various base designs: mechanical ball, dovetail, dimpled, chemo/mechanical, silane-coated buttons, microcrystalline, and polymeric bases. All these base designs are intended to provide a better mechanical interlock to the adhesive material and facilitate the debonding process (Russell, 2005). In addition, mechanical stability of polycrystalline ceramic brackets reduces the risk of bracket fracture (Theodorakopoulou *et al.*, 2004). Reutilization of these brackets, however, is of interest as rebonding of brackets is necessary in cases of improper bracket position and clinical bond failures. While bond failures of metal brackets have been investigated before and range between 5 and 10 per cent (O'Brien *et al.*, 1989; Underwood *et al.*, 1989), survival rates of ceramic brackets are still unknown.

Rebonding of ceramic brackets was investigated by Lew *et al.* (1991) for the first time. Single crystalline brackets were debonded and thermally reconditioned to eliminate adhesive left on the bracket base. To re-establish an adequate bond, a silane coupling agent was added for chemical conditioning. Gaffey *et al.* (1995) tried hydrofluoric acid in auxiliary for conditioning the bracket base prior to rebonding, which actually was

decreasing SBS. Later studies focused on polycrystalline ceramic brackets, including sandblasting to generate a conditioned bracket base (Chung *et al.*, 2002; Toroglu and Yaylali, 2008). Sandblasting in combination with silane coupling agents was found to be effective in rebonding ceramic brackets (Atsu *et al.*, 2006; Toroglu and Yaylali, 2008).

Recently, silane coupling agents have been improved: three components, silane metacrylate, phosphoric acid metacrylate, and sulfide metacrylate, provide for a durable chemical bond between adhesive and aluminium oxide surfaces. The distinct affinity between phosphoric acid and aluminium oxide ceramics is used to form a low soluble phosphate layer to generate a strong adhesion. In addition, the metacrylate groups are chemically responding with the adhesive bonding material (Attia *et al.*, 2011). Data regarding orthodontic bracket bonding with this new silane coupling agent are not available at the moment.

The purpose of this study was to evaluate the bond and rebond strength of polycrystalline ceramic brackets with conventional and new silane coupling agents.

The null-hypotheses stated:

1. Ceramic bracket rebonding is not influenced by the conditioning method.
2. Ceramic bracket bonding is not influenced by the bracket base designs.

Materials and methods

Polycrystalline ceramic brackets (n = 144) of the new generation (upper central incisor) with varying base designs were used in this *in vitro* study:

1. Clarity SL bracket (3M unitek, Monrovia, California, USA) with a microcrystalline surface,
2. In-OvationC bracket (GAC, Bohemia, New York, USA) with a dimpled surface,
3. Fascination 2 bracket (Dentaurum, Ispringen, Germany) with a silane-coated button surface.

Bracket bonding was performed on feldspathic veneered (Akzent Vita VK Vita, Bad Säckingen, Germany) zirconium dioxide ceramic specimens (Zeno Zr Wieladent, Lenzing, Austria). The ceramic specimens were conditioned by sandblasting (50 μm Al^2O^3 Micron 50 +; GAC) with a microblaster (Dento-prep Ronvig, Daugaard, Denmark) for 2 seconds at an air pressure of 2.5 bar (36 psi). Silane coupling agent (Monobond-S Ivoclar Vivadent, Schaan, Liechtenstein) was applied for 60 seconds followed by light-cure bonding adhesive (Transbond XT; 3M unitek) as described previously by Karan *et al.* (2007) and Falkensammer *et al.* (2011).

Brackets for rebonding were obtained as described previously by Chung *et al.* (2002). Brackets were seated onto unconditioned ceramic specimen with light-cure adhesive (Transbond XT; 3M unitek). Excessive adhesive

was removed carefully and light-cured for 30 seconds (1000 mW/cm², 420–480 nm, Ortholux LED; 3M unitek). The bonded brackets were gently removed with a Weingart plier from the ceramic specimen. Subsequently, the brackets were sandblasted (50 μm Al^2O^2 Micron 50+GAC) with a microblaster (Dento-prep Ronvig; Daugaard) at an air pressure of 2.5 bar (36 psi) to remove the adhesive from the bracket base. Optical evaluation of the sandblasted bracket bases was done by a stereomicroscope (magnification ×20; Mantis FX Vision Engineering/Woking, Surrey, UK) to assure complete removal of the adhesive.

Each bracket type was assigned to one of the following testing procedures (Figure 1).

Rebonding + new silane

Debonded and sandblasted ceramic brackets (n = 16) were silanated with new silane coupling agent (Monobond plus; Ivoclar Vivadent) for 60 seconds. Light-cure bonding adhesive (Transbond XT; 3M unitek) was applied on the bracket bases. Brackets were seated onto the sandblasted and silanated ceramic specimens with a light-cure adhesive (Transbond XT; 3M unitek). Excessive adhesive was removed carefully, followed by light curing for 30 seconds (1000 mW/cm², 420–480 nm, Ortholux LED; 3M unitek).

Rebonding + silane

Debonded and sandblasted ceramic brackets (n = 16) were silanated with conventional silane coupling agent (Monobond-S; Ivoclar Vivadent) for 60 seconds. Light-cure bonding adhesive (Transbond XT; 3M unitek) was applied on the bracket bases. Brackets were seated onto the sandblasted and silanated ceramic specimens with a light-cure adhesive (Transbond XT; 3M unitek). Excessive adhesive was removed carefully, followed by light curing for 30 seconds (1000 mW/cm², 420–480 nm, Ortholux LED; 3M unitek).

Regular bonding (=control group)

Ceramic brackets (n = 16) were seated onto the preconditioned ceramic specimens with a light-cure adhesive (Transbond XT; 3M unitek). Excessive adhesive was removed carefully, followed by light curing for 30 seconds (1000 mW/cm², 420–480 nm, Ortholux LED; 3M unitek).

After bonding and rebonding the brackets, the specimens were stored in an isotonic saline solution (NaCl 0.9 per cent B-Braun; Maria Enzersdorf, Austria) at 37°C for 24 hours followed by thermocycling according to the International Organization for Standardization standard TR 11450 (500 cycles/5–55°C).

Shear bond testing was performed with a universal testing machine (Z010-TND Zwick, Ulm, Germany) at a crosshead speed of 1 mm/minute. The specimens were seated in the testing machine and manually fixed at the extension arm. The shearing wedge was positioned at the bracket base.
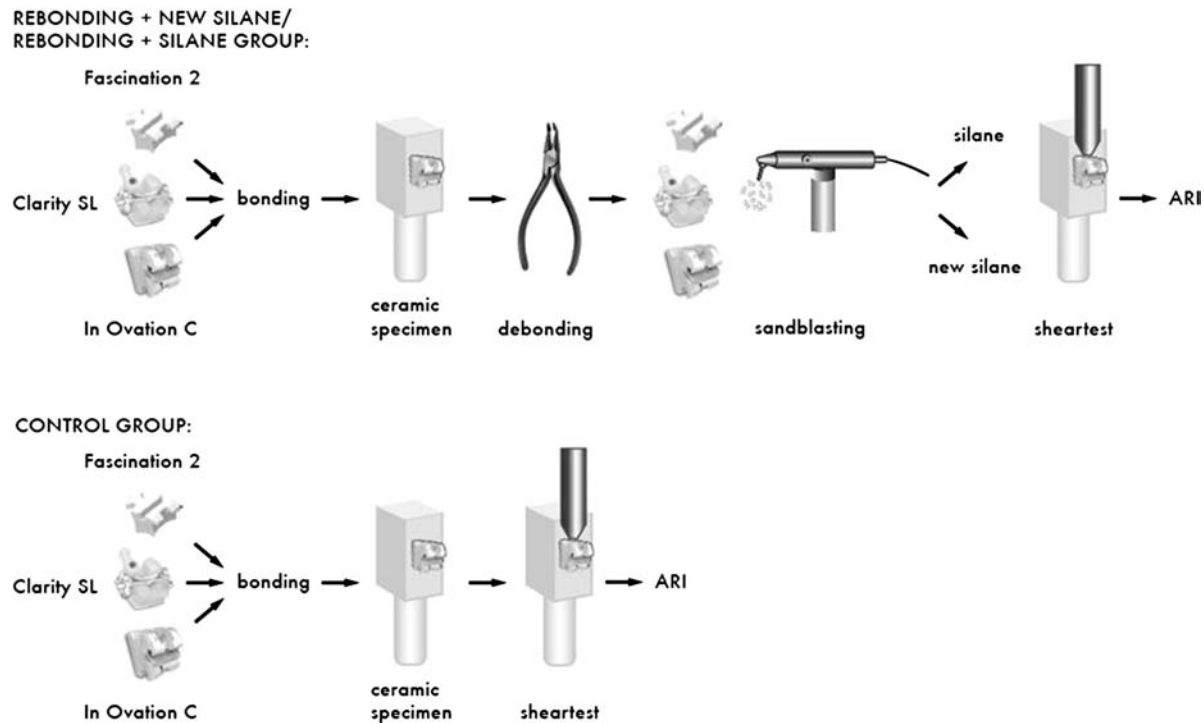
Figure 1 Schematic chart of the different bonding procedures prior to shear bond testing.

Table 1 Shear bond strength data of the testing groups.

Groups	Bracket	n	Mean (MPa)	SD	Range
Rebonding + new silane	Fascination 2	16	41.24	5.80	29.71–49.89
	Clarity SL	16	36.48*	7.50	20.98–53.59
	In-OvationC	16	37.44*	4.84	30.66–45.98
Rebonding + silane	Fascination 2	16	29.91*	5.42	19.68–40.12
	Clarity SL	16	20.20	9.84	7.85–38.97
	In-OvationC	16	25.21*	3.59	20.43–29.78
Regular bonding	Fascination 2	16	41.56	10.06	25.08–57.32
	Clarity SL	16	22.16	6.69	15.46–35.88
	In-OvationC	16	17.06	2.83	11.36–22.06

*Groups statistically different to regular bonding groups ($P < 0.001$).

SBS (megapascal = Newton per square millimetre) was measured at debonding and recorded automatically. The adhesive remnant index (ARI) score was used to determine the amount of adhesive remaining on the specimen surface (Årtun and Bergland, 1984). The ARI score and the ceramic fracture (CF) rate were evaluated with a stereomicroscope (magnification ×20, Mantis FX Vision Engineering; Montasser and Drummond, 2009). Scanning electron microscope (SEM) photographs (magnifications ×30 and ×500; XL 30-ESEM Philips, Eindhoven, the Netherlands) were printed of each bracket type for qualitative evaluation of the effect of sandblasting. In addition, an optical three-dimensional (3D) surface analysis (Infinite Focus G4; Alicona Imaging GmbH, Graz, Austria) was performed for quantitative evaluation of the effect of sandblasting.

Data from the shear test were automatically stored digitally by a computer connected to the universal testing machine. The statistical analyses were run on Microsoft Office Excel 2003 (Microsoft Corporation, Redmond, Washington, USA). Descriptive statistics of the SBS data led to the decision of using a parametric method. SBS were subjected to one-way analysis of variance to test for difference between the conditioning groups and the bracket types. The significance level was set at $P = 0.001$.

Results

For better readability, the SBS (mean, standard deviations, and minimum and maximum values) of the tested ceramic brackets are shown in Table 1 and in a descriptive diagram (Figure 2).
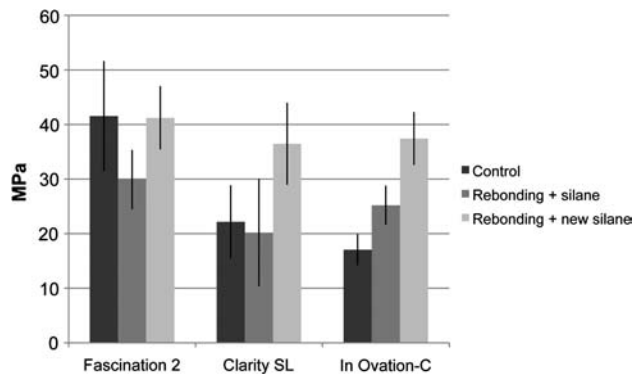
Figure 2 Mean shear bond strength (megapascal) and standard deviation among the different bonding procedures and bracket types.

Table 2 Frequency distribution of the adhesive remnant index (ARI) scores and the ceramic fracture (CF) rate.

| | ARI score | | | | CF |
	0	1	2	3	
Rebonding + new silane					
Fascination 2	10	5	1	—	—
Clarity-SL	6	3	—	—	7
In-OvationC	2	3	—	—	11
Rebonding + silane					
Fascination 2	16	—	—	—	—
Clarity-SL	16	—	—	—	—
In-OvationC	10	1	—	—	5
Regular bonding					
Fascination 2	13	—	—	—	3
Clarity-SL	16	—	—	—	—
In-OvationC	8	—	—	—	8

0 = no adhesive left on ceramic surface; 1 = less than half of the adhesive left on ceramic surface; 2 = more than half of the adhesive left on ceramic surface; and 3 = all adhesive left on ceramic surface.

Rebonding with the new silane coupling agent resulted in significantly ($P < 0.001$) higher SBS for Clarity SL and In-OvationC brackets as compared to regular bonding. In addition, significantly ($P < 0.001$) higher SBS resulted for all bracket types in comparison to rebonding with conventional silane coupling agent. Rebonding with the conventional silane coupling agent resulted in significantly ($P < 0.001$) higher SBS for In-OvationC brackets but significantly ($P < 0.001$) lower SBS for Fascination 2 as compared to regular bonding. Regularly bonded brackets showed significantly ($P < 0.001$) higher SBS for Fascination 2 as compared to Clarity SL and In-OvationC.

Rebonding with the new silane coupling agent showed low ARI scores (Table 2) for all brackets combined with a large number of ceramic specimen surface fractures for Clarity SL and In-OvationC brackets. Rebonding with the conventional silane coupling agent, as well as, regularly bonding showed low ARI scores in most instances. In

addition, In-OvationC brackets showed few ceramic specimen fractures.

The SEM evaluation of the sandblasted ceramic bracket surfaces (Figure 3) showed a slight microabrasion on Fascination 2 brackets (Figure 3, A3). The microcrystalline bracket base of Clarity SL bracket was totally removed by sandblasting (Figure 3, B3). In-OvationC brackets showed no changed surface pattern (Figure 3, C3). The optical 3D surface analysis showed a change in surface roughness Ra (= arithmetic mean value) by sandblasting for the Fascination 2 bracket (1.05–1.93 μm, Figure 3, A4) for the Clarity SL bracket (7.6–1.25 μm Figure 3, B4) and for the In-OvationC bracket (1.36–3.12 μm, Figure 3, C4).

Discussion

Rebonding of brackets is routine work in daily practice, not only when brackets get loose but also when improper placement is evident. While the first is found to have a clinical bond failure frequency of 5–10 per cent with metal brackets, the latter is seen at a frequency of 2–7 per cent (O'Brien *et al.*, 1989; Underwood *et al.*, 1989; Shah and Chadwick, 2009). Thus, a certain number of brackets will need to be rebonded in every case.

Bonding brackets to ceramic surfaces is different to bonding brackets to enamel surfaces. In this study, sandblasting was used to create a microretentive surface yielding to a mean Ra value of 8.4 μm for the tested ceramic specimen surfaces. However, this roughness value seems to be insufficient for a microretentive adhesion. Thus, a chemical additive was added, i.e. a silane coupling agent as previous studies have shown to be effective (Karan *et al.*, 2007; Falkensammer *et al.*, 2011).

Rebonding of ceramic brackets to ceramic surfaces using the new silane coupling agent resulted in high SBS for all ceramic brackets. High SBS might be provided by the previously described low soluble phosphate layer on the polycrystalline aluminium oxide bracket base, generated by the phosphoric metacrylates in the coupling agent. Previously, ceramic bracket rebonding was tested with various procedures to establish a clean bracket base for rebonding (Lew *et al.*, 1991; Gaffey *et al.*, 1995; Martina *et al.*, 1997). Sandblasting of the bracket base was found to be a viable option (Chung *et al.*, 2002; Atsu *et al.*, 2006; Toroglu and Yaylali, 2008). Together with silane coupling agent application, a chemically conditioned bracket base for rebonding is achieved. A significant reduction of rebond strength as compared to regularly bonded brackets was observed (Lew *et al.*, 1991; Martina *et al.*, 1997; Chung *et al.*, 2002; Toroglu and Yaylali, 2008). In the present study, sandblasting and conventional silane coupling agent application resulted in a significant reduction in rebond strength in the Fascination 2 brackets only. Nevertheless, this finding is of minor clinical relevance due to high SBS in this group. The In-OvationC bracket showed significantly higher
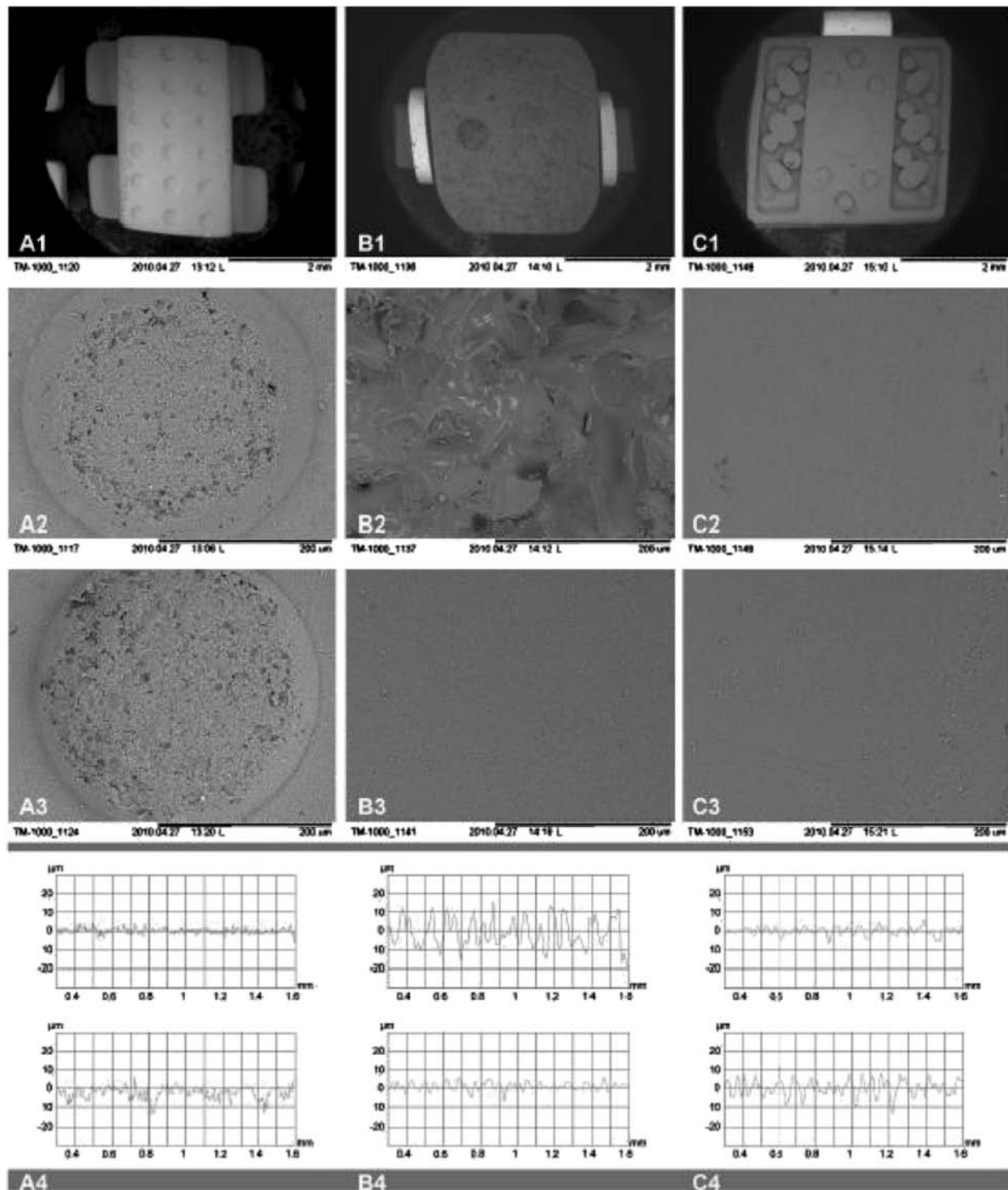
Figure 3 Scanning electron microscope photographs (×30 and ×500) and optical three-dimensional surface roughness measurements of the different bracket bases. A1: Fascination 2 bracket/A2: new/A3: sandblasted/A4: surface roughness before (upper) and after (lower) sandblasting; B1: Clarity SL bracket/B2: new/B3: sandblasted/B4: surface roughness before (upper) and after (lower) sandblasting; C1: In-OvationC bracket/C2: new/C3: sandblasted/C4: surface roughness before (upper) and after (lower) sandblasting.

rebond strength. Other authors also achieved increased rebond strengths using silica-coated aluminium oxide for sandblasting (Atsu *et al.*, 2006; Toroglu and Yaylali, 2008).

In the control group, the different SBS indicated an influence of the bracket base design on bracket adhesion to ceramic surfaces. The bracket type with a silane-coated base

showed the highest SBS values compared to the microcrystalline and dimpled bracket. This finding is consistent with those of other authors (Karamouzos et al., 1997; Wang et al., 1997; Russell, 2005). Ceramic brackets with microcrystalline and dimpled base design showed clinically adequate SBS comparable to previously published ceramic bracket shear test studies (Mundstock et al., 1999; Chung et al., 2002; Klocke et al., 2003; Theodorakopoulou et al., 2004; Speer et al., 2005; Atsu et al., 2006; Samruajbenjakul and Kukiattrakoon, 2009; Kukiattrakoon and Samruajbenjakul, 2010; Uysal et al., 2010).

The evaluation of the ceramic specimen surface showed low ARI values in most instances. Adhesive was left on the specimen surfaces (score 1) with noticeable amount of CFs when brackets were rebonded with the new silane coupling agent, i.e. the adhesive bond strength between the bracket and the adhesive exceeded the cohesive strength of the ceramic specimen. Further investigations on bracket bonding behaviour with the new silane coupling agent are still lacking. No adhesive was left on ceramic surfaces (score 0) when brackets were regularly bonded or rebonded with conventional silane coupling agent, i.e. the adhesive bond strength to the sandblasted and silanated ceramic specimen surface failed. Due to varying specimen surface preparations, previous ceramic bracket shear test studies showed different results with higher ARI scores (score 1–3) and few specimen fractures when ceramic brackets were regularly bonded or rebonded with conventional silane coupling agent (Gaffey et al., 1995; Martina et al., 1997; Chung et al., 2002; Atsu et al., 2006; Elekdag-Turk et al., 2007; Toroglu and Yaylali, 2008).

It might be speculated that the bracket base design influences the adhesive and cohesive conditions of the bracket–composite–ceramic interface. Ceramic brackets with the dimpled base design showed a high risk of ceramic specimen fracture in all bonding groups, also when low SBS were achieved. Previous ceramic bracket shear test studies reported a high variance in specimen fractures (Gaffey et al., 1995; Martina et al., 1997; Chung et al., 2002; Atsu et al., 2006; Elekdag-Turk et al., 2007; Toroglu and Yaylali, 2008; Samruajbenjakul and Kukiattrakoon, 2009; Kukiattrakoon and Samruajbenjakul, 2010. Therefore, the significant influence on these fractures remains still unclear. It might be speculated that special debonding pliers have an influence by reducing debonding forces, leading to minor ceramic surface fractures in clinical practice (Bishara et al., 1994).

The quantitative evaluation of the surface change by sandblasting showed the most significant changes in the Clarity SL bracket. The total removal of the prefabricated silicate ceramic bracket surface showed a homogeneous surface without any microretentions. This still resulted in unchanged or significantly higher SBS when the conventional or new silane coupling agents were applied.

A slight surface change, i.e. microabrasion, was detected on Fascination 2 and In-OvationC brackets. It might be speculated that these surface changes have minor influence on bracket adhesion, due to varying SBS when brackets were rebonded. The following conclusions can be drawn:

1. Both null-hypotheses had to be rejected.
2. Rebonding with the new silane coupling agent showed high SBS and CFs.
3. Rebonding with the conventional silane coupling agent showed clinically adequate SBS.
4. Regular bonding ceramic brackets showed clinically adequate to high SBS depending on the bracket base design.
5. Debonding characteristics were dependent on the ceramic bracket type and the conditioning method.
6. Considering the likelihood of CFs with the new silane coupling agent, final debonding of rebonded brackets should be performed cautiously using alternative debonding methods.

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