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Impact of resin cement viscosity on bond strength to different zirconia ceramics after aging condition

Impacto da viscosidade do cimento resinoso na resistência de união a diferentes cerâmicas de zircônia após envelhecimento

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ABSTRACT

Objective: The current study examined how varying resin cement viscosities (high and low) impact the microshear bond strength (μSBS) of two distinct zirconia ceramics – 3Y-TZP and 4Y-PSZ– following an aging process. **Material and Methods:** Square zirconia samples were prepared and encased in PVC cylinders using acrylic resin, then sorted into four groups according to the resin cement viscosity (high or low) and zirconia type (3Y-TZP or 4Y-PSZ) factors. The ceramic surfaces were treated with air abrasion using 45 μm aluminum oxide particles, followed by the application of an MDP-containing primer agent. Starch tubes were filled with resin cement of differing viscosities. Subsequently, the resin cement cylinders (n = 20) underwent an aging process, which involved 12,000 cycles of thermocycling and storage for 120 days, followed by microshear bond strength testing. Statistical analysis was performed using two-way ANOVA and Tukey's post-hoc tests. **Results:** Neither the resin cement ($p = 0.42$) nor the type of ceramic ($p = 0.97$) significantly influenced the bond strength. Scanning electron microscopy analysis demonstrated similar surface topography for both ceramics after air abrasion. This resemblance was further confirmed by atomic force microscopy (AFM), showing similarities in topography and fractal dimension between the ceramics. Moreover, the predominant failure mode observed was adhesive. **Conclusion:** Within the present context, resin cement viscosity does not adversely affect the achievement of satisfactory bond strength values in the evaluated zirconia ceramics.

KEYWORDS

Aging; Composite resin; Ceramics; Dental adhesives; Shear strength.

RESUMO

Objetivo: O presente estudo avaliou como diferentes viscosidades de cimento resinoso (alta e baixa) afetam a resistência de união por microcisalhamento (μSBS) de duas cerâmicas de zircônia distintas – 3Y-TZP e 4Y-PSZ – após um processo de envelhecimento. **Material e Métodos:** Amostras quadradas de zircônia foram preparadas e fixadas em cilindros de PVC com resina acrílica, sendo divididas em quatro grupos de acordo com os fatores viscosidade do cimento resinoso (alta ou baixa) e tipo de zircônia (3Y-TZP ou 4Y-PSZ). As superfícies cerâmicas foram tratadas com jateamento com partículas de óxido de alumínio de 45 μm, seguida da aplicação de um agente primer contendo MDP. Tubos de amido foram preenchidos com cimento resinoso de diferentes viscosidades. Em seguida, os cilindros de cimento resinoso (n = 20) passaram por um processo de envelhecimento, que envolveu 12.000 ciclos de termociclagem e armazenamento por 120 dias, sendo posteriormente submetidos ao teste de resistência de união por microcisalhamento. A análise estatística foi realizada utilizando ANOVA de dois fatores e testes post hoc de Tukey. **Resultados:** Nem o cimento resinoso ($p = 0,42$) nem o tipo de cerâmica ($p = 0,97$) influenciaram significativamente a resistência de união. A análise por microscopia eletrônica de varredura demonstrou topografia superficial semelhante para ambas as cerâmicas após a jateamento, o que foi confirmado pela análise por microscopia de força atômica (MFA), que revelou similaridades na topografia e na dimensão fractal entre as cerâmicas. Além disso, o modo de falha predominante observado foi do tipo adesivo. **Conclusão:** Dentro do contexto do presente estudo, a viscosidade do cimento resinoso não compromete a obtenção de valores satisfatórios de resistência de união nas cerâmicas de zircônia avaliadas.

PALAVRAS-CHAVE

Envelhecimento; Resina composta; Cerâmicas; Adesivos dentários; Resistência aos cisalhamentos.

INTRODUCTION

Zirconia ceramics demonstrate exceptional biocompatibility with oral tissues and possess excellent mechanical strength owing to their polycrystalline structure and the process of transformation toughening [1,2]. This toughening mechanism involves the transition of zirconia grains from a tetragonal to monoclinic phase, which not only increases the grain size but also induces compressive stress around imperfections. As a result, this phenomenon significantly reinforces the material's ability to resist crack propagation when subjected to different environmental stimuli, whether chemical or mechanical [1,3].

Among zirconia variations, Yttria-Stabilized Tetragonal Zirconia Polycrystals containing 3 mol% yttrium oxides (3Y-TZP) stand out for their exceptional mechanical strength within the field of dental ceramics although characterized by significant opacity due to the inherent birefringence [2,4]. With increasing emphasis on dental aesthetics, there was a growing focus on improving the optical properties of zirconia ceramics. This quest has led to the development of a more translucent variant with higher yttrium oxide content (Y_2O_3) [1]. The Yttria-Partially Stabilized Zirconia with 4 mol% Y_2O_3 (4Y-PSZ) demonstrates heightened translucency owing to its increased Y_2O_3 content and a greater presence of the cubic phase, enabling superior light transmission compared to tetragonal phase grains [5]. However, despite 4Y-PSZ may undergo phase transformation after stimulus, it does not exhibit the same toughening mechanism found in 3Y-TZP [6]; nevertheless, it is still superior to vitreous ceramics in terms of mechanical strength [2].

Despite the mechanical advantages offered by these materials, a major challenge in clinical use is achieving reliable adhesion, as zirconia's crystalline structure makes it resistant to hydrofluoric acid etching [7-9]. This hinders chemical bonding, and debonding remains a leading cause of failure. Air abrasion with aluminum oxide particles is the standard method to improve mechanical retention by creating surface irregularities [10]. However, the influence of resin cement viscosity on adhesion among different types of zirconia ceramics has not been fully explored, considering the subtle structural alterations mentioned previously.

The resin cement can penetrate surface defects caused by air abrasion treatment sealing them [11], enhancing retention, and still reinforcing the marginal adaptation of the restoration [12,13]. Moreover, Marshall et al., proposed that one of the key principles of adhesion is the proper viscosity of the resin cement, as it can impact the wettability of ceramic surfaces, consequently influencing adhesion [14,15]. However, the viscosity is subject to modification through different industrial methods. These include changing the proportion of the resin matrix [16], employing different compositions [17], or varying inorganic filler sizes and morphologies [18]. These modifications are significant as they can affect the cement's ability to infiltrate surface irregularities. According to Aguiar et al., low-viscosity resin cement more easily infiltrates surface irregularities in restorations, potentially contributing to increased zirconia bond strength [19]. On the other hand, high-viscosity resin cements demonstrate reduced susceptibility to sorption and solubility due to lower organic content compared to low-viscosity equivalents, thereby prolonging their adhesive performance within the oral cavity [20]. However, despite the advancements in resin cement formulations, there remains a gap in understanding the specific impact of viscosity on the adhesion of polycrystalline ceramics. This gap in knowledge underscores the need for further research to elucidate how variations in resin cement viscosity influence the degree of infiltration and mechanical interlocking on the treated surface of zirconia.

Additionally, resin cements may degrade in moist environments [20], making it important to evaluate their performance after aging. Thermocycling is a relevant method to simulate this degradation [21,22]. Differences in thermal expansion between the ceramic, cement, and substrate can lead to interfacial stresses and potential failures [22,23].

Therefore, this study aimed to assess the impact of resin cement viscosities on two zirconia types (3Y-TZP and 4Y-PSZ) concerning microshear bond strength (μSBS) following the aging process. The hypotheses were: (1) low-viscosity resin cement will yield higher bond strength values compared to high-viscosity resin cement, and (2) the bond strength values will exhibit similarities between 3Y-TZP and 4Y-PSZ.

MATERIAL AND METHODS

The description of the materials employed in the current study is provided in Table I.

Table I - The material type, commercial name, manufacturer, composition of the materials and batch number used in this study

<table>
<tr><th>Material type</th><th>Commercial name</th><th>Manufacturer</th><th colspan="2">Composition[1]</th><th>Batch number</th></tr>
<tr><td rowspan="2">Zirconia Ceramics</td><td>IPS e.max® ZirCAD MO (3Y-TZP)</td><td>Ivoclar</td><td colspan="2">ZrO_2 (88.0 – 95.5 wt%); Y_2O_3 (>4.5 – ≤ 6.0 wt%); HfO_2 (≤5.0 wt%); Al_2O_3 (≤1.0 wt%); other oxides (≤1.0 wt%)</td><td>V26180</td></tr>
<tr><td>IPS e.max® ZirCAD MT (4Y-PSZ)</td><td>Ivoclar</td><td colspan="2">ZrO_2 (86.0 – 93.5 wt%); Y_2O_3 (>6.5 – ≤8.0 wt%); HfO_2 (≤5.0 wt%); Al_2O_3 (≤1.0 wt%); other oxides (≤1.0 wt%)</td><td>X27533</td></tr>
<tr><td rowspan="4">Resin Cement</td><td>Variolink® N</td><td rowspan="2">Ivoclar</td><td colspan="2">Catalyst:</td><td>Y18540</td></tr>
<tr><td>High viscosity</td><td>Barium glass filler, mixed oxide (52.2 wt%); Dimethacrylates (22.0 wt%); Ytterbiumtrifluoride (25.0 wt%); Initiators and stabilizers (0.8 wt%); Pigments (<0.1 wt%)</td><td rowspan="3">Base: Barium glass filler, mixed oxide (48.4 wt%); Dimethacrylates (26.3 wt%); Ytterbiumtrifluoride (25.0 wt%); Initiators and stabilizers (0.3 wt%); Pigments (<0.1 wt%)</td><td>Y23659</td></tr>
<tr><td>Variolink® N</td><td rowspan="2">Ivoclar</td><td>Catalyst:</td><td></td></tr>
<tr><td>Low viscosity</td><td>Barium glass filler, mixed oxide (46.2 wt%); Dimethacrylates (27.9 wt%) Ytterbiumtrifluoride (25.0 wt%); Initiators and stabilizers (0.9 wt%); Pigments (<0.1 wt%)</td><td>Y18005</td></tr>
<tr><td>Aluminum oxide</td><td>Aluminum oxide</td><td>Polidental</td><td colspan="2">Aluminum oxide (45 μm)</td><td>53947</td></tr>
<tr><td>Primer</td><td>Monobond® N</td><td>Ivoclar</td><td colspan="2">Alcohol solution of silane methacrylate, phosphoric acid methacrylate, and sulphide methacrylate</td><td>Z00DTK</td></tr>
</table>

[1]The composition is described according to the manufacturers' information.

Table II - Experimental design

Viscosity of resin cement	Ceramics	Group codes
High viscosity	3Y-TZP	3Y-High
Low viscosity	(Yttria-Stabilized Tetragonal Zirconia Polycrystals)	3Y-Low
High viscosity	4Y-PSZ	4Y-High
Low viscosity	(Yttria-Partially Stabilized Zirconia)	4Y-Low

This in-vitro microshear bond strength study comprises four groups (n = 20, determined based on pilot study, with a cement cylinder considered as an experimental unit). The groups are defined according to two factors: resin cement viscosity (high and low) and ceramic type (3Y-TZP and 4Y-PSZ), as defined in Table II.

Sample preparation

Ceramic discs of the Yttria-Partially Stabilized Zirconia (4Y-PSZ) (IPS e.max® ZirCAD MT A2, Ivoclar; Liechtenstein) and the Yttria-Stabilized Tetragonal Zirconia Polycrystals (3Y-TZP) (IPS e.max® ZirCAD MO B40L, Ivoclar) were cut into square-shaped samples (20.0 × 15.0 × 1.6 mm) using a water-cooled precision cutting machine (IsoMet 1000, Buehler; United States). Following this, all ceramic slices were hand-polished on both sides with #1200 grit silicon carbide papers (SiC) (Norton; Saint-Gobain of Brazil Prod. Ind. and to Constr. Ltda; Brazil) under running water to eliminate any defects or irregularities introduced during the cutting process.

An in-Lab CAD/CAM (Computer-Aided Design/ Computer-Aided Manufacturing) milling simulation protocol was then executed to achieve a level of roughness similar to that of the CEREC milling process [24,25]. For this, all ceramic samples underwent manual grinding performed by a single trained operator. The grinding process involved applying light digital pressure for 2 seconds along each marked axis (*x* and *y*), using a wet #220 grit SiC paper (Norton), with one SiC paper used for each sample [26]. After simulating the CAD/CAM milling roughness, the ceramic slices were cleaned for 5 minutes in distilled water within an ultrasonic bath (1440 D, Odontobras, Ind. and Com. Equip. Med. Odonto. LTDA; Brazil), and then sintered (Vita Zyrcomat 6000 MS, Vita Zahnfabrik; Germany) at a temperature of 1500 °C for 120 minutes, in accordance with the manufacturer's recommendations. The final dimensions of the slice specimens were 16 × 12 × and 1.3 mm (± 0.2 mm) in thickness.

After sintering, the roughness of the intaglio surface of the slices was measured. Six measurements were conducted on each specimen along both the *x* and *y* axes. The mean roughness (Ra) and mean distance between the five highest peaks and valleys (Rz) were determined using a contact surface roughness tester (Mitutoyo SJ-410, Mitutoyo Corporation; Japan) according to ISO 4287-1997 [27]. The roughness means achieved through the in-Lab simulation were numerically similar to those generated by CEREC CAD/CAM milling (Ra = 1.8 μm; Rz = 12.0 μm) [25]. Specifically, the roughness means for this study were Ra = 1.84 μm and Rz = 12.28 μm for 3Y-TZP, and Ra = 1.83 μm and Rz = 12.04 μm for 4Y-PSZ.

The zirconia slices were subsequently embedded in polyvinylchloride (PVC) cylinders (Grupo TIGRE S.A; Brazil). The side that simulated CAD/CAM milling was fixed to double-sided tape (3M Company; São Paulo, Brazil) and secured on a flat bench. Subsequently, the PVC cylinders were centered over the slice, and acrylic resin (JET, Artigos Odontológicos Clássico, Brazil) was mixed and applied into the PVC. After the acrylic resin had polymerized, the set was cleaned for 5 minutes with isopropyl alcohol (78.5%) in an ultrasonic bath (1440 D, Odontobras).

Surface treatments and luting procedure

The surface treatment of each zirconia specimen was performed by air abrasion with 45 μm aluminum oxide particles (Polidental Indústria e Comércio; Brazil), using oscillatory movements for 10 seconds at a distance of 10 mm from the ceramic surface to the sandblaster tip, under a pressure of 2.8 bar [28]. Subsequently, the slices were air-dried to remove any debris.

Then a primer agent containing 10-metha cryloxydecyl dihydrogen phosphate (MDP) (Monobond N, Ivoclar) was applied according to the manufacturer's recommendations. The specimens were then gently air-dried to facilitate solvent evaporation.

Following this, starch tubes (height = 1 mm; internal diameter = 1.15 mm) (Isabela, M. Dias Branco S.A. Indústria e Comércio de Alimentos; Brazil) were affixed with wax #7 (Lysanda Produtos Odontológicos; Brazil) over the treated ceramic surfaces [29]. The dual-curing resin cement (Variolink® N, Ivoclar) with different viscosities (high and low) was manipulated as recommended by the manufacturer, and then inserted inside the tubes with a stainless-steel dental finger spreader (Maillefer, Dentsply Sirona; Switzerland) and condensed using explorer probe #5 (Golgran; Brazil) for all groups. The dual-curing resin cement was light-activated for 40 seconds (1200 mW/cm^2, Radii-cal LED curing light SDI; Australia). After 24 hours of storage in distilled water at 37 °C, the starch tubes were carefully removed using explorer probe #5 (Golgran), and the resin cement cylinders were individually inspected with a 2× magnifying glass and light to ensure that no bubbles or any failures had occurred at the interface. If any irregularity was detected, the resin cement cylinder was replaced. Finally, there were three slices of each ceramic (3Y-TZP and 4Y-PSZ); two slices had seven cylinders of each resin cement viscosity (high and low), and one slice had six cylinders of each viscosity.

Aging conditions

The specimens underwent an aging process involving thermocycling (12,000 cycles) with baths for 30 seconds transitioning between 5 °C and 55 °C, and with a transfer time of 2 seconds (Nova Ética Produtos e Equipamentos Cientificos, Ltda; Brazil). Subsequently, they were stored in distilled water at 37 °C for 120 days before the microshear bond strength test [21,30].

Atomic Force Microscopy (AFM) – Topography and fractal dimension analysis

AFM topography imaging was performed in five random areas on one specimen of each ceramic type, using tapping mode with a silicon probe (TAP300-G Budget Sensors; Bulgaria). Images (5 × 5 μm^2) were captured at resolutions of 512 × 512 or 256 × 256 pixels and a scanning speed of 0.7 Hz, processed with Park SmartScan software (version 1.0. RTM11a). Surface complexity was evaluated using the fractal dimension via the box-counting method (Park XEI Software version 4.3.4 Build22.RTM1), yielding values between 2 and 3 — closer to 3 indicates greater complexity [31-33].

Microshear bond strength test (μSBS)

For the bond strength test, the PVC tube containing the zirconia slice was secured in the testing apparatus on a universal testing machine

(EMIC DL-2000, EMIC; Brazil), with a cell load of 500 N. The test was conducted using the wire-loop method, employing stainless-steel wire (Ø = 0.2 mm) looped around the resin cement cylinder as closely as possible to the adhesive interface. The bond strength test was then executed at a crosshead speed of 0.5 mm/min until failure occurred. Bond strength was determined using the following formula:

$$\mu S\ BS : \frac{L}{A} \tag{1}$$

Where: "μSBS" represent the bond strength in MPa, "L" denotes the load at failure in Newtons, and "A" signifies the interface area of the cylinder, which remained constant for all the samples (1.04 mm^2).

Topographic analysis

Representative samples (n = 1) of 3Y-TZP and 4Y-PSZ were cleaned, sputter-coated with gold, and analyzed under Scanning Electron Microscopy (SEM-Vega3, Tescan; Czech Republic) to examine the surface characteristics of ceramics subjected to CEREC CAD/CAM milling simulation and CEREC CAD/CAM milling simulation plus air abrasion.

Failure analysis

A failure analysis was conducted on all specimens after the μSBS test. A stereomicroscope (SteREO Discovery.V20, Carl Zeiss; Germany) was employed to examine the failure pattern, which was categorized as follows: predominantly adhesive failure (more than 50% of the failure occurring between the resin cement cylinder and zirconia); predominantly cohesive failure (more than 50% of the failure within the ceramic slice or the resin cement cylinder). Subsequently, one representative failure from each group was selected for further analysis in SEM images (Vega3, Tescan).

Statistical analysis

The statistical analysis was performed using the Statistix program (Analytical Software Inc., version 8.1; United States). Data normality was assessed with the Shapiro–Wilk test ($p < 0.01$), and homogeneity of variances with Levene's test ($p = 0.521$). Although normality was not fully met, a two-way ANOVA was carried out, as this test is considered robust to deviations from normal distribution [34]. The analysis evaluated the effects of viscosity (high vs. low), ceramic type (3Y-TZP vs. 4Y-PSZ), and their interaction on bond strength. When significant differences were identified, Tukey's post-hoc test was applied, since the groups had equal sample sizes. All analyses were conducted at a 5% significance level.

RESULTS

The CEREC CAD/CAM milling simulation protocol generated an irregular surface on both 3Y-TZP and 4Y-PSZ ceramics due to the SiC paper grains (Figure 1). At lower magnification (500×), the topography appeared similar between the two zirconia, while at higher magnification (5000×), grooves from aluminum oxide particles' impact became evident, indicating enhanced micromechanical interlocking.

Fractal dimension analysis showed that the surface complexity of both ceramics was similar after CEREC CAD/CAM milling simulation combined with air abrasion and aging, with values of 2.17 (0.01) for 3Y-TZP and 2.17 (0.02) for 4Y-PSZ (Figure 2). This similarity is confirmed by the atomic force microscopy topographic images.

Two-way ANOVA revealed no significant effects of viscosity ($p = 0.42$), ceramic type ($p = 0.97$), or their interaction ($p = 0.126$) on bond strength, indicating statistical similarity among all groups (Table III). Failure analysis showed predominantly adhesive failures between the resin cement and zirconia surface, with no pre-test failures observed (Table III; Figure 3).

Table III - Microshear bond strength values in MPa and standard deviation (SD)

Groups	μSBS mean (SD)[1]	Failures (Predominantly adhesive-%)
3Y-High	32.58 (7.1)^A	100%
3Y-Low	29.16 (7.5)^A	100%
4Y-High	30.40 (4.8)^A	100%
4Y-Low	31.45 (6.1)^A	100%

[1]Equal letters indicate statistically similar μSBS reported by two-way ANOVA and Tukey's post-hoc test (α = 0.05).

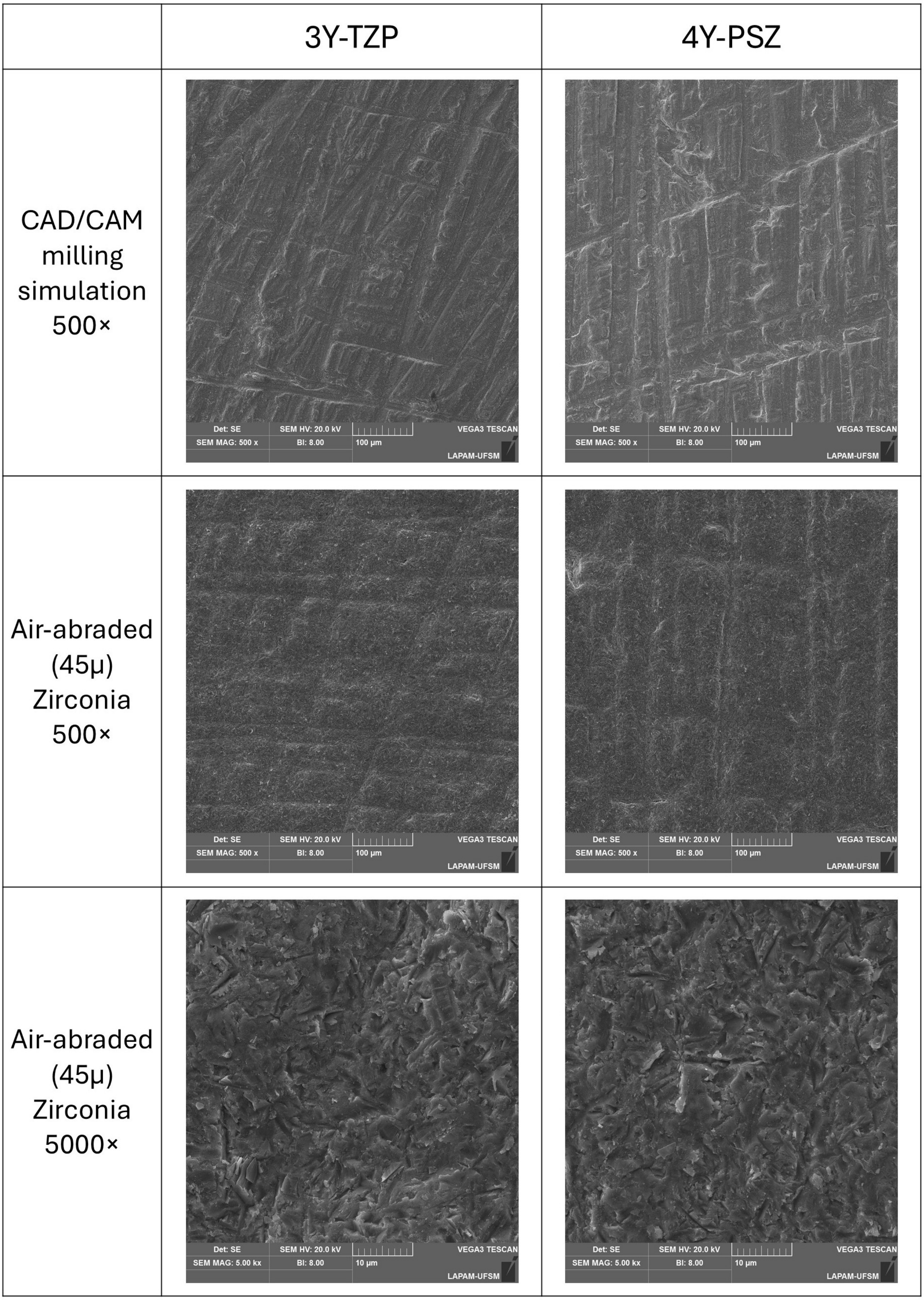


Figure 1 - Topographical micrographs (500× magnification) of 3Y-TZP and 4Y-PSZ after the in-lab CAD/CAM milling simulation protocol, and after the air-abraded zirconia (45 μm) (500× and 5000× magnifications). Both ceramic surfaces appear to be similar at higher magnification after air abrasion.

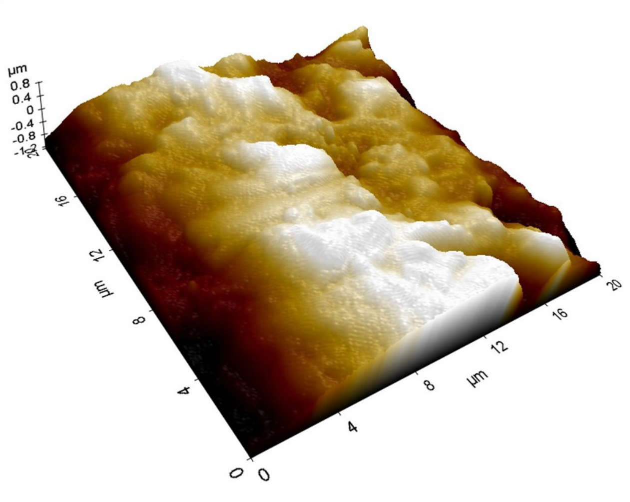
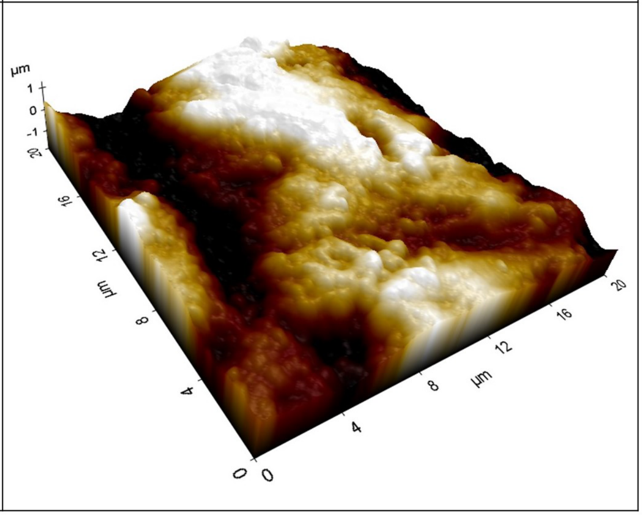
3Y-TZP	4Y-PSZ
2.17 (0.01)	2.17 (0.02)
	

Figure 2 - Quantitative (mean and standard deviation) and qualitative analysis (AFM analysis images) of the surfaces in each type of ceramic. Both ceramic surfaces present similarities in quantitative and qualitative analyses.

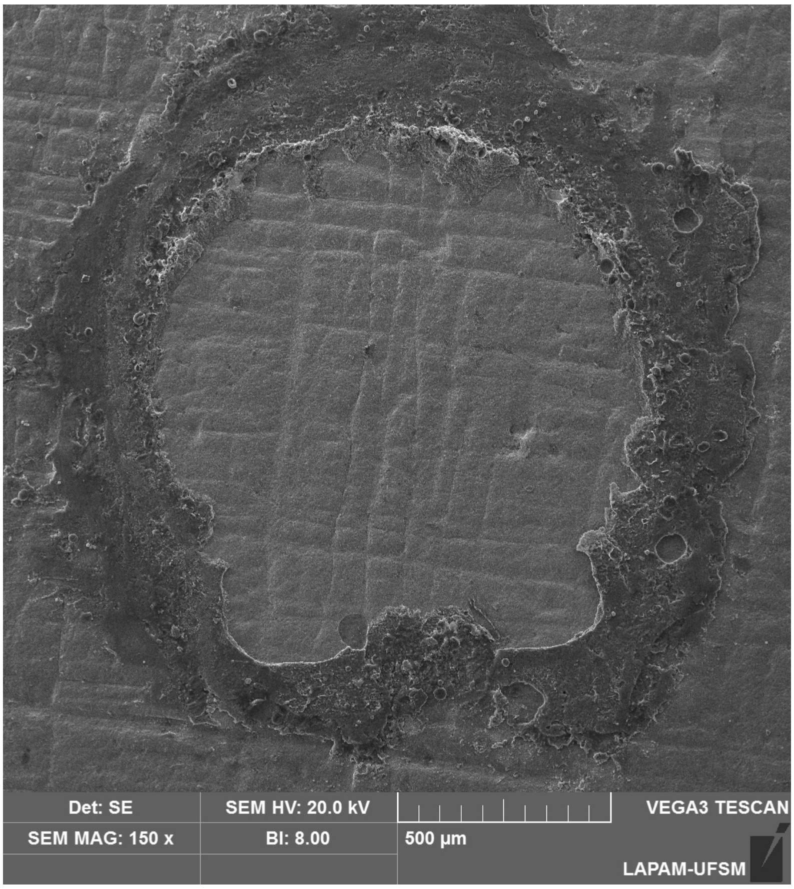


Figure 3 - Representative SEM image of microshear test specimen under 150× magnification; with predominantly adhesive failure.

DISCUSSION

This study found that resin cement produced similar bond strength values when applied to the different ceramics studied, regardless of the viscosities evaluated (high and low). Consequently, the first hypothesis that low-viscosity resin cement will yield higher bond strength values compared to high-viscosity resin cement was rejected.

Establishing a durable and resilient bond between resin cement and zirconia ceramics is essential for ensuring their enduring clinical performance [35]. Air abrasion is widely recognized as the most effective surface treatment for polycrystalline ceramics [36,37], as it cleans the surface, increases roughness and wettability, and promotes micromechanical interlocking [10,38,39]. Study by Mehari et al., demonstrated that air abrasion using aluminum oxide (50 μm) significantly enhanced the bond strength for different types of zirconia (3Y-TZP, 4Y-PSZ, and 5YSZ) [36]. In this context, this study employed air abrasion with aluminum oxide 45 μm (section 2.2), resulting in a similar topography for different ceramics, such as 3Y-TZP and 4Y-PSZ, as seen in Figure 1. Considering what was mentioned, it is plausible to explain that the resin cement may effectively fill surface defects similarly.

The primer used in this study contains silane methacrylate, phosphoric acid methacrylate, and sulfide methacrylate in an alcohol solution. Phosphate monomers (MDP), such as the phosphoric acid 2-hydroxyethyl methacrylate ester, have a strong affinity for metal ions, binding to ceramic oxides (e.g., zirconium) and copolymerizing with the resin matrix [40,41]. According to Grasel et al., combining alumina air abrasion with universal primers containing multiple bonding agents like MDP enhances zirconia-resin cement adhesion [42]. Furthermore, the study by Kukiattrakoon and Kosago also reported improved bond strength outcomes in the groups that received, in addition to airborne-particle abrasion with 50 μm aluminum oxide, the application of a primer to the bonding surface. Although the commercial brand used was not the same as in the present study, its composition is similar due to the presence of components such as 3-methacryloxypropyl trimethoxy silane and MDP [43].

Furthermore, the organic chemical compositions of the resin cement are similar following the manufacturer's guidelines [44] and both catalysts (high and low) share the same base. According to the manufacturer, there is a difference in the filler volume between the cements, with the high-viscosity resin containing 77.2% filler by weight and the low-viscosity cement containing 71.2%. It was confirmed by a previous study [45] that the high- and low-viscosity catalysts exhibit different viscosities at body temperature. However, this variance in filler content does not appear to significantly affect the rheology of the cement to the extent that it impacts the penetration of the cement into the ceramic. This observation holds true, at least for the surface treatment applied in the present study. Consequently, this may clarify why both viscosities yielded similar bond strength values. Additionally, this was also observed in a study by Dapieve et al., where a glass ceramic with different surface treatments was employed [45]. It appears that the smoother topographical characteristics may enable similar micromechanical interlocking for both resin cements, as was used in the present study, leading to a comparable adhesive behavior, as observed here, thus corroborating our results.

Both 3Y-TZP and 4Y-PSZ exhibited similar bond strength values regardless of resin cement viscosity, supporting the second hypothesis. This similarity may be related to the comparable surface topography after air abrasion (Figure 1) and confirmed by atomic force microscopy, which showed similar quantitative (fractal dimension = 2.17) and qualitative surface characteristics after aging (Figure 2). As fractal dimensions closer to 3 indicate higher surface complexity [31-33], the resemblance suggests that both resin cement viscosities likely infiltrated surface defects similarly.

A previous study compared different surface treatments (with and without silica) using two distinct zirconia (3Y-TZP and 5YSZ) and found that the bond strength of 5YSZ was comparable to that of 3Y-TZP under the same surface treatments. This suggests that the bond strength is linked to the varying chemical bonding mechanisms employed in surface treatments [46]. In the current study, air abrasion appeared to have a similar impact on both zirconia ceramic surfaces, as the bond strength was specifically assessed on the ceramic surface without the restoration context in an oral environment, potentially explaining this result. Furthermore, all failures observed were predominantly adhesive (Table III and Figure 3), indicating that the adhesion between the ceramics and the cement was effectively evaluated [21].

It is important to emphasize that this study has some limitations. These limitations included the use of simplified geometric specimens, and the absence of an oral environment simulation scenario, such as variation in temperature and pH, as well as lateral movements that occur during cyclic loading. Additionally, the duration of thermocycling and storage may require investigations involving different aging conditions. Furthermore, while the viscosity of the resin cements showed similar behavior with the evaluated zirconia materials, it is essential to exercise caution during the manipulation of cements and the placement of the restoration on the tooth, as these factors can influence the performance of the overall tooth/restoration set. However, these findings suggest that the selection of resin cement viscosity may be less critical than previously thought for adhesion to zirconia ceramics. Nevertheless, future studies should consider other materials for luting should be considered, since our results evaluated only one resin cement available on the market into consideration.

CONCLUSION

This study demonstrates that the viscosity of resin cement does not significantly influence the bond strength to 3Y-TZP and 4Y-PSZ zirconia ceramics, even after aging. Both zirconia ceramics exhibited similar topographical features and surface complexity following air abrasion, facilitating comparable adhesive behavior regardless of the resin cement viscosity. These findings suggest that the micromechanical interlocking and chemical bonding mechanisms provided by the surface treatment and primer application were effective across both ceramics and resin cement viscosities.

These results indicate that resin cement viscosity may be less critical than previously considered for achieving durable adhesion to zirconia ceramics, provided adequate surface treatments and primer agent are applied.

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Author's Contributions

GCA, PMS: Conceptualization. GCA, PMS: Data Curation. GCA, PMS: Formal Analysis. GCA: Investigation. GCA, PMS: Methodology. GCA: Writing – Original Draft Preparation. GKRP, LFV, MPR: Supervision. GKRP, LFV, MPR: Validation. GKRP, LFV, MPR: Visualization. PMS, GKRP, LFV, MPR: Writing – Review & Editing. LFV: Project Administration. MPR: Funding Acquisition. MPR: Resources.

Conflict of Interest

No conflicts of interest declared concerning the publication of this article.

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Regulatory Statement

Not applicable.

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