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# *In vitro* shear bond strength of dual-curing resin cements to two different high-strength ceramic materials with different surface texture

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**Abstract**

***Objective.*** The purpose of this study was to evaluate the shear bond strength (SBS) of two dual-curing resin cements to two high-strength ceramics with different surface texture. ***Material and methods.*** Composite cylinders were bonded to aluminum oxide (A) and zirconium oxide (Z) ceramic disks with six different surfaces. Investigated surfaces were for both ceramics: dry-pressed Procera Crown (A1, Z1), machined Procera Bridge (A2, Z2), airborne particle abraded Procera bridge (A3, Z3). Additional surfaces were, for alumina, dry-pressed Procera Laminate (A4) and, for zirconia, two modified surfaces (Z4, Z5). Two adhesive resin cements were used (Clearfil Esthetic and RelyX ARC). SBS was tested in a universal testing machine before and after artificial aging by thermal cycling. ***Results.*** Mean SBS ranged from 6.1 to 38.4 MPa before and from 0.0 to 41.4 MPa after aging. Clearfil Esthetic in A3, A4, and Z3 performed better than RelyX ARC. Aging decreased SBS, except for Z1, Z4, and Z5. For alumina, A4 was higher in SBS than A2, but similar to A1 and A3. For zirconia, Z5 showed the highest SBS. Z4 was higher than Z2 and Z3, but similar to Z1. ***Conclusions.*** Shear bond strength to alumina and zirconia increases with surface roughness. The modified zirconia surface Z5 provides stable long-term shear bond strength and can be bonded to either of the two used cements.

**Key Words:** *Alumina, Procera, zirconia*

## Introduction

Successful long-term bonding to ceramic requires two key factors: formation of chemical bonds and micromechanical interlocking [1]. So far, chemical bonds to high-strength ceramics (aluminum oxide or zirconium oxide ceramic) are assumed to be established only by cement systems containing the adhesive phosphate monomer, 10-methacryloyloxydecyl dihydrogen phosphate (MDP) [1–5]. Conventional Bis-GMA resin luting cements did not yield durable long-term bond strength to high-strength ceramic materials [2,3,6–9].

Micromechanical retention is determined by the surface texture of the internal surface of the restoration. Depending on the manufacturing technique, morphologic characteristics of these surfaces will be different, influencing bond strength values [2,10–13]. Therefore, only bonding protocols that have been tested and verified on specimens that possess the actual internal surface of that particular restoration should be used [14]. The surfaces of dry-pressed alumina (Procera Crown Alumina, Procera Laminate) or zirconia (Procera Crown Zirconia) copings have an inherent roughness, resembling the roughness of the refractory die against which the ceramic powder was pressed before sintering. In comparison, machined surfaces (Procera Bridge Alumina and Procera Bridge Zirconia) are relatively smooth microscopically, depending on the grit of the burrs used in the milling process. In order to increase surface roughness and bond strength of machined alumina or zirconia surfaces, airborne particle abrasion is usually used [1–3,6,15–17]. An increase of surface roughness increases the size of the surface area and surface energy. Some research groups suggest that this surface treatment might

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introduce micro-cracks into the ceramic and reduce its strength [18,19].

To overcome the risks involved with the subtractive technique of airborne particle abrasion on high-strength ceramics, additive surface treatment techniques have been described [13,20–22]. These techniques create surfaces that do not require any post-manufacture manipulation by airborne particle abrasion. Such a surface was recently introduced (NobelBond, Nobel Biocare AB, Göteborg, Sweden) [22], but is not yet commercially available.

To create the mentioned surface, pre-sintered or fully sintered and milled zirconia objects, e.g. implants, copings, or resin-bonded FPD frameworks are covered with an emulsion containing zirconia ceramic powder and a pore former. During the following sintering process, the pore former burns off and leaves a porous surface. Modification of the surface can be achieved by using different sizes of pore formers or repeating the coating and sintering process [22]. A recent study showed that this modified surface provided significantly higher shear bond strength in comparison to machined and airborne particle abraded zirconia after artificial aging. Stable long-term bond strength could be achieved with either of the used resin luting cements, regardless of their chemistry [22].

The purpose of the present investigation was to evaluate shear bond strength of a MDP containing resin cement system (Clearfil Esthetic) and a regular Bis-GMA resin cement (RelyX ARC) to two different high-strength ceramic materials (aluminum oxide and zirconium oxide ceramic) with six different internal surfaces (Procera Crown, Procera Bridge, Procera Bridge airborne particle abraded, Procera Laminate, NobelBond1, NobelBond2). Subgroups of specimens were tested after both short-term and long-term water storage with repeated thermal cycling. The following hypotheses were tested:

1. Artificial aging by thermocycling and water storage reduces shear bond strength.
2. Shear bond strength for the MDP containing resin cement system Clearfil Esthetic is higher than for the conventional Bis-GMA resin cement RelyX ARC.
3. Shear bond strength for all surfaces is different.
4. Shear bond strength for high strength ceramic zirconia is higher than for high strength ceramic alumina with similar surfaces (A1/Z1, A2/Z2, A3/Z3).

## Material and methods

Three-hundred-and-sixty square specimens ($10 \times 10 \times 2$ mm) of densely sintered high-purity aluminum oxide ($n = 160$; Procera Alumina, Nobel Biocare, Göteborg, Sweden) and zirconium oxide ceramic ($n = 200$; Procera Zirconia, Nobel Biocare, Göteborg, Sweden) with six different surface textures were manufactured (Table I).

Among the aluminum oxide ceramic specimens, 40 specimens had the manufacturer specific internal surface for crown copings (A1; Procera Crown). Another 40 specimens had the specific internal surface for laminates (A4; Procera Laminates). Eighty had the specific machined internal surface for fixed partial denture frameworks (A2; Procera Bridge), from which 40 were used as delivered by the manufacturer and the remaining 40 were treated with airborne particle abrasion (A3). For this surface treatment, 50 µm large aluminum oxide ($Al_2O_3$) particles (Cobra 50 µm white; Renfert, Hilzingen, Germany) at an air pressure of 2.8 bar applied with a fine blasting unit (Basic

Table I. Used ceramics, surface treatments, and luting cements (*n* per group = 20)

| Group | Ceramic | Surface | Luting cement |
|---|---|---|---|
| A1CL | Alumina | Procera Crown (dry-pressed) | Clearfil Esthetic |
| A1RE | | | RelyX ARC |
| Z1CL | Zirconia | Procera Crown (dry-pressed) | Clearfil Esthetic |
| Z1RE | | | RelyX ARC |
| A2CL | Alumina | Procera Bridge (machined) | Clearfil Esthetic |
| A2RE | | | RelyX ARC |
| Z2CL | Zirconia | Procera Bridge (machined) | Clearfil Esthetic |
| Z2RE | | | RelyX ARC |
| A3CL | Alumina | Procera Bridge airborne-particle abraded $Al_2O_3$ 50 µm | Clearfil Esthetic |
| A2RE | | | RelyX ARC |
| Z3CL | Zirconia | Procera Bridge airborne-particle abraded $Al_2O_3$ 50 µm | Clearfil Esthetic |
| Z3RE | | | RelyX ARC |
| A4CL | Alumina | Procera Laminate (dry-pressed) | Clearfil Esthetic |
| A4RE | | | RelyX ARC |
| Z4CL | Zirconia | NobelBond 1 (modified) | Clearfil Esthetic |
| Z4RE | | | RelyX ARC |
| Z5CL | Zirconia | NobelBond 2 (modified) | Clearfil Esthetic |
| Z5RE | | | RelyX ARC |

Quattro IS, Renfert, Hilzingen, Germany) were used at a distance of 10 mm for 13 s.

The zirconium oxide ceramic specimens consisted of 40 specimens with the internal surface for crown copings (Z1; Procera Crown); 80 specimens with the internal surface for fixed partial denture frameworks (Z2; Procera Bridge), from which 40 specimens were used as delivered by the manufacturer and 40 were treated with airborne particle abrasion (Z3) as mentioned above. Another 80 specimens were delivered with a new modified, experimental surface (NobelBond, Nobel Biocare, Göteborg, Sweden). The modified surface was delivered in two different configurations. Forty of the samples had deep microporosities (Z5), the other 40 had shallower microporosities (Z4).

Every group of 40 specimens was divided into two sets of 20 specimens each to be cemented to composite cylinders with two different cements. Following the bonding procedure, each set was further divided into two subgroups with 10 specimens to be tested for shear bond strength before and 10 to be tested after thermal cycling and 90 d of water storage.

Before bonding, all specimens were cleaned with 96% isopropyl alcohol for 3 min in an ultrasonic bath (PC3; L&R Ultrasonic, Kearny, NJ, USA). Then composite resin cylinders (TPH3 Micro matrix Restorative; Dentsply/Caulk, Milford, Del., USA) with a diameter of 3 mm and a height of 2.9 mm were bonded to the ceramic disks using two different dual curing resin luting cements in combination with their corresponding silane/ceramic primers (CL–Clearfil Esthetic and Clearfil porcelain bond activator, Kuraray, Tokyo, Japan; RE – RelyX ARC and RelyX Ceramic Primer, 3M ESPE, St. Paul, Minn., USA). The assigned luting cement for each group is given in Table I. Characteristics and composition of used luting cements and silanes are shown in Table II. All luting cement systems were mixed and applied according to the manufacturer's recommendations. After placing the specimens in a custom-made alignment device (Technical Department, Case Western Reserve University), they were loaded with a weight of 1000 g. Excess resin cement was removed and the specimens finally were light-polymerized from 4 sides for a total of 160 s (Elipar 2500 Halogen Curing Light; 3M ESPE, St. Paul, Minn., USA).

Ten specimens from each group were tested after 3 d storage in distilled water for (early) shear bond strength. The remaining 10 specimens per group were tested after 90 d storage in distilled water and artificial aging by thermal cycling with 20,000 cycles at 5°C and 60°C with 15 s dwell time and 7 s transfer time (late shear bond strength).

Shear bond strength was determined using a universal testing machine (model 1125; Instron Corp, Norwood, Mass., USA) at a crosshead speed of 1 mm/min. Mode of failure (cohesive in composite, cohesive in cement, cohesive in ceramic, adhesive at ceramic/cement interface, or adhesive at cement/composite interface) was assessed with a stereo microscope (Wild M7; Wild Herrbrugg AG, Heerbrugg, Switzerland) at ×60 to ×200 magnification. Representative specimens of each group were selected for scanning electron microscopic analysis (xT Nova Nanolab 200; FEI Company, Hillsboro, Oreg., USA).

Statistical analysis of the obtained data was performed with non-parametric tests (Kruskal-Wallis and Mann-Whitney) due to missing homogeneity of variance of the data using the software SPSS (version 16.0, SPSS Inc., Chicago, Ill., USA). Because of multiple comparisons, the alpha-level was adjusted to $\alpha = 0.001$ using the Bonferroni adjustment.

## Results

Shear bond strength values are illustrated in Figure 1. For statistical analysis, an ANOVA model was not supported because homogeneity of variance was not met (Levene's test $p < 0.05$). Therefore, non-parametric models were used. Mean shear bond strength of the non-thermal cycled and thermal cycled samples was compared across the two

Table II. Characteristics and composition of used luting cements and silanes

| Luting cement | Type | Component/batch | Main composition* | Manufacturer |
|---|---|---|---|---|
| Clearfil Esthetic | Dual-polymerizing resin cement | Base/Catalyst 0002AA 2008-10 | Bis-GMA, TEGDMA, DMA, silica, Ba-Si glass, CQ, initiators, accelerators, pigments | Kuraray, Tokyo, Japan |
| Clearfil Ceramic Primer | Silane | 00002B 2008-10, 00003A 2008-10 | Ethanol, 3-trimethoxysilylpropyl methacrylate, 10-Methacryloyloxydecyl-dihydrogen-phosphate | Kuraray, Tokyo, Japan |
| RelyX ARC | Dual-polymerizing resin cement | Base/catalyst FAGH 2008-07, FKGW 2009-05 | Bis-GMA, TEGDMA, zirconia/silica filler | 3M ESPE, St. Paul, Minn., USA |
| RelyX Ceramic Primer | Silane | GXM 2009-08 | Ethyl alcohol, Water, 3-Methacryloyloxypropyltrimethoxy-silane | 3M ESPE, St. Paul, Minn., USA |

Bis-GMA: Bisphenol-A-Glycidylmethacrylate; DMA: aliphatic dimethacrlylate; CQ: Camphorquinone.
*According to information provided by manufacturers.

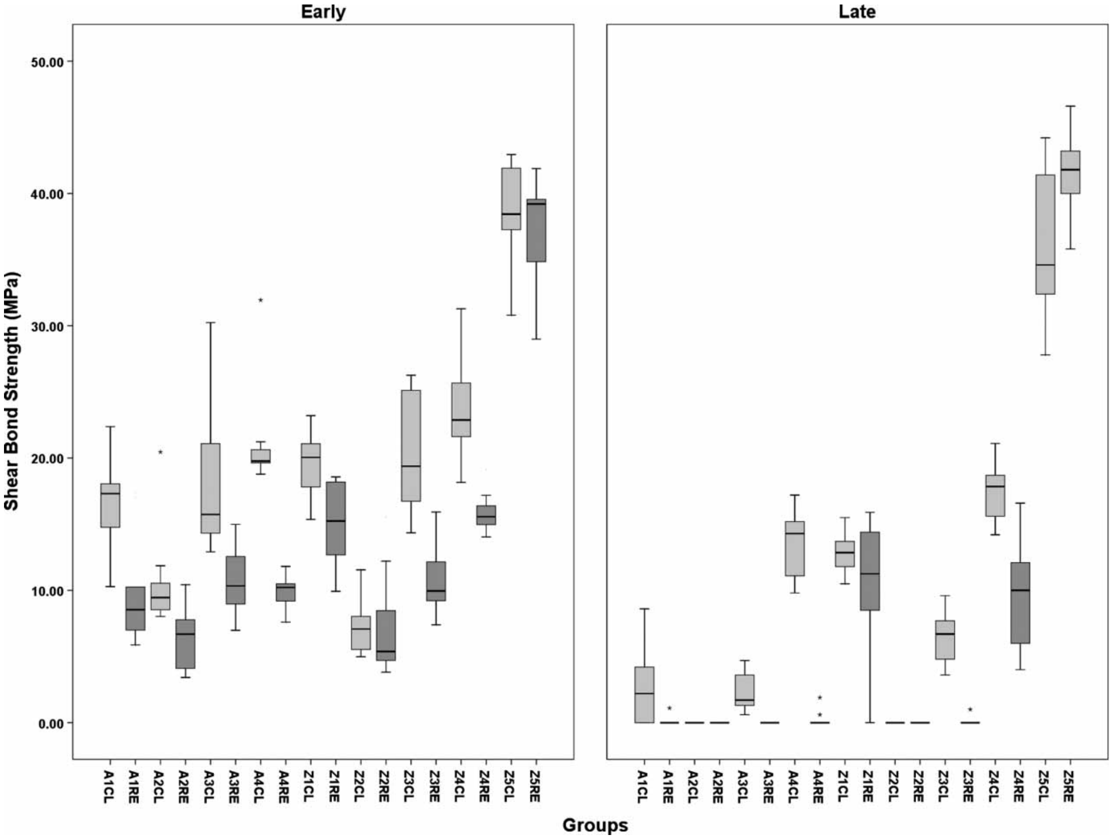

Figure 1. Boxplots of shear bond strength in MPa.

ceramics, using two types of cements bonded to six different surfaces, and the data analyzed with Kruskal-Wallis tests. For paired comparisons, Mann-Whitney tests were used with a corrected level of significance of $\alpha = 0.001$ using Bonferroni adjustment. A total of 50 comparisons were made.

Before thermal cycling (Figure 1), shear bond strength values ranged from 6.4 to 38.4 MPa. Among the aluminum oxide ceramic specimens, A4CL achieved the highest (21.1 MPa) and A2RE the lowest (6.4 MPa) values. For zirconium oxide ceramic specimens, Z5CL showed the highest shear bond strength value at 38.4 MPa and Z2RE the lowest value at 7.1 MPa.

Late bond strength values after water storage and thermal cycling (Figure 1) ranged from 0 MPa to 41.4 MPa. For alumina specimens, A4CL showed the highest value (13.8 MPa), whereas A2CL, A2RE, and A3RE failed with 0 MPA, because all specimens debonded spontaneously before testing. Zirconium oxide ceramic specimens in groups Z5CL and Z5RE exhibited 35.6/41.4 MPa shear bond strength; machined zirconia specimens (Z2CL and Z2RE) also debonded before testing, resulting in 0 MPa shear bond strength.

The main effects of cements, thermal cycling, surfaces and ceramic were significant ($p < 0.001$) according to Kruskal-Wallis tests.

*Cements:* Shear bond strength values for Clearfil Esthetic were higher ($p < 0.001$) than for RelyX ARC in groups with airborne particle abraded alumina (A3) and zirconia (Z3) surfaces and in groups with the Procera laminate surface (A4). In all other groups, both cements performed similarly.

*Aging:* Artificial aging with thermal cycling and water storage reduced shear bond strength for all groups ($p < 0.001$) except Z1, Z4, and Z5 ($p > 0.001$).

*Surfaces:* Among all surfaces, the modified surface Z5 achieved higher shear bond strength ($p < 0.001$). The modified surface Z4 was similar to the A4 surface ($p = 0.002$) in shear bond strength, but higher than the remaining three surfaces ($p < 0.001$). The A4 surface was comparable to A3/Z3 ($p = 0.067$) and A1/Z1 ($p = 0.962$). A1/Z1 also were similar in shear bond strength to A3/Z3 ($p = 0.019$). Machined surfaces (A2/Z2) had lower shear bond strength values ($p < 0.001$) compared to all other surfaces. If the surfaces were analyzed for each high-strength ceramic separately, alumina surface A4 achieved the highest and A2 the lowest values ($p < 0.001$). Values for A1 and A3 were within range of the A4 surface values ($p > 0.001$). For zirconia surfaces, Z5 achieved the highest

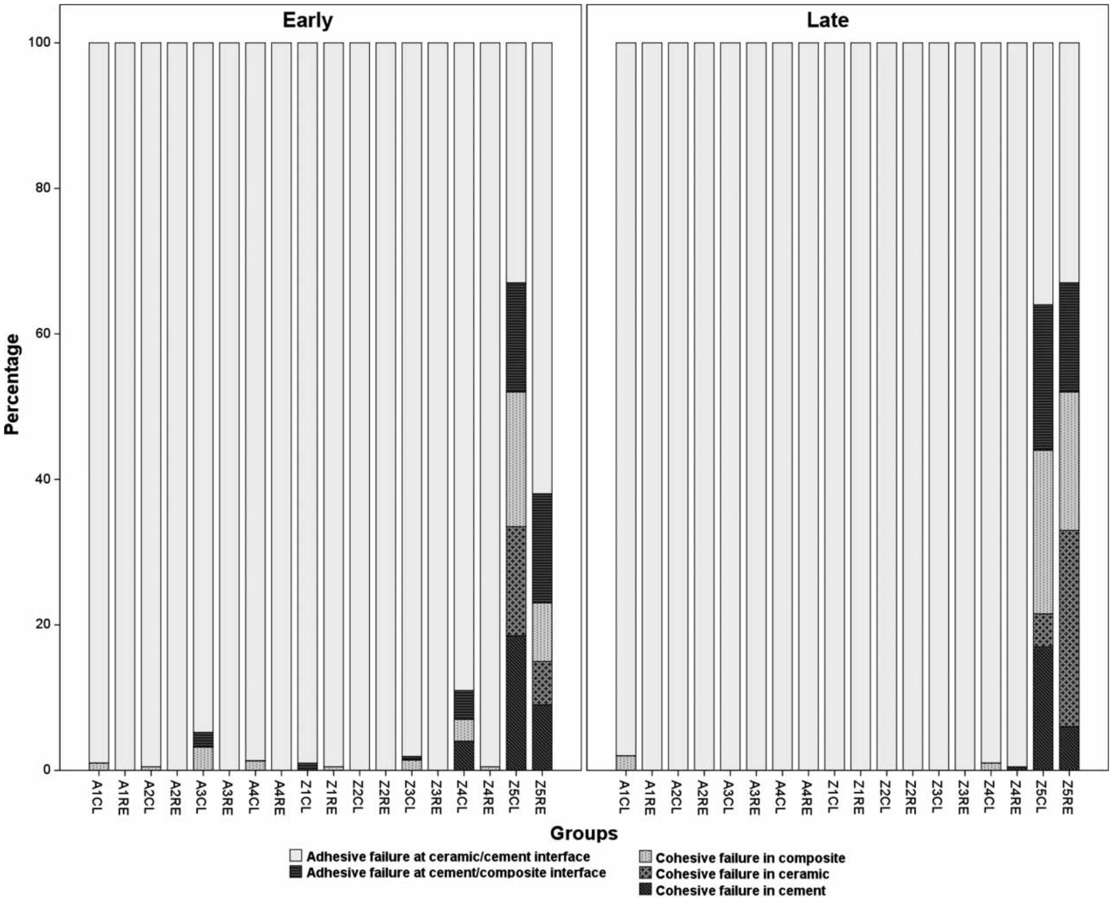

Figure 2. Modes of failure.

values, which were higher than for all other zirconia surfaces ($p < 0.001$). Z4 was higher than Z2 and Z3 ($P < 0.001$), but similar to Z1 in shear bond strength ($p = 0.065$).

*Ceramics:* Comparison of both high strength ceramics alumina and zirconia against each other for the surfaces dry-pressed, machined, and airborne particle abraded surface together showed that both materials achieved similar results in shear bond strength ($p = 0.005$). If both ceramic materials are separately compared for each surface, alumina and zirconia are similar in shear bond strength for the machined (A2/Z2; $p = 0.611$) and airborne particle surfaces (A3/Z3; $p = 0.453$). But for the dry-pressed surface, zirconia (Z1) achieved higher values than alumina (A1; $p < 0.001$). However, if the surfaces A4, Z4, and Z5 were included in the analysis, zirconia showed higher bond strength values than alumina ($p < 0.001$).

*Failure mode:* Modes of failures are shown in Figure 2.

The ultra structural analysis revealed significant differences on the ceramic surfaces (Figure 3 and 4). Machined alumina (A1; Figure 3a) and zirconia (Z1; Figure 4a) surfaces were characterized by regularly and evenly distributed crystal grains. The main difference was found on the size of the crystal grains. The mean crystal grains area for machined alumina was 15.53 $\mu m^2$ and 0.75 $\mu m^2$ for machined zirconia. In addition, alumina crystal grains were slightly rougher than those of the zirconia ones. After airborne particle abrasion, the crystals grains were no longer discernible for both alumina (A3; Figure 3c) and zirconia specimens (Z3; Figure 4c). Both air-abraded alumina and zirconia displayed comparable surfaces, displaying a significant increase of roughness and surface area. However, after air abrasion some crystal grains were removed from the alumina surface, being a deleterious potential for crack initiation. On alumina and zirconia crown copings (A2 and Z2) the crystal grains were consistently distributed (Figure 3b and 4b); however, both surfaces were considerably more irregular than those of the machined surfaces. An increased surface area was more evident for zirconia coping (Z2; Figure 4b). Alumina laminate (A4) displayed minor microporosities, ranging from 0.3 to 6.0 μm extension and 1.0 to 4.1 μm depth (Figure 3d). Both modified zirconia surfaces (Z4, Z5) exhibited abundant, intricate microporosities (Figure 4d and 4e). Z4 had intense non-symmetric microporosities ranging from 1.6 to 26.2 μm extension and 7.3 to 10.4 μm depth (Figure 4d). Z5 displayed even

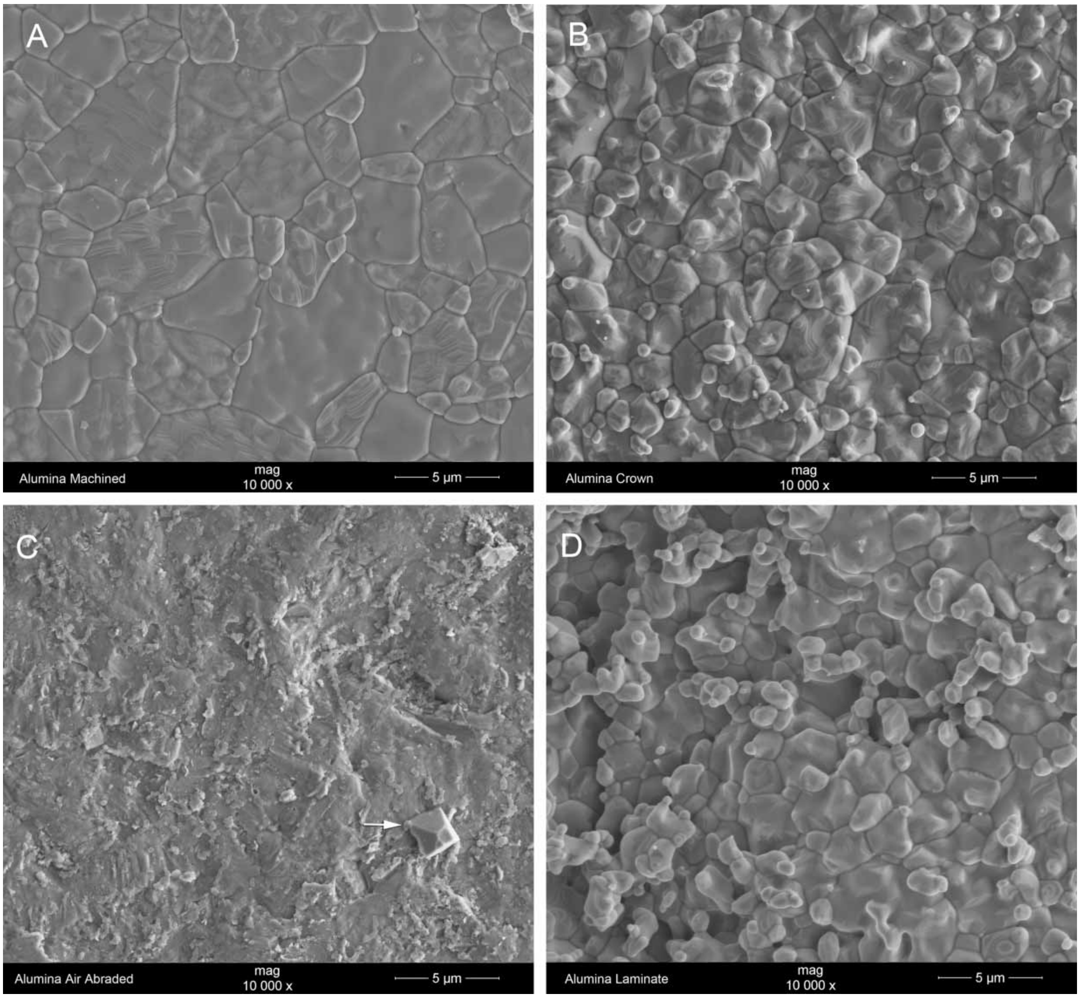

Figure 3. Fe-SEM micrograph of alumina surfaces at magnification ×10,000. A. Procera Bridge – A2; B. Procera Crown – A1; C. Procera Bridge airborne particle abraded – A3; white arrow: aluminum-oxide particle left after sandblasting; D. Procera Laminate – A4.

more reticular microporosities ranging from 27.3 to 69.9 μm extension and 19.9 to 46.9 μm depth (Figure 4e). Figure 4f shows the penetration of the resin cement into the microporosities of the modified surface Z4 (Nobel Bond 1). For both modified zirconia surfaces the resin cement filled the microporosities, resulting in micromechanical interlocking and cohesive failure of the cement. However, Z5 (not shown) revealed deeper penetration of the resin cement due to the deeper microporosities than that observed for Z4.

## Discussion

The proposed hypothesis, that shear bond strength for all surfaces is different, was accepted. The remaining three hypotheses were partially rejected.

In this investigation, two dual-curing resin cements were used. The RelyX ARC (3M ESPE) is a conventional Bis-GMA cement, which has a flexural strength of 163 ± 16 MPa [23]. In combination with the RelyX Ceramic Primer, which contains the silane 3-methacryloyloxy-propyltrimethoxysilane, it allows bonding to silica-based ceramics, but does not provide a stable long-term bond strength to high strength ceramics [2,6–9]. Clearfil Esthetic is a Bis-GMA resin cement and has a flexural strength of 167.9 ± 5.5 MPa [5] and is designed to bond to silica-based ceramics and to non-silica-based high-strength ceramics such as alumina and zirconia. But unlike other MDP-containing resin cements from the same manufacturer (Panavia F2.0, Panavia 21; Kuraray, Tokyo, Japan), the cement paste of the Clearfil Esthetic is a Bis-GMA resin cement, which does not contain the MDP itself, but does in the ceramic primer, which also contains the silane 3-trimethoxysilylpropyl methacrylate for bonding to silica-based ceramics. Sadan et al. [3] and Blatz et al. [2] showed that regular Bis-GMA resin cements improve in bond strength to alumina and zirconia if they are combined with a MDP containing silane. The Clearfil Esthetic exhibited good long-term bond strength to silica-based and non-silica based ceramics [4,5]. However, long-term bond strength to silica-based ceramics has not been tested in this present study. By relying more on micromechanical retention, rather than on the assumed chemical bond by MDP monomers, even the use of a regular

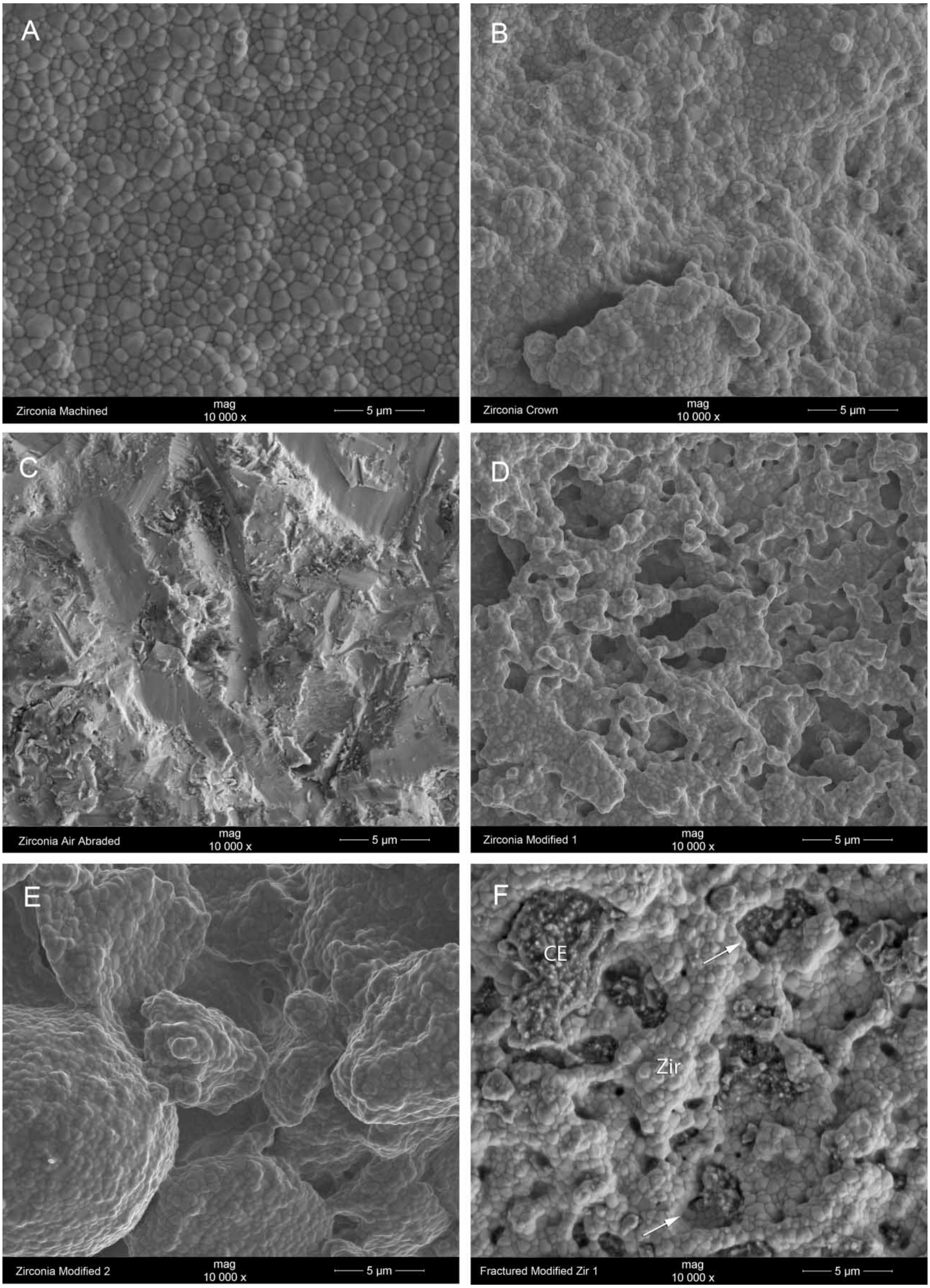

Figure 4. Fe-SEM micrograph of zirconia surfaces at magnification ×10,000. A. Procera Bridge – Z2; B. Procera Crown – Z2; C. Procera Bridge airborne particle abraded – Z3; D. Modified surface 1 – Z4; E. Modified surface 2 – Z5; F. Modified zirconia surface 1 (Z4) bonded with Clearfil Esthetic after fracture (Zir: modified zirconia surface; CE: resin cement Clearfil Esthetic; white arrows: microporosities filled with cement).

Bis-GMA resin cement without MDP seemed to be successful in this study. Similar results were found in a previous study in which all three used resin cement systems (Panavia F2.0, RelyX ARC, RelyX Unicem) performed comparably in shear bond strength to the modified surface, regardless of their chemistry [22].

Commercial all-ceramic systems vary in their physical and esthetic properties due to their different methods of fabrication, composition, and sintering conditions. These parameters also determine the inherent, system-specific internal surface, which may have an influence on the micromechanical retention of bonding and luting agents [1,2,10,12,13]. In the present study, different system-specific internal surfaces for two different high-strength ceramics were compared against each other. The results showed that shear bond strength differed significantly between the six different surfaces. Surfaces with more roughness or presenting microporosities achieved higher shear bond strength values than surfaces with less roughness. None of the specimens with smooth machined surfaces (A2/Z2) survived the water storage and thermal cycling. Due to the microporosities, the modified surfaces (Z4 and Z5) can provide more mechanical interlocking for micromechanical retention than the other tested surfaces [13,20,22]. As seen in Figure 4f, the resin cement is locked in the microporosities of the modified surface. In a previous study evaluating shear bond strength to the modified surface, it was shown that this surface provides higher shear bond strength than machined or with 50 or 110 μm aluminum oxide particles abraded zirconia surfaces [22]. The role of the microporosities in increasing micromechanical retention could be shown in the same study by airborne particle abrasion of the modified surface that effaced the rough surface and decreased shear bond strength significantly [22]. Other internal surfaces with inherent, system-specific surface irregularities and microporosities are the dry-pressed Procera Crown [13] and Procera Laminate surfaces. The SEM micrographs clearly show the differences in surface texture among different surfaces. Whereas airborne particle abrasion makes the machined surface rougher, the air-abraded surface is still smoother than the dry-pressed surfaces A1, Z1, or A4. Derand [13] showed that surface roughness of the internal surfaces of Procera alumina and zirconia crown copings was higher with 0.95 and 2.31 μm than the surface roughness of the same Procera alumina (0.07 μm) and zirconia (0.32 μm) surfaces after airborne particle abrasion. In the same study, no difference in pull-out bond strength between the alumina and zirconia crown coping surface compared to airborne particle abraded surfaces was found, if bonded with Panavia 21, supporting the findings of this study. But if the zirconia crown copings were cemented with zinc phosphate cement, pull-out bond strength decreased significantly in groups with airborne particle abraded surfaces. Airborne particle abrasion seemed to smoothen the structured surface [13].

Nonetheless, airborne particle abrasion has an important role in increasing bond strength to machined alumina and zirconia surfaces. If applied to a smooth-machined surface, the subtractive surface treatment results in a limited increase in surface area and roughness, which provides more micromechanical retention [1,2,6–12,15,16,24–27]. But in the present study the gain in micromechanical retention and bond strength was not as high as that provided by the modified surface.

The two high-strength ceramics alumina and zirconia were similar in shear bond strength if compared against each other for the machined and airborne particle abraded surfaces. For the Procera Crown surface, zirconia was higher than alumina, a result also found by Derand et al. [13], probably due to the greater roughness of the zirconia coping surface compared to the alumina coping surface.

In order to include clinically relevant parameters to identify superior bonding methods and materials, simulated aging of the resin bond to alumina and zirconia has been used [2,6–9,11,12,15–17,27]. In the mouth, water and repeated thermal changes continually degrade and hydrolyze the ceramic/composite-resin interface [28,29]. For this purpose, long-term water storage and thermal cycling are accepted methods [2,6,7,11,12,16,17,27]. Long-term thermal cycling has a much higher impact on the resin bond strength to high strength ceramic than long-term water storage at a constant temperature [17]. In the aforementioned studies, shear bond strength was also tested before artificial aging and showed a significant decrease after water storage and thermal cycling. In the present study, decreased shear bond strength due to thermal cycling was also observed, except for specimens with the Procera Crown zirconia surface (Z1) and the modified surfaces (Z4 and Z5), which is consistent with data from a previous study in which shear bond strength to the modified surface did not decrease after aging [22].

Selection of materials and recommendations for resin bonding systems to ceramics are based on mechanical laboratory testing. The methods vary and include tensile, microtensile, shear bond strength, or pull out tests. Shear bond strength testing was chosen for this study because it is a commonly used method and has proved to be reliable in previous studies [2,3,12,13,24]. But this method has been discussed because non-uniform interfacial stresses might cause cohesive failures in the bonded substrate that may result in misinterpretation of the resultant data [7,30]. The presence of stress concentrations near the loading site reduces the calculated shear bond strength below the true failure stress levels [31–33]. Also variations in design or preparation, e.g. existing defects, introduced during the bonding procedure could affect the data [32]. By bonding composite cylinders to the adhesive resin cement, some of the failures might occur at the composite/cement interface rather than at the ceramic/cement interface. But, in the present study, mainly adhesive failures were found with minimal to no failures at the composite/cement interface or cohesive failures in the composite cylinders/ceramic, except for group Z5, indicating the validity of the applied testing method.

Our results show that the MDP containing resin cement system Clearfil Esthetic and the conventional Bis-GMA resin cement RelyX perform similarly on surfaces that provide more micromechanical retention, i.e. a modified surface that maximizes roughness. More critical than the chemistry of the cements is the surface texture of the internal surfaces. Shear bond strength to alumina and zirconia increases with surface roughness.

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