1. Introduction

Zirconia is widely used in prosthodontics, with zirconia-based restorations being more often used than porcelain fused to metal in 2016 in the United States [1], and the market is expanding significantly with new generations of high-translucency zirconia materials to produce monolithic restorations, notably chairside. Three generations of zirconia materials can be distinguished as a function of their composition, particularly in terms of yttrium oxide content, which significantly influences material microstructure and properties. The first generation of zirconia materials, known as 3Y-TZP (3 mol% yttria-stabilized tetragonal zirconia), contains 3 mol% yttria, with less than 15% cubic phase in addition to 0.25 wt% alumina and is characterized by high strength and toughness (flexural strength: 900 - 1500 MPa, toughness: 3.5 - 4.5 MPa.m^1/2). Due to its high opacity, first-generation zirconia is used as a framework, which is veneered to produce crowns and fixed partial dentures [2]. However, such prostheses can encounter failures related to fracture of the veneer layer, which constitutes the weak link of the restoration [3-5]. Moreover, sufficient tooth structure must be removed to accommodate the veneer thickness [2]. In an attempt to overcome problems associated with bilayered ceramic restorations, a second generation of zirconia materials ("translucent" zirconia), which can be used to perform monolithic restorations, was introduced. These materials exhibit a reduced alumina content and/or are sintered at a higher temperature to reduce the porosity and increase the grain size, consequently improving the overall translucency. However, they do not achieve the required esthetic outcome to be used as anterior restorations, and their use...
is limited to posterior regions [2,6]. Further modifications in structure led to the development of third-generation zirconia materials (“high translucent” zirconia) in 2015. They are formed of 4 mol % and 5 mol % yttria to produce partially stabilized monolithic zirconia restorations (4Y-PSZ and 5Y-PSZ, respectively) and are characterized by an increase in the cubic phase (>25% for 4Y-PSZ and >50% for 5Y-PSZ), which imparts high translucency to the material. Third-generation zirconia materials can be used in the anterior region; however, this increase in translucency arises at significant expense of the mechanical properties (flexural strength: 600 - 1000 and 500 - 900 MPa, toughness: 2.5-3.5 and 2.2-2.7 MPa.m1/2 for 4Y-PSZ and 5Y-PSZ, respectively) [2]. Currently, speed firing procedures (1500-1600°C for ~30 min) have been developed to use these materials for chairside work, which is in line with the economic trend, but the influence of this process on material properties needs to be studied [7].

A main disadvantage of zirconia materials is their bonding properties, which are reputed to be inferior to glass-ceramics. Different studies have been implemented to evaluate the most suitable pre-treatment method for the bonding of composite cements with 3Y-TZP zirconia. Bond strength values after airborne-particle abrasion with Al2O3 or tribochemical coating with silica particles were shown to be higher than after etching, and airborne-particle abrasion was the common recommended procedure [8-10].

Although conventional and resin-modified glass-ionomer cement are indicated for cementation of zirconia restorations, they result in lower bond strength values than composite cements [11-15]. This is reputed to be due to a lack of chemical adhesion, which is supposed to be the main contributor to bond strength with zirconia. On the other hand, many composite cements contain organophosphate functional monomers, such as 10-methacryloyloxydecyl dihydrogen phosphate (MDP), which promote bonding to zirconia by forming chemical bonds with the metal oxide. The phosphate-ester group in MDP forms a strong P-O-Zr covalent bond at the zirconia surface, while the other end contains a vinyl terminal group that copolymerizes with the resin, resulting in a strong hydrophobic bond with composite cements [16-20].

However, currently, the data available for the bonding performance of translucent (second-generation) and high-translucent (third-generation) zirconia are limited. Some studies have reported that the bond strength values (shear or microtensile) of first-generation zirconia to MDP-containing cements are similar to those obtained with second- and third-generation zirconia [21-23]. On the other hand, recent studies have highlighted the importance of airborne-particle abrasion with Al2O3 particles and applying MDP-containing primers to influence the bond strength of third-generation zirconia with composite cements [24,25].

In vitro studies evaluating the bonding performance of composite cements and glass-ionomer cements with zirconia materials have been mostly performed using the shear bond strength test [26], which is known for its simplicity, while some other studies have utilized tensile or microtensile bond strength tests [8-10]. However, the shear bond strength test suffers from many drawbacks related mainly to cohesive failures of the substrates, which do not give an accurate indication of the bond strength [27,28]. Recently, there has been increasing interest in fracture mechanics to evaluate the interfacial fracture toughness (Kic) of the adhesive interface [28-33]. Several modifications of Kic have been introduced for use with dental materials, such as single-edge notched beam, simple edge pre-cracked beam, surface crack in flexure, and chevron notch short rod or beam test, which can be used to evaluate the properties of the interface by stably initiating a crack and measuring its resistance to propagation in a peeling manner [34-37]. The notchless triangular prism (NTP) test is a modification of the chevron notch rod test [32,33] introduced by Ruse et al. [38]. It is known for its simplicity [31] for evaluating the fracture toughness of materials and the fracture toughness of bonded interfaces [38,39], and it has been recently used to evaluate the interfacial fracture toughness (IFT) of composite cements with different CAD-CAM composites and ceramic materials [40-42].

Consequently, the objective of the present study was to use the NTP test to compare, at mouth temperature, the IFT of two composite cements containing functional monomers (MDP), Panavia V5 (self-etch composite cement) + Primer and Panavia Self Adhesive Cement Plus (Kuraray Noritake, Tokyo, Japan), and a resin-modified glass-ionomer cement (RMGIC) GC Fuji Plus Capsule (GC Corporation, Tokyo, Japan), with Katana Zirconia CEREC CAD-CAM blocks (Kuraray Noritake) for chairside restorations after airborne-particle abrasion (AB) with 50 µm Al2O3 particles at 0.5 bar and 2.5 bar and upon thermocycling aging. The null hypothesis is that there is no difference in IFT between the different cements used and that increasing AB pressure has no effect on IFT.

2. Materials and Methods

2.1. Preparation of samples

All the materials used in this study and their compositions are listed in Table 1.

2.1.1. Prism manufacturing (Fig. 1)

Third-generation Katana Zirconia was provided as pre-sintered CAD-CAM blocks (12Z/STML Multilayered) (Kuraray Noritake, Tokyo, Japan) with dimensions of 20.2 x 15.4 x 19.2 mm. The blocks were cut with a low-speed saw (Isomet, Buehler, Lake Bluff, IL, USA) under continuous water irrigation at an angle of 60° to produce prism-shaped samples (4 samples per block). The samples were then ground using 220-grit silicon carbide (SiC) paper at 150 rpm under water cooling (Struers, Ballerup, Denmark) using a custom-built specimen holder to produce 20.0 (±0.1) mm long triangular prisms with a side width of 8 (±0.1) mm. The samples were manufactured with large dimensions to compensate for shrinkage after sintering. All the prisms were then split into two pieces, and the bonding surfaces were polished with 1000-grit SiC paper under water cooling to obtain 8.0 (±0.1) mm long half-prisms.

2.1.2. Sintering of prisms

Sintering was performed following the manufacturer’s recommendations by heating from room temperature to 1550°C at a rate of 10°C/min, holding the temperature for 2 hrs, and then cooling at the same rate until room temperature (Zyrcomat furnace, Vita Zahndfabrik, BadSäckingen, Germany).

2.1.3. Surface pretreatment

Following sintering, the desired equilateral half-prisms with dimensions of 6.0 (±0.1) mm were ultrasonically cleaned in ethanol for 3 min and then dried with oil-free air for 10 s prior to AB. Samples were then split into 2 groups, and each group comprised 30 samples.
and 60 half-prisms. The first group was subjected to AB at 0.5 bar, and the second group was subjected to AB at 2.5 bar. AB was performed using 50 µm Al₂O₃ particles (Danville, Zürich, Switzerland) for 5 s in a perpendicular direction at a distance of 1 cm from the sample. Samples were then ultrasonically cleaned in ethanol for 3 min following AB and air-dried.

2.1.4. Bonding of prisms

Each of the two groups was then further divided into three sub-groups (n=10) according to the bonding system: 1) Panavia V5 (self-etch composite cement) + Clearfil Ceramic Primer Plus (Kuraray Noritake) (V5); 2) Panavia Self Adhesive Cement Plus (Kuraray Noritake) (SA) and 3) GC Fuji Plus Capsule RMGIC (GC Corporation, Tokyo, Japan).

Half-prisms were fixed with a custom-made metallic fixation system onto a computer-controlled (SMC 100, Newport Corporation, California, USA) motorized alignment system (Newport Motion Controller), which controls the space between samples during bonding, therefore controlling the cement thickness at a precision of 0.1 µm. All products were used following the manufacturers’ recommendations. For V5, a thin layer of primer was applied on the bonding surface using a plastic brush, left for 60 s, and then dried with a gentle stream of air for 10 s. Afterwards, cement was applied onto each of the pretreated surfaces using a plastic spatula. For SA, the cement was applied directly with no primer. RMGIC was applied following the manufacturer’s recommendations. Capsules were mixed for 10 s and applied using a special capsule applicator (GC Corporation) without further light curing. Prisms were placed in contact with each other, and the cement thickness was set at 50 µm. For the composite
cements, high-power (1200 mW/cm²) light applications were performed for each of the three sides of the prisms at close proximity for 20 s (Bluephase 20i; Ivoclar Vivadent; Schaan, Liechtenstein), and, to ensure optimal curing, an additional 40 s of curing was applied at a distance of 2 mm for each side after removal from the alignment apparatus.

2.1.5. Aging

The samples were left in water for 24 hr at 36°C and 90% humidity (VCN 100, Vötsch Industrietechnik GmbH, Balingen, Germany), after which they were polished to remove the excess composite cement using 1000-grit SiC and then submitted to thermocycling for 10,000 cycles at 5-55°C, with a dwelling time of 30 s in each bath [43].

2.2. Interfacial fracture toughness testing

Evaluation of the IFT was performed using the NTP test following the procedure described by Ruse et al. [38]. Samples were fixed into one half of a NTP specimen holder, and a crack initiation point (~0.1 mm) was made at the bonded interface using a sharp scalpel under a light microscope at a magnification of ×20. The samples were mounted onto a computer-controlled (Bluehill, Instron Canada, Burlington, ON) universal testing machine (Instron model 5565) within a water bath at 36°C after securing the other half of the specimen holder and tested at a cross-head speed of 0.05 mm/min. The strain values were recorded at failure arrest in tensile mode, and the meniscus holder and tested at a cross-head speed of 0.05 mm/min. The flexural strength, \( \sigma_f \), was calculated according to the following equation:

\[
\sigma_f = \frac{3FL}{2bh^2}
\]

where \( F \) is the load at fracture, \( L \) is the span, \( h \) is the specimen width, and \( c \) is the specimen height. For each sample, the \( h \) and \( c \) values were measured prior to testing using a digital caliper (Mitutoyo).

2.2.1. Evaluation of the IFT values (means and standard deviations) for the different composites, which were then tested for flexural strength using a 3-point bending device (span width of 15 mm), with the polished surface (surface previously in contact with the glass slab) in tension, using a computer-controlled (Bluehill; Instron) universal testing machine (Instron model 5565) within a water bath at 36°C after securing the other half of the specimen holder and tested at a cross-head speed of 0.05 mm/min. The strain values were recorded at failure arrest in tensile mode, and the meniscus holder and tested at a cross-head speed of 0.05 mm/min.

2.2.2. SEM fractography analysis

Two prisms from the two different composite groups were randomly selected for SEM fractography analysis.

2.7. Contact angle analysis

The same samples used for interface analysis were used to view the contact angle for the cements with the zirconia surface using a digital microscope (VHX-7000, Keyence, IL, USA). For each cement, eight angles were measured from two drops of the cement on the zirconia surfaces treated with AB at 0.5 bar and 2.5 bar.

2.8. Surface roughness

The same samples used for SEM surface characterization were used to detect the surface roughness of zirconia after AB at 0.5 bar and 2.5 bar. Five measurements were performed on each of the zirconia surfaces treated with AB at different positions to calculate the arithmetic mean height (Sa).

2.9. Statistical analysis

Statistical differences between IFT experimental groups were assessed using Instat software (GraphPad, California, USA). Parametric data were analyzed using 1-way ANOVA followed by Tukey’s multiple comparison test (α=0.05). For the flexural strength and surface roughness parameter (Sa), a t-test was used. Variations were considered to be statistically significant when the p value was < 0.05. The normality of the results distribution was assessed with the Kolmogorov-Smirnov test, and the power (1-β) was calculated to be 97.4%. Weibull distribution analysis was calculated for IFT data using the Weibull statistics option in Excel (Microsoft, USA). For contact angle measurements of the composite cements with zirconia surfaces, 1- and 2-way ANOVA were used followed by Tukey’s multiple comparison test (α=0.05).

3. Results

3.1. IFT

IFT values (means and standard deviations) for the different groups, along with the statistical analysis, are displayed in Figure 2.
and Table 2. The Weibull modulus is displayed in Table 2. All RMGIC samples de-bonded while thermocycling, and were, therefore, not included in the statistical analysis. SA (2.5 bar) showed a significantly higher IFT (1.65 MPa.m\(^{1/2}\) ± 0.40) compared to the other groups. The Weibull modulus of SA (2.5 bar) was higher than that of the three other groups, and the Weibull modulus of SA was generally higher than that of V5 (Table 2).

3.2. Flexural strength

The mean (± standard deviation) flexural strength values were 124.0 ± 9.4 and 118.7 ± 11.3 MPa for SA and V5, respectively. The results were not significantly different following the t-test (p< 0.05).

Table 2. Representative Means and Standard Deviations (SD) of the Interfacial Fracture Toughness (IFT) (n=10/group) and Weibull modulus of the groups tested

| Group         | Mean IFT ± SD (MPa.m\(^{1/2}\)) | Weibull modulus |
|---------------|----------------------------------|-----------------|
| V5 (0.5 bar)  | 1.0 ± 0.27 b                     | 4.03            |
| SA (0.5 bar)  | 1.08 ± 0.30 b                    | 4.29            |
| V5 (2.5 bar)  | 1.22 ± 0.36 b                    | 4.0             |
| SA (2.5 bar)  | 1.65 ± 0.40 a                    | 4.83            |
| RMGIC (0.5 bar)| 0                                | -               |
| RMGIC (2.5 bar)| 0                                | -               |

Statistical analysis was assessed for composite cement groups (V5 and SA). The same superscript letters indicate statistically homogeneous subgroups (1-way analysis of variance followed by Tukey’s test, α = 0.05). All the RMGIC samples de-bonded before performing the IFT tests, and were, therefore, given a zero value and not included in the statistical analysis. V5 is Panavia V5 + Primer; SA is Panavia Self Adhesive Cement Plus; RMGIC is Fuji Plus resin-modified glass ionomer cement. The numbers (0.5 and 2.5) correspond to the airborne-particle abrasion pressure with 50 µm Al\(_2\)O\(_3\).

3.3. SEM surface characterization

SEM characterization images of zirconia are displayed in Figures 3a and 3b. SEM characterization highlights the difference in microroughness created by increasing the AB pressure from 0.5 bar to 2.5 bar. For the Vita Mark II sample, an important surface microroughness was observed on the surface after etching (Fig. 3c).

3.4. SEM interface analysis

SEM interface analysis images are shown in Figure 4. Both composite cements penetrate efficiently into the created zirconia microroughness, whether the sample is treated with AB at 0.5 bar or 2.5 bar.
3.5. SEM fractography analysis

SEM fractography images (Figs. 5 and 6) highlighted typical adhesive patterns with both SA and V5 cements after performing the NTP test.

3.6. Contact angle analysis

The mean and standard deviations for the contact angle measurements are shown in Table 3, and the images are shown in Figure 7. The lowest values significantly (p<0.05) (indicating better wettability) were shown by V5 0.5 bar (54.9° ± 2.7), followed by V5 2.5

Table 3. Representative means and standard deviations (SD) of the measured contact angles, along with the statistical analysis (n=8/group)

| Group       | Mean Contact Angle ± SD (°) |
|-------------|-----------------------------|
| SA (0.5 bar)| 82.2 ± 3.8 a                |
| SA (2.5 bar)| 76.7 ± 2.5 b                |
| V5 (0.5 bar)| 54.9 ± 2.7 d                |
| V5 (2.5 bar)| 61.1 ± 2.9 c                |

The same superscript letters indicate statistically homogeneous subgroups (1-way analysis of variance followed by Tukey’s test, α = 0.05).
bar (61.1° ± 2.9), SA 2.5 bar (76.7° ± 2.5) and SA 0.5 bar (82.2° ± 3.8).

Two-way ANOVA revealed that the wettability of composite cements on zirconia was significantly influenced by 1) the type of cement (V5 or SA) and 2) the combined effect of cement and AB pressure. However, the effect of AB pressure alone did not significantly affect the wettability.

3.7. Surface roughness

The mean (± standard deviation) surface roughness (Sa) values were 0.24 ± 0.05 and 0.6 ± 0.0 for 0.5 MPa and 2.5 MPa, respectively. The results were significantly different following the t-test (p<0.0001).

4. Discussion

In view of the IFT results, the null hypothesis was rejected for bonding of V5 and SA after AB with 2.5 MPa Al2O3. Regarding the method used in the study, the NTP test was chosen because it is a simple fracture toughness measurement method [31] proven successful in evaluating adhesive interfaces in previous studies [40-42]; however, the initial cost of the materials is high, and the preparation of prisms is time-consuming. In the present study, the cement thickness was fixed at 50 µm for all samples using a custom-made motorized alignment system to provide close approximation to mouth conditions [44,45]. To further resemble mouth conditions and avoid any bias related to changes in temperature while testing, IFT testing was carried out in a water bath at 36°C. The type of surface pretreatment was the same for all groups (AB with 50 µm Al2O3 particles), while the pressure was changed. Indeed, increasing the AB pressure resulted in a significantly higher surface microroughness (Sa), which promotes the micromechanical bonding and increases the IFT, regardless of the type of cement. However, concerns regarding the negative influence on the flexural strength of zirconia on increasing the AB pressure have been raised before, and the recommended pressure that would not induce subsurface damage was found to be 2.5 bar [46]. It must be noted that the microroughness obtained after zirconia AB is not as important as that of etched glass-ceramic, which constitutes the gold standard (Fig. 3c). Thermocycling was performed following recent guidelines [43], in which 10,000 cycles correspond to approximately 1 year of aging in the oral cavity [47]. Indeed, aging has an important influence on the reliability of adhesive interfaces due to hydrolytic degradation of the bonding interface, as well as expansion and contraction of the materials [48].

Regarding the IFT results, all RMGIC samples failed during thermocycling, which indicates that RMGIC is not well adapted for bonding zirconia restorations compared to composite cement. In contrast, the highest bonding performance was achieved by SA at 2.5 bar, while the rest of the groups also performed very well with Katana Zirconia CAD-CAM blocks, and, as shown by SEM fractography (Figs. 5 and 6), all the samples failed in a typical adhesive pattern. At low AB pressure, both cements gave IFT values that were not significantly different. Moreover, the Weibull modulus of both composite cements was high, indicating high reliability for both cements (Table 2). SEM interface analysis (Fig. 4) showed effective penetration of the cements into the microroughness created at both 0.5 bar and 2.5 bar. Conversely, Aung et al. [24] showed no difference in tensile bond strength values between V5 and SA when used on Katana zirconia treated with AB at 2 bar after 150 days of water storage.

A previous study [40] also utilized the NTP test under the same conditions with IPS e.max CAD lithium disilicate glass-ceramic, etched with 5% hydrofluoric acid and bonded with Variolink Esthetic DC composite cement + primer. Variolink Esthetic DC (Ivoclar Vivadent, Schaan, Liechtenstein) is a dual-cure composite cement that does not contain MDP and is used on tooth tissues in combination with an etch and rinse adhesive. The mean Kic value was 1.31
MPa.m$^{1/2}$, while it was 1.22 MPa.m$^{1/2}$ and 1.65 MPa.m$^{1/2}$ for SA and VS bonded to Katana Zirconia respectively, after AB with 2.5 bar [40]. This comparison indicates that proper pretreatment and composite cement choice can lead to similar bonding performance for translucent zirconia compared to a glass-ceramic material, which constitutes a reference from this point of view. Variolink Esthetic DC was also used in another study to bond translucent zirconia treated with AB and etched IPS e.max Press to enamel. Zirconia showed higher shear bond strength values than IPS e.max Press; however, the samples were not subjected to aging to evaluate the long-term bonding effect [49].

Indeed, bond strength has two aspects: the micromechanical bond, which is related to the creation of surface roughness by etching or AB, and the chemical bond between the two materials, which can be improved by using specific primers. Both aspects complement each other. Certainly, the effect of micromechanical retention is considered an important contributor to bond strength with zirconia and cannot be neglected: it was shown that more roughness was created on Katana Zirconia’s surface by AB at a pressure of 2.5 bar (Fig. 3b) than 0.5 bar (Fig. 3a), and increasing the AB pressure increased the IFT for both composite cements, particularly SA. However, care must be taken not to induce damage to zirconia materials [50]. In fact, the adopted method for surface roughening in this study was determined following recent recommendations [51]. This involves using 30-50 µm alumina particles at a pressure of 0.5–2.5 bar and a distance of 1 cm to create a moderately rough surface without damage. The influence of zirconia generation on surface properties and then bonding performance can be discussed. Although it is difficult to obtain information about the material composition and microstructure from the company’s website, it can be supposed, with respect to its flexural strength (approximately 740 MPa according to the manufacturer), that the zirconia used to produce Katana Zirconia CEREC CAD-CAM blocks is 4Y-PSZ. Its higher cubic phase content compared to the first generation (and consequently lower metastability, which influences the response to AB) and the probable higher grain size could influence the surface properties. However, previous studies on bonding to zirconia did not show any difference between the first and third generations [21-23]. A study of translucent zirconia [52] evaluated the flexural strength and shear bond strength after applying different Al$_2$O$_3$ AB pressures ranging from 1 to 5 bar. The flexural strength decreased significantly after increasing the pressure to above 2 bar, creating cracks and defects at a pressure of 5 bar, as observed by SEM, while the highest shear bond strength values with a composite cement and MDP-containing primer were obtained at AB pressures ranging between 2 and 3 bar.

The observed differences in IFT values between groups cannot be explained by the respective intrinsic flexural strengths of the VS and SA cements, which are similar. Although AB at a pressure of 2.5 bar showed significantly higher roughness (Sa) than AB at a pressure of 0.5 bar, the SEM interface analysis (Fig. 4) indicates effective penetration of both cements into the microroughness created at both 0.5 bar and 2.5 bar of pressure. However, the measured contact angle values (Table 3 and Fig. 7), which could influence cement penetration in the microroughness and then micromechanical retention, are more in favor of VS, which gave lower IFT values than SA. Considering the results of the present study, one can hypothesize that the chemical composition of SA is more performant than VS and the related primer. Notably, having the silane incorporated within the cement paste could be more efficient in terms of chemical bonding than applying it separately. The chemical composition of SA includes two important contributors to the adhesive bond: 1) a long carbon-chain silane coupling agent, which is believed to form a chemical bond to the ceramic surface (porcelain and lithium disilicate) and the composite resin upon curing, and 2) conventional phosphate monomers (MDP) that bond to the zirconia and tooth surfaces. On the other hand, in the VS system, MDP is incorporated only in the primer. The suspected influence of the chemical composition of the cement could also explain the poor RMGIC results, which do not contain any coupling agents for zirconia. On the one hand, RMGIC contains polyacrylic acid for chemical bonding to the tooth structure, while, on the other hand, RMGIC does not contain agents such as MDP to enhance their bonding with zirconia. Zirconia treated with AB is coated with a metal oxide layer that binds chemically with the hydrophobic phosphate monomer of MDP, therefore enhancing the chemical bond and possibly acting as a barrier against the infiltration of water at the formed interface [16-20]. Therefore, the hypothesis is that the absence of chemical bonds between RMGIC and zirconia in addition to possible water penetration can lead to debonding during thermocycling.

Finally, the retention of a prosthesis to a tooth or an implant abutment, such as a titanium base or zirconia abutment, which was recently reported to be a cause of short-term failures with monolithic zirconia screw-retained implant restorations [53], does not rely only on the bonding properties of the material to the cement but also on the quality of the interface between the cement and the abutment. Therefore, the results of the present study are not sufficient to lead to clinical recommendations, most of all, knowing that the cement choice can vary as a function of various clinical parameters. However, the bonding properties of the material to the cement are critical in this choice, particularly in the context of translucent zirconia, since third-generation zirconia is recommended not only by manufacturers for full contour restorations but also for partially bonded restorations, such as veneers, onlays and Maryland bridges, which do not benefit from the same macromechanical retention.

5. Conclusion

Within the limitations of this study, the findings show that composite cements containing functional monomers (MDP) (Panavia SA Cement Plus and Panavia V5 + Primer) perform in an excellent manner with third-generation zirconia (Katana Zirconia) when treated with AB with 50 µm Al$_2$O$_3$ particles. When treated with AB at a pressure of 2.5 bar instead of 0.5 bar, the self-adhesive composite cement (Panavia SA Cement Plus) constituted the most performant approach. This type of cement is also simple to use since it does not require any pretreatment with a primer. However, although increasing the AB pressure increases the micromechanical retention and bonding performance, care must be taken to avoid any damage to the zirconia surface. Consequently, future research should be performed to analyze the influence of AB on zirconia material properties.

Conflicts of interest

The authors declare that they have no competing interests with respect to the authorship and/or publication of this article. This research was funded by Kuraray Noritake (Tokyo, Japan). The company had no authority and no impact on the decision to submit the report for publication.
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