Effect of ultrasound on preheated resin composites used as ceramic luting agents
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This study investigated the effect of ultrasound application when luting ceramic using two preheated composites that show distinct responses to preheating at 69°C: Filtek Z100 and Z350XT. RelyX Veneer was the control. Feldspar disks were luted using the resin-based luting agents (RBLAs), and ultrasound was tested. Biaxial flexure strength (σbf) was calculated at z-axial positions of the luted disks (z=0; z=−t2). Microtensile bond strength (μTBS) to ceramic was tested (n=30). Data were analyzed at α=0.05. At z=0, the σbf was higher for Z350 when ultrasound was not used. When ultrasound was applied, the σbf was similar between Z350 and Z100. At z=−t2, differences across the RBLAs were observed: Z350 was superior than Z100 and control without ultrasound. Ultrasound increased σbf for Z100 at both axial positions. The preheated composites yielded higher μTBS than the control. Ultrasonication increased the mechanical performance of ceramic luted with Z100 without influencing the film thickness.

Keywords: Ultrasonication, Ceramic veneers, Resin-based materials, Reinforcement, Bonding ability

INTRODUCTION
Ceramic and resin composite materials used for indirect restorations can be luted to supporting tooth or material structures with varied types of resin-based luting agents (RBLAs), and ultrasound was tested. Biaxial flexure strength (σbf) was calculated at z-axial positions of the luted disks (z=0; z=−t2). Microtensile bond strength (μTBS) to ceramic was tested (n=30). Data were analyzed at α=0.05. At z=0, the σbf was higher for Z350 when ultrasound was not used. When ultrasound was applied, the σbf was similar between Z350 and Z100. At z=−t2, differences across the RBLAs were observed: Z350 was superior than Z100 and control without ultrasound. Ultrasound increased σbf for Z100 at both axial positions. The preheated composites yielded higher μTBS than the control. Ultrasonication increased the mechanical performance of ceramic luted with Z100 without influencing the film thickness.

that application of ultrasound over the ceramic can be an effective film thinning method as the increased flowability of the un polymerized preheated composite gained by ultrasonication may improve its extrusion on restorative margins, ultimately reducing film thickness. It has been reported that ultrasound may reduce the thickness of preheated composites by up to 49%, and that it may work even when the material is no longer warm8. However, whether the ultrasound application could impact the mechanical performance of the bonded ceramic or its bond strength to resin composites has not yet been addressed. This information could be useful to enable the preheating technique to be more clearly envisioned and suggest ways to make it more clinically applicable.

The aim of this study was to assess the effect of ultrasound application when luting a feldspar ceramic using restorative preheated resin composites. This study investigated the mechanical properties of the bonded ceramic as well as the bond strength between the RBLAs and ceramic. The null hypothesis was that ultrasound would not affect the mechanical performance or bonding ability.

MATERIALS AND METHODS

Study design and materials tested
This in vitro study involved a 2×2 factorial design to investigate the influence of two different preheated restorative resin composites (microhybrid Filtek Z100 and nanofill Filtek Z350 XT; 3M ESPE, St. Paul, MN,
USA) and use of ultrasound (yes/no) on the RBLAs used to lute a feldspar ceramic (Vitablocs Mark II A1C; Vita Zahnfabrik, Bad Säckingen, Germany). A diagram summarizing the study design and response-variables tested is presented in Fig. 1. Formulation of the resin-based agents tested as luting agents is presented in Table 1. The restorative composites were selected because they are from the same manufacturer but have differences in resin phase composition. In addition, these two composites showed distinct responses to preheating in a previous study. The photoactivated resin cement RelyX Veneer (3M ESPE) was used as a positive control but was not subjected to preheating or ultrasound application. The reason why not subjecting the resin cement to preheating or ultrasound is to compare this ‘conventional’ technique using a flowable resin cement and the ‘modified’ technique, in which the luting agent is a preheated resin composite. A negative control group was defined by testing the ceramic alone, i.e. without bonding to any RBLA. Response-variables for characterization of the RBLAs were viscosity (Pa.s, n=3), modulus of elasticity (E, n=3) and Poisson’s ratio (v, n=3). Response-variables for the luted ceramic specimens were biaxial flexure strength (σbf, n=30) and its characteristic strength (σ0, n=30), microtensile bond strength (μTBS, n=30) and its characteristic bond strength (μTBS0, n=30), and Weibull moduli (m) for both σbf and μTBS. The number of 30 specimens for each group was used to allow appropriate Weibull analyses.

Characterization of the RBLAs: Viscosity, E, and v

Viscosity of the two restorative resin composites at 69°C and the resin cement at 25°C (n=3) was measured with an oscillation rheometer (R/S-CPS+; Brookfield, Middleboro, MA, USA). A standard 0.5 mL volume of each material was placed on the lower plate of the equipment and positioned with a 0.05 mm gap between lower and upper plates. The temperature was controlled by the rheometer and viscosity (Pa.s) was registered 30 s after reaching the designated temperature using a constant shear rate of 2 s⁻¹. For E and v, three rectangular, bar-shaped specimens (60×10×4 mm) were prepared for each RBLA tested. The resin composites were preheated for 5 min after reaching 69°C (HotSet; Technolife, Joinville, Brazil) before being placed in the molds. The top and bottom surfaces of the specimens were light-cured using 20 s photoactivation windows to cover the entire bar using a LED unit (Radii; SDI, Bayswater, Australia) with 1,200 mW/cm² irradiance. The specimens were tested 24 h after storage in water at 37°C by using an impulse excitation technique (Sonelastic; ATCP Physical Engineering, Ribeirao Preto, Brazil). E and v were calculated, as previously detailed, from the acoustic response emitted by the specimen after suffering a small stroke in the test considering material isotropy. The properties were later used for data calculation in the flexure test.

Luting procedures and film thickness

The feldspar ceramic CAD-CAM blocks were milled to obtain a cylinder shape, then sectioned into disks with thickness of 0.8 ±0.1 mm, and 12 mm in diameter, which were randomly assigned to the different test groups (n=30 per group). Geometry and dimensions of the ceramic specimens were chosen so that they would resemble

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**Table 1** Formulation of the resin-based agents tested as luting agents. Means (standard deviations) for viscosity, modulus of elasticity (E) and Poisson’s ratio (v), n=3

| Resin-based luting agent | Type | Formulation (resin phase and fillers) | Viscosity, Pa.s × 10⁴ | E, GPa | v           |
|-------------------------|------|--------------------------------------|-----------------------|-------|-------------|
| RelyX Veneer (3M ESPE)–control | Photoactivated resin cement | Bis-GMA, TEGDMA, 66 wt% of filler particles | 1.6 (0.2)b | 10.7 (1.6)c | 0.36 (0.24)ab |
| Filtek Z100 (3M ESPE) | Microhybrid resin composite | Bis-GMA, TEGDMA, 80 wt% (66 vol%) of Zr/Si particles | 2.7 (0.1)b | 20.2 (0.1)a | 0.20 (0.03)b |
| Filtek Z350 XT (3M ESPE) | Nanofill resin composite | Bis-GMA, UDMA, Bis-EMA, PEGDMA, TEGDMA, 72.5 wt% (55.6 vol%) of Zr/Si particles | 14.3 (1.2)a | 17.3 (0.2)a | 0.79 (0.08)a |

Distinct letters in the same column indicate statistically significant differences between resin-based luting agents (α=0.05). Bis-GMA, bisphenol A-glycidyl dimethacrylate; TEGDMA, triethyleneglycol dimethacrylate; UDMA, urethane dimethacrylate; Bis-EMA, bisphenol A ethoxylated dimethacrylate; PEGDMA, polyethylene glycol dimethacrylate
feldspar ceramic veneers. The disk surfaces were sequentially wet-finished with 600- and 1200-grit SiC abrasive papers (Norton Abrasivos, Guarulhos, Brazil) to standardize the surface conditions and dimensions were checked anew. A monolayer ceramic group (negative control) was tested, in which the specimens were acid-etched and silanized but not coated with any RBLA. In the other five groups, one of the ceramic surfaces was etched with 10% hydrofluoric acid for 60 s (Condac Porcelana; FGM, Joinville, Brazil), rinsed with water for 60 s, and dried with water- and oil-free compressed air for 30 s. For cleaning, the surface was also etched for 30 s with 37% phosphoric acid (Condac 37; FGM), then rinsed and dried. Two layers of a silane coupling agent (RelyX Ceramic Primer; 3M ESPE) were applied and, after 60 s, dried again. Two layers of a silane coupling agent (RelyX 37% phosphoric acid (Condac 37; FGM), then rinsed and dried for 30 s. A thin layer of an unfilled Ceramic Primer; 3M ESPE) was applied and, after 60 s, dried again. Two layers of a silane coupling agent (RelyX 37% phosphoric acid (Condac 37; FGM), then rinsed and dried for 30 s. A thin layer of an unfilled adhesive (Scotchbond; 3M ESPE) was applied but not photocured at this time. All materials were used in accordance with the manufacturers’ directions.

In the luting sequence, the restorative composites were preheated for 5 min after reaching 69°C and immediately used after being removed from the heating device. A standard 0.1 mL volume of RBLA was placed at the center of the treated ceramic disk that was placed on a polyester strip facing down so that the RBLA layer faced the strip, and this set was placed on a glass slide. Then a 5 N cementation load was placed on the top, untreated ceramic, and was applied for 2 min using a custom-made loading device to standardize seating. In groups in which the ultrasound was applied, the ultrasonic polycrystalline tip, which has a cone trunk shape, was positioned perpendicularly on top and resting on the ceramic surface after seating. The ultrasound tip was kept static at the center of the specimens and vibration was applied for 30 s, simulating the luting of indirect restorations in the clinical scenario. The equipment operated at 40% power (DentSurg Pro; CVdentus, São Jose dos Pinhais, Brazil). Excess RBLA was removed with a microbrush and photoactivation was performed through the ceramic for 40 s. No attempt was made to remove the oxygen inhibition layer. Film thickness (n=30) was measured with a digital caliper accurate to 1 μm (Mitutoyo, Tokyo, Japan) and calculated as the difference in thickness between the luted specimen and ceramic disk alone. The specimens were dry-stored at 37°C in the dark for 24 h.

**Biaxial flexure test**

The σBF was evaluated using a ball-on-ring setup on a mechanical testing machine (DL500; Instron EMIC, São Jose dos Pinhais, Brazil). The specimens were placed on top of a knife-edged support (ring), 10 mm in diameter, and centrally loaded with a spherical indenter (ball), 4 mm in diameter, at a crosshead speed of 1 mm/min until failure. A thin section of rubber dam sheet was used to accommodate slight distortions in specimen geometry. The σBF of the uncoated ceramic (monolayer configuration) and luted ceramic (bilayer) were calculated using by using different equations and the measured E and v mean values of the RBLAs. The E and v of the ceramic were 70 GPa and 0.25, respectively. In the bilayers, the σBF was calculated at z-axial positions in the center of specimens: the ceramic surface at the bonded interface (z=0) and the RBLA surface above the ring (z=−t2). Equation 1 was used for the uncoated ceramic disks (monolayer):

\[
\sigma_{BF} = \frac{3P(1+v)}{4\pi t^2} \left[ 1+2\ln\left(\frac{a}{b}\right) + \frac{1-v}{1+v} \left( 1 - \frac{b^2}{2a^2} \right) \right]^2 \quad \text{Eq. (1)}
\]

where P is the fracture load (N), v the Poisson’s ratio of ceramic, t the disk thickness (mm), a the radius of the knife-edged support (mm), R the radius of the disk-shaped specimen (mm), and b the radius of the loading contact area at the center of the specimen (mm), which was determined using Equation 2:

\[
b = \frac{t_1 + t_2}{3} \quad \text{Eq. (2)}
\]

For calculating the σBF of the bilayer configurations, the E of the ceramic (E1) and RBLAs (E2) were calculated as a function of the Poisson’s ratio of the ceramic and RBLAs, according to Equation 3:

\[
E_{eff} = \frac{E_1}{1-v_1^2} \quad \text{Eq. (3)}
\]

where E1 is the E of ceramic, E2 the measured E of the RBLAs, and v1 and v2 are the Poisson’s ratios of the ceramic and RBLAs. The neutral plane (tn) of the bonded ceramic disks was calculated considering the different thicknesses of the ceramic and RBLAs (t1 and t2), and the calculated EBF and E, using Equation 4:

\[
t_n = \frac{E_1^* (t_1)^2 - E_2^* (t_2)^2}{2(E_1^* t_1 + E_2^* t_2)} \quad \text{Eq. (4)}
\]

The σBF of the coated specimens was then calculated at the z-axial positions at the center of the disks (z=0 and z=−t2) according to Equations 5, 6, and 7:

\[
\sigma_{BF} = \frac{3P(1+v)(z-t_n)}{2\pi t^2} \left[ 1+2\ln\left(\frac{a}{b}\right) + \frac{1-v}{1+v} \left( 1 - \frac{b}{a} \right) \right]^2 \left( \frac{a}{b} \right)^2 \quad \text{Eq. (5)},
\]

\[
\sigma_{BF} = \frac{3P(1+v)(z-t_n)}{2\pi t^2} \left[ 1+2\ln\left(\frac{a}{b}\right) + \frac{1-v}{1+v} \left( 1 - \frac{b}{a} \right) \right]^2 \left( \frac{a}{b} \right)^2 \quad \text{Eq. (6)},
\]

\[
\sigma_{BF} = \frac{3P(1+v)(z-t_n)}{2\pi t^2} \left[ 1+2\ln\left(\frac{a}{b}\right) + \frac{1-v}{1+v} \left( 1 - \frac{b}{a} \right) \right]^2 \left( \frac{a}{b} \right)^2 \quad \text{Eq. (7)}
\]

**μTBS of the RBLAs to ceramic and failure analysis**

The ceramic blocks were sectioned to dimensions of 12×14×5 mm and sequentially wet-polished as described in the previous section of this article. Resin composite blocks with the same dimensions as those of the ceramic
blocks were prepared using a resin composite (Resin Spectra Basic; shade A3, Dentsply Sirona, York, PA, USA). This resin composite was selected to be different from the two composites used as preheated RBLAs. The block was prepared using up to 2 mm increments each photoactivated for 20 s. The ceramic and composite blocks were bonded to each other in order to simulate the procedure of luting of an indirect restoration, and allow beam-shaped ceramic-composite specimens to be obtained for the μTBS test. The blocks were randomly selected and luted using the same procedures described here before except for the photoactivation procedure, which was performed through the top ceramic surface using three photoactivation windows of 20 s each. The specimens were stored in water at 37°C for 24 h, then sectioned into beam-shaped specimens with a bonded area of ~0.72 mm² (0.85×0.85 sides, 10 mm length). For each group, 30 beam-shaped specimens were obtained and subjected to μTBS test on a mechanical testing machine. The specimens were measured, fixed to a notched gripping device and tested under tensile stress at a crosshead speed of 0.5 mm/min until failure. Both sides of the fractured specimens were examined by optical microscopy (×40) and failure modes were classified as premature failure (spontaneous debonding), adhesive failure (failure at the interface), mixed failure (involving more than one bonded substrate), or cohesive failure (within one substrate). Premature and cohesive failures were not considered in the μTBS calculation.

Data analysis
Statistical analyses were carried out using SigmaPlot 12.0 (Systat Software, San Jose, CA, USA). Viscosity, E, and v data were analyzed by one-way analysis of variance (ANOVA), whereas μTBS data were analyzed using two-way ANOVA (resin composite use of ultrasound). Non-parametric data were transformed to ranks before the analysis. All pairwise post hoc comparisons were made by the Tukey’s method (α=0.05). Weibull moduli were calculated for σ and μTBS data, including m, σ, μTBS, 95% upper and lower bounds of the confidence interval. The estimates were calculated using the maximum likelihood method (Minitab v.18.0; Minitab, State College, PA, USA). Groups were considered significantly different when the 95% confidence intervals did not overlap. Descriptive statistics was used to report the failure modes.

RESULTS
Results for viscosity, E, and v were material dependent (Table 1). Preheated Z350 was significantly more viscous than preheated Z100 and RelyX Veneer (p<0.001), which had similar viscosity (p=0.221). E differed significantly across the three RBLAs tested. RelyX Veneer showed significantly lower E (p≤0.021) and v (p≤0.028). Table 2 shows estimates for the biaxial flexure tests. At z=0, the factors RBLA (p<0.021) and ultrasound (p=0.027) were both significant, whereas their interaction was not

| Axial position z=0 | σbf, MPa | σc, MPa | m |
|--------------------|----------|----------|---|
|                     | Without ultrasound | With ultrasound | Without ultrasound | With ultrasound | Without ultrasound | With ultrasound |
| Ceramic             | 110 (106–116) | 116 (112–120) | 10.4 (8.0–13.4) | — | — |
| RelyX Veneer        | 129 (122–135) | 136 (130–142) | 8.8 (6.7–11.6) | — | — |
| Filtek Z100         | 119 (115–123) | 124 (121–128) | 13.3 (9.9–17.7) | 7.7 (6.0–9.8) | — |
| Filtek Z350 XT      | 142 (129–155) | 156 (143–169) | 4.4 (3.3–5.9) | 7.4 (5.5–10.0) | — |

Axial position z=–t3

| RelyX Veneer | 24 (22–25) | 26 (24–27) | 6.7 (5.1–8.8) | — | — |
| Filtek Z100  | 45 (43–47) | 52 (49–56) | 8.5 (6.5–11.1) | 6.5 (5.1–8.3) | — |
| Filtek Z350 XT | 233 (205–264) | 260 (230–293) | 3.2 (2.4–4.3) | 5.2 (3.9–7.1) | — |

For each axial position, distinct lowercase letters in a same column indicate differences between the resin-based luting agents, whereas uppercase letters in a same row indicate differences between using ultrasound or not (α=0.05).
significant \((p=0.062)\). When ultrasound was not used, the \(\sigma_{bf}\) was higher for ceramic bonded with Z350 compared with Z100 and the non-bonded ceramic \((p<0.002)\). RelyX Veneer had similar performance to both preheated composites \((p \geq 0.093)\). When ultrasound was used, the \(\sigma_{bf}\) of the ceramic bonded with Z350 or Z100 was similar \((p=0.515)\). Application of ultrasound yielded higher \(\sigma_{bf}\) for the ceramic bonded with Z100 compared with no ultrasound used \((p<0.001)\), whereas for Z350 the use of ultrasound made no significance \((p=0.26)\). All groups exhibited significant differences in \(\sigma_0\) when ultrasound was not used, Z350 resulted in the highest \(\sigma_0\). When ultrasound was used, Z100 and Z350 had similar performance. The use of Z350 as luting agent negatively affected \(m\), whereas the other RBLAs and the control ceramic had similar \(m\) (Fig. 2). When ultrasound was applied, however, \(m\) was similar between Z350 and Z100, and lower for the latter compared with no ultrasound use.

At \(z=-t_2\), the two factors and their interaction were significant \((p<0.012)\). Significant differences across the RBLAs were shown in the majority of conditions. Z350 showed superior \(\sigma_{bf}\) \((p<0.001)\) and \(\sigma_0\) compared with Z100 and RelyX Veneer without ultrasound. The effect of ultrasound was significant for Z100 by increasing both \(\sigma_{bf}\) \((p<0.001)\) and \(\sigma_0\). In addition, \(m\) was similar between Z350 and Z100 with ultrasound. Results for film thickness (Fig. 3) showed that Z350 yielded significantly thicker films than the other two RBLAs \((p<0.001)\), which in general showed similar results. In addition, the application of ultrasound did not lead to significant lower film thickness of the preheated resin composites.

Results for \(\mu\)TBS are presented in Table 3. The factor resin composite was significant \((p<0.001)\), whereas the factor ultrasound \((p=0.065)\) and the interaction between factors \((p=0.364)\) were not significant. When ultrasound was not used, the \(\mu\)TBS was higher for Z100 compared with RelyX Veneer \((p<0.001)\), which had a similar bonding performance to that of Z350. The \(\mu\)TBS of both preheated resin composites was similar irrespective of ultrasound application, and both had higher \(\mu\)TBS than RelyX Veneer. In the \(\mu\)TBS analysis, \(m\) was not affected by the choice of RBLA or use of ultrasound. Failure analysis (Fig. 4) revealed a large predominance of adhesive failures and very low frequency of other types of failure, with no appreciable differences among the RBLAs or influence of ultrasound application.
Adhesive failures were largely predominant, and no appreciable differences were observed across groups.

**Table 3** Means (95% confidence intervals) for microtensile bond strength to ceramic (μTBS), characteristic strength (μTBS₀), and Weibull modulus (m), n=30

|                     | μTBS, MPa Without ultrasound | μTBS₀, MPa Without ultrasound | Without ultrasound | With ultrasound |
|---------------------|------------------------------|-------------------------------|--------------------|-----------------|
| RelyX Veneer        | 13.4 (11.8–15.1)             | 14.9 (13.3–16.7)             | 3.3 (2.5–4.3)      |
| Filtek Z100         | 29.9 (26.1–34.4)ᵃᵇ          | 36.6 (29.4–38.5)ᵃᵇ          | 2.8 (2.2–3.7)ᵃᵇ   |
| Filtek Z350 XT      | 23.1 (20.2–26.5)ᵃᵇ          | 25.9 (22.7–29.6)ᵃᵇ          | 2.8 (2.1–3.8)ᵃᵇ   |

Distinct lowercase letters in a same column indicate differences between the resin-based luting agents, whereas uppercase letters in a same row indicate differences between using ultrasound or not (α=0.05).

**DISCUSSION**

The findings of this study indicated that the application of ultrasound yielded different effects on the preheated resin composites used for luting simulated feldspar ceramic restorations. Ultrasound was able to increase the mechanical performance of the ceramic bonded with Z100, whereas no major influence was observed when Z350 was the RBLA used. At the same time, ultrasound did not lead to significantly lower film thickness and did not impact the bond strength between the preheated resin composites and ceramic, or the failure modes. Therefore, the null hypothesis should be rejected.

The present results corroborated those of previous investigations, suggesting that selection of the composite is a relevant step in the preheating technique⁵,⁶,¹⁰,¹². As composites with distinct viscosities at 69°C were tested, one could expect that Z350 could be affected to a greater extent by ultrasound application since it was 5× more viscous than Z100. The flexure tests indicated the opposite, there was a positive effect of ultrasound on improving the ceramic reinforcement only in Z100. The distinct performances of Z100 and Z350 when subjected to ultrasound raised questions that could not be undisputedly answered by this study. A potential reason for this could be an improved flow of Z100 over the acid-etched ceramic leading to better mechanical interlocking, but the μTBS test did not reveal a significant influence of ultrasound on bonding ability. Improved homogeneity within the composite layer as a result of ultrasonication could also be speculated, but the mechanical reliability of the ceramic bonded with Z100 was negatively affected by the ultrasound. This is a significant finding that deserves attention in future studies for possible implications in clinical practice. Other potential reasons could be related to characteristics of Z350, which was perhaps too viscous for the purpose of luting ceramics. A recent study⁶ not only showed that preheating Z350 at 69°C reduced 71% of its viscosity, but also that it was still much more viscous than all the other nine composites tested, before or after preheating. In addition, the flexural resistance of Z350 could have been high enough not to be impacted by ultrasound application in the flexure tests¹⁴.

The geometry and dimensions of the ceramic specimens used in this study resembled those of feldspar ceramic veneers. This type of restoration has been shown to depend largely on the adhesive bonding to supporting tooth structures¹⁵,¹⁶ as well as providing on a reinforcing effect by coating the brittle ceramic with a polymeric composite⁵,¹⁰–¹²,¹⁷. The reinforcement provided by adhesive cementation was even shown to overcome the strength degradation caused by surface treatments such as hydrofluoric acid etching or airborne-particle abrasion¹²,¹⁸. Irrespective of the distinct behavior observed for the two composites, all RBLAs were able to reinforce the ceramic structure when compared with the negative control group. The Z350 yielded the highest mechanical reinforcement, which could be explained by its high biaxial flexural resistance and E¹⁴. Previous studies have described the association of improved flexural properties and stiffness of the RBLA with increased ceramic reinforcement¹⁰,¹². The Z350 is a highly filled composite that has zirconia-containing...
nanoscale particles or nanoagglomerates as fillers. Differences in nanoparticle content have the potential to affect the mechanical properties and stability of composites\(^{19}\). Microstructural differences affecting microcrack deflection within the different composites could also be involved\(^{19,20}\). Another potential reason that could explain the results of Z350 was raised in another study\(^{20}\), \textit{i.e.}, the increased film thickness in specimens luted with Z350 compared with the other two RBLAs. In biaxial flexure, failure stresses are sensitive to the thicknesses of layers, which may modify the neutral axis in the bilayer specimens and the degree of shear stresses concentrated at the interface between layers\(^{21}\). The highest magnitude of ceramic strengthening not yielded by the stiffest composite supported the possibility that thicker layers of RBLA could be seen as a reinforcement strategy for feldspar ceramic. This topic warrants further studies.

The impact of the RBLA was also highlighted by the results observed at the axial position \(z = -t_2\). The preheated resin composites showed much higher mechanical strength compared with the photoactivated resin cement. Studies have discussed the possibility that a large mismatch in mechanical and elastic properties between the RBLA layer and ceramic could lead to higher stresses reaching the restoration and lower the magnitude of ceramic strengthening\(^{12,22}\). In this scenario, restorative composites could have advantages over resin cements, which have lower filler loads and \(E\), resulting in a larger mismatch in stiffness with the ceramic. The bond strength to ceramic yielded by both preheated composites also was higher than that provided by the resin cement, irrespective of using ultrasound or not. Another study showed that the bond strength of restorative composite to lithium disilicate ceramic inlays was higher when compared with the bond strength yielded by a dual-cured resin cement\(^{29}\). However, it should be taken into consideration that no aging procedures were carried out in the present study, which means that the results should be considered immediate. Further investigation on the bonding and mechanical stability of ceramics luted with preheated resin composites and subjected to ultrasound application are warranted.

Adhesive failures were predominant in the \(\mu\)TBS test, with no differences among the RBLAs or relative to the application of ultrasound. The predominance of interfacial failures could be attributed to the use of CAD-CAM blocks to obtain the ceramic specimens. Creating a ceramic surface that offers effective micromechanical retention is crucial for an adequate adhesive bond. Distinct laboratorial processing techniques might influence the ceramic surface characteristics and topography\(^{24,25}\). Industrial blocks are fabricated with a dense and homogenous structure to minimize flaws, and they are sometimes even subjected to a pre-sintering procedure to increase the packing of glass and crystalline content. Different ceramic processing methods might affect the ceramic surface roughness after acid-etching, its bonding ability, and probability of survival after fatigue simulation\(^{24,25}\). For a lithium disilicate ceramic after acid etching, the hot-pressing technique may have a more heterogeneous, less complex, and rougher surface compared with its CAD-CAM version\(^{26}\). Another investigation showed that CAD-CAM ceramics showed no appreciable differences in surface irregularities between untreated and acid-etched versions\(^{27}\). This corroborated the findings of another study that reported that a CAD-CAM ceramic showed a high percentage of premature failures of specimens prepared for a \(\mu\)TBS test\(^{27}\). These aspects highlight the importance in assessing the longevity of the bonds between the RBLAs and different types of ceramic in future studies.

The use of ultrasound did not lead to significantly lower film thickness, a result that was somewhat surprising since in a previous study, we observed that ultrasound reduced the film thickness of Z100 by 32\% and Z350 by 25\%\(^{6}\). In that study, application of ultrasound was carried out when the preheated material was no longer warm to resemble clinical procedures. The two studies, however, used different specimens and methods to measure film thickness. In the present study, ceramic disks were used to simulate veneer restorations, whereas the film thickness was measured between two glass plates in the other study\(^{6}\), a method suggested by ISO 4049 standard\(^{28}\) but one that may not reflect the real clinical situation. As clinical practice observations suggest that ultrasound could help to optimize the thickness of the composite layer, the way ultrasonication was carried out in the present study could perhaps have influenced the results. The ultrasound was applied statically at the center of the ceramic specimen whereas in the clinical setting a dynamic oscillation of the ultrasonic tip over the restoration may favor the flow of composite and reduce the resulting film. It seems that there is room for improving the method of ultrasonication and control of film thickness when preheated composite is used as luting agent. Different results relative to the structural reliability of bonded ceramic could also be observed for this improved ultrasonication method, a topic that should be tested in further studies.

\textbf{CONCLUSION}

This \textit{in vitro} study showed that restorative composites that reacted differently to preheating at 69°C were distinctly affected by the application of ultrasound on ceramic during the luting procedure. The ultrasonication procedure generally increased the mechanical performance of the feldspar ceramic bonded with Filtek Z100, whereas no major influence was observed for Filtek Z350 XT. Both preheated restorative resin composites yielded higher immediate bond strength to the ceramic when compared with a resin cement, but the application of ultrasound was unable to reduce film thickness.

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