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Grinding of composite cores using diamond burs with different grit sizes: the effects on the retentive strength of zirconia crowns

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Aim: To evaluate the retention of Y-TZP crowns cemented in aged composite cores ground with burs of different grit sizes. Methods: Sixty composite resin simplified full-crown preparations were scanned, while 60 Y-TZP crowns with occlusal retentions were milled. The composite preparations were stored for 120 days (wet environment-37°C) and randomly distributed into three groups (n=20) according to the type of composite core surface treatment. The groups were defined as: CTRL (control: No treatment), EFB (extra-fine diamond bur [25µm]), and CB (coarse diamond bur [107µm]). The grinding was performed with an adapted surveyor standardizing the speed and pressure of the grinding. The intaglio surfaces on the crowns were air-abraded with silica-coated alumina particles (30 µm) and then a silane was applied. The crowns were cemented with self-adhesive resin cement, thermocycled (12,000 cycles; 5/55°C), stored (120 days) and submitted to a retention test (0.5mm/min). The retentive strength data (MPa) were analyzed using one-way analysis of variance and Tukey test, as well as Weibull analysis. Failures were classified as 50C (above 50% of cement in the crown), 50S (above 50% of cement in the substrate) and COE (composite core cohesive failure). Results: No statistical difference was observed among the retention values ($p=0.975$). However, a higher Weibull modulus was observed in the CTRL group. The predominant type of failure was 50S (above 50% of cement in the substrate composite). Conclusion: The retention of zirconia crowns was not affected by grinding using diamond burs with different grit sizes (coarse/extra-fine) or when no grinding was performed.

Keywords: Composite resin. Dental bonding. Dental retention. Surface properties. Zirconium.

Introduction

Yttria-stabilized tetragonal zirconia polycrystal (Y-TZP) ceramics have been increasingly used over the years because of their superior flexural strength, flexural toughness, and phase-transformation toughening mechanism compared with traditional materials[1]. However, in spite of its excellent mechanical properties, zirconia is resistant to acid etching because of its highly crystalline microstructure, hence limiting adhesion to resin materials[1,2]. To improve the bond strength of zirconia to resin cements, tribochemical air-abrasion is commonly employed. This technique uses alumina particles coated with silica to generate micromechanical retention and a reactive surface for silanization[1].

Although many strategies have been proposed to improve the bond strength of Y-TZP to resin cements, there has been very little focus on the substrate over which the restoration is cemented. Significant loss of coronal tissue is commonly observed in endodontically treated teeth, resulting in the need for post-retained restorations for both aesthetic and functional rehabilitation[3]. These restorations can be performed with prefabricated fiber-post cementation followed by a core build-up with composite resin[3]. Recently, Amaral et al.[4] showed that the retention of Y-TZP crowns is higher when cemented to dentin in comparison with composite resin. Preparation for restorations includes core build-up, prosthetic preparation and impression. Following these procedures, composite resin cores present few unreacted methacrylate groups at their surface, which reduce the potential for their adhesion to the resin cement[5]. During the clinical treatment with prosthetics, dentists will often use provisional restorations in patients before permanent restoration can be performed. During this period, the composite core build-up can be exposed to moisture, variances in pH and temperature[6] and temporary luting cements[7]. As a result, surface alterations of the composite core could be required to improve their adhesion to resin cements and for optimal crown retention[6].

When a composite core is built up, its external surface is completely cured[7-10]. The interaction with the surrounding environment may promote water absorption, leading to softening of the matrix, the formation of micro-cracks, resin degradation, debonding of the filler/matrix interface, and leaching of some constituents[8-10]. Some *in vitro* methods, such as thermocycling and water storage for different periods, can be used to simulate the aging process of resin-based composites that occurs *in vivo*[11-13].

Thus, some studies have proposed that the surface treatment of aged resins could increase their adhesions to fresh resins. Some of these techniques include: grinding with a diamond bur[14-16] or with a diamond bur followed by acid etch/adhesive[11,17,18], lasers irradiation[19-23], air abrasion with aluminum oxide particles and silanization[15,16,18,24], air abrasion with silica-coated alumina particles and silanization[14,15,24,25], and treatment with hydrofluoric acid[18,26-28]. However, some of these techniques (e.g., air-abrasion and laser) require extra armamentarium in the clinical setting. As a result, the cost of the treatment increases[29], a rubber dam is required to avoid damage to the patient's periodontium and inhalation of particles[24], and materials that are potentially unsafe (e.g., silica particles and hydrofluoric acid can be corrosive and toxic) are used intra-orally.

In terms of crown retention, the retentive strength of ceramic crowns is associated with tooth preparation, as well as the type of luting material and polymerization used[30,31]. Factors such as temperature, exposure to saliva, and mechanical stresses during mastication can influence the longevity of bond stability of the zirconia crown-resin cement-dentin complex[32]. In previous studies, when castings were cemented onto the surfaces of teeth using conventional cements (e.g., zinc phosphate), the rough surfaces seemed to influence the retention of crowns[33,34]. Indeed, the retention quality of conventional cements is associated with both their physical strength and the micromechanical retention of the filler particles on the rough surface of the prepared tooth (and not with adhesive quality)[33]. However, with advances in adhesive technology for promoting adhesion between different substrates, there could be an increase in interaction between the composites used for core build-up and resin cements[7].

Until now, we unknown studies has evaluated the use of diamond burs with different grit sizes of composite cores for finishing (i.e., grinding) on the retention of Y-TZP crowns cemented with resin-luting cements. Thus, the aim of this study was to evaluate the effect of finishing (i.e., grinding by diamond burs with different grit sizes) of the prosthetic preparation made of composite resin on the retentive strength of zirconia crowns. We tested the hypothesis that grinding with a coarse diamond bur (i.e., rougher surface) would generate higher retentive strength than grinding with an extra-fine diamond bur and no treatment (i.e., smoother surface).

Materials and methods

Composite core prosthetic preparation, aging, and finishing method

Split transparent templates were used to produce sixty composite resin prosthetic preparations (Tetric EvoCeram, Ivoclar Vivadent, Schaan, Liechtenstein) with identical, simplified full-crown preparations (16 mm in total height: 6 mm in preparation height with a total occlusal convergence angle of 12° with rounded corners + 10 mm in base height). Small portions of composite resin (2 mm) were inserted incrementally into the templates, until they were filled completely. Next, a screw of 25 mm in height was screwed into the center of the composite. This screw was used to help with the fixation of the composite preparation sample in the embedding resin for the purpose of a retention test (Figure 1). Each surface of composite resin preparation was photo-activated for 20 s with a high-power LED (1200 mW/cm^2, RadiiCal, SDI, Bayswater, VIC, Australia) and placed into a vacuum-mirrored polymerization chamber (Visio™ Beta Vario Light Unit, 3M ESPE, Seefeld, BY, Germany) using a specific protocol for photo curing materials (1 min of light followed by 1 min of vacuum and light) to increase the conversion degree. Afterwards, the composite preparations were stored in a bacteriological furnace (wet environment, 37°C) for 120 days[11-13].

After aging, the composite preparations were assigned to three groups (n=20) according to the grit size of the diamond bur used to finish the surface:

- **CTRL (control)**: without roughening the surface,
- **Extra-fine Bur**: roughening the surface with an extra-fine bur (878EF.314.014 – parallel-chamfer, torpedo – Komet, Gebr. Brasseler, Lemgo, NW, Germany),

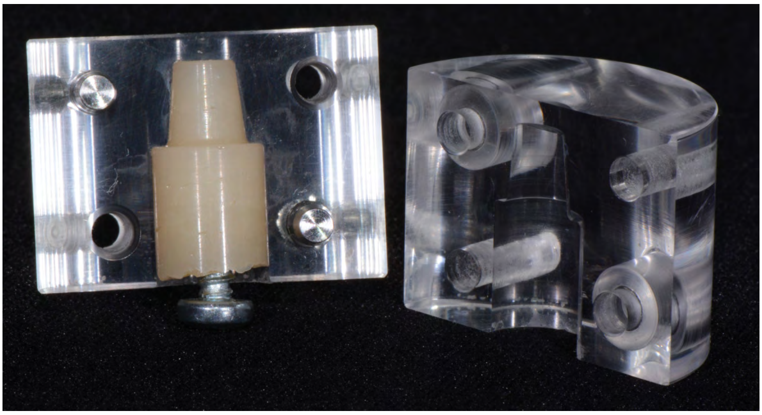

Figure 1. Split transparent templates used to produce the composite cores (note the screw on the composite base center).

- **Coarse Bur**: roughening the surface with a coarse bur (878.314.014 – parallel--chamfer, torpedo – Komet, Gebr. Brasseler, Lemgo, NW, Germany).

To perform the grinding procedures, the composite core preparations were placed in a rotatory mounting of a purposely-built device allowing the core to rotate counter-clockwise around its own axis at a speed of 30 rpm. The diamond burs (Extra-fine and Coarse bur) were installed on a handpiece (Kavo Dental GmbH/Kaltenbach & Voigt GmbH, Biberach an der Riß, BW, Germany) oriented to steadily hold the bur axis parallel to the composite core surface. The bur rotated at 20.000 rpm in the opposite direction (clockwise) of that of the core. The whole rotatory mounting was positioned above a movable X-Y micrometric table: this arrangement allowed a standardized core grinding by setting the cutting depth on a dial caliber (Make, Model, 0.001 micron resolution). A cutting depth pattern of 5.0 ± 1 µm with a total of three rounds (or revolutions) for each preparation was performed (Figure 2A, 2B, 2C). The abrasion was carried-out under water cooling exclusively on the axial surfaces, preserving the preparation shoulder (chamfer) which remained intact. In the manner here described, it was possible to standardize the same geometry and surface type in each composite core specimen.

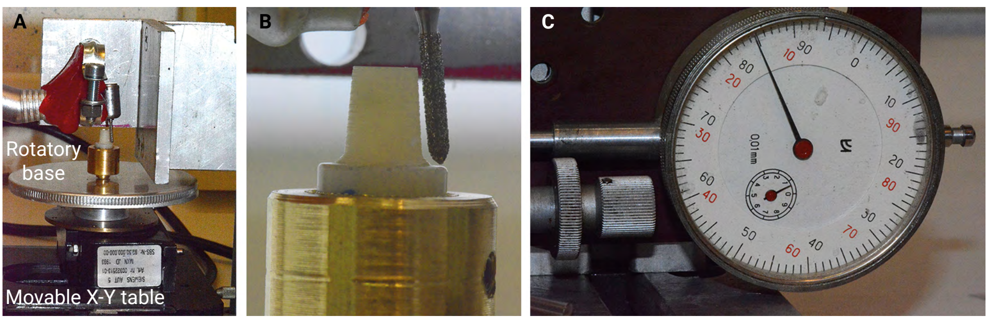

Figure 2. A. Special device for grinding the composite preparations. B. Composite core after grinding (bur positioned parallel to the composite surface). C. Micrometer installed onto a movable X-Y table to standardize the grinding pressure.

Zirconia crowns production, cementation, and aging

Each composite preparation was scanned (inEos X5, Sirona Dental Systems, Bensheim, Germany) and the images were transferred to the inLab software (Sirona SW 15.0, Sirona). Crowns with occlusal retentions were designed for each preparation and the Y-TZP crowns were milled by a milling machine (Cerec InLab MC XL4, Sirona) (IPS e.max ZirCAD for inLab C-15, dimensions of 14.5 x 15.5 x 18.5 mm^3, Ivoclar Vivadent) with a cement space of 80 µm.

Sintering was produced according to the manufacturer's instructions (Zircomat, VITA Zahnfabrik, Bad Säckingen, Germany). The crowns of each preparation were checked for passive adaptation (Carbono Arti-Spray, Bausch, Bausch Articulating Papers, Inc., Nashua, NH, USA) and cleaned with an ultrasonic device (1440 D – Odontrobras, Ind. & Com. Equip. Méd. Odonto. LTDA, Ribeirao Preto, SP, Brazil) and distilled water for 10 min.

To standardize the procedure, the intaglio surface of Y-TZP crowns were air-abraded with an adapted device using silica-coated aluminum oxide particles (30 µm) (Cojet Sand, 3M ESPE, Seefeld, BY, Germany) at a distance of 15 mm for 10 s and a pressure of 2.8 bar[35]. A coupling agent based on methacryloxypropyltrimethoxysilane (RelyX Ceramic Primer S, 3M ESPE) was applied with a microbrush and crowns were left untouched for 5 min to allow for evaporation of the solvent. Self-adhesive resin cement (RelyX U200, 3M ESPE) was manipulated according to the manufacturer's instructions and applied to the intaglio surface of the crowns, which were positioned on the composite preparation. With an adapted surveyor (B2, BioArt, Sao Carlos, SP, Brazil), a load of 750 g was applied to the crown, the cement excess was removed, and photo-activation was performed for 20 s on each surface (1200 mW/cm^2, Radii-Cal, SDI, Bayswater, VIC, Australia). The specimens were stored in distilled water (37°C) for 24 h, submitted to thermocycling (12.000 cycles; 5°C-55°C; 30 s per bath and 5 s between baths; Ethik Technology, Vargem Grande Paulista, SP, Brazil), and then stored for 30 days in a wet environment at 37°C.

Embedding and retentive strength test

Before a retentive strength test, the specimens were partially embedded inside the acrylic resin to fix the zirconia crown and the composite preparations. The margins of the crown preparations were kept free for testing. First, the crown from the crown/preparation assembly was fixed onto an adapted surveyor perpendicular to the X axis (B2, BioArt) to keep the adequate orientation of the specimen. Subsequently, this preparation allowed the base of the composite preparation to be embedded in self-curing resin (VIPI Flash, VIPI, Pirassununga, SP, Brazil) until 2 mm above the marginal zone. After acrylic-resin polymerization, the previously embedded part was fixed onto the surveyor perpendicular to X axis (for the same aforementioned reason) and the zirconia crown was embedded until the occlusal retentions were covered. Both parts were then embedded using metallic templates with transversal holes that allowed for the attaching of the superior part (crown) and inferior part (composite preparation) in the universal testing machine (DL-1000, Emic, São José dos Pinhais, PR, Brazil). The superior part was fixed to a load cell (1000 N) which was attached to movable axle of the testing machine, while the inferior part was fixed at the fixed base of the machine. Next, a retention force (pull-out) was applied until failure (0.5 mm/min).

Adhesive area calculation

The amount of adhered area (129 mm^2) was calculated by SolidWorks software (DS SolidWorks Corporation, Waltham, MA, USA) according to the measures of the composite cores. The retentive strength (R) was calculated using the formula:

$R = F_{max}/A$,

where F_{max} = maximum force for failure (decementation) and A = adhered area.

Failure analysis

To evaluate the type of fracture, the tested assemblies were analyzed under a stereomicroscope (Discovery V20, Carl-Zeiss, Gottingen, NI, Germany), and the fractures were classified according to the localization of the largest portion of cement. These classifications are described as follows: 50C (more than 50% of the cement on the crown), 50S (more than 50% of the cement on the substratum (composite core preparation)), and COE (cohesive failure of composite preparation) (these data were not included in the statistical analysis). Representative images were taken with a scanning electronic microscope (SEM) (JSM-6360LV, JEOL USA, Inc., Peabody, MA, USA). This classification was adapted from Amaral et al.[4] and Rippe et al.[6].

Data analysis

The retentive strength data were statistically analyzed with the SPSS software (Version 21, IBM, Chicago, IL, USA). Both normality and homoscedasticity were verified, and the data were subjected to one-way analysis of variance (ANOVA) and post-hoc Tukey's test. The reliability of the retentive strength values (*m*: Weibull modulus) and the characteristic retentive strength (σ_0: strength value at which 63.2% of the specimens survive) were performed by a Weibull analysis.

RESULTS

A one-way ANOVA showed no statistical difference among the retention values (p=0.975) (Table 1). In addition, no difference in characteristic strength (σ_0) was

Table 1. Means (standard deviation) of the tensile strength (MPa), Weibull analysis (m= modulus; σ_0= characteristic tensile resistance (MPa); IC= confidence interval), and percentage of failure types.

Groups	Tensile Strength*	Weibull Parameters**				Failures***		
		m	IC	σ_0	IC	50C (%)	50S (%)	COE (%)
No-treatment (control)	2.1 (0.41)^a	5,9^a	3.3 – 8.3	3.4^a	3 – 3.8	5 (25)	9 (45)	6 (30)
Coarse diamond bur	2.03 (1.03)^a	2,1^b	1.2 – 2.9	3.3^a	2.4 – 4.5	-	15 (75)	5 (25)
Extra-fine diamond bur	2.04 (0.97)^a	2,2^b	1.3 – 3	3.3^a	2.5 – 4.5	1 (5)	16 (80)	3 (15)

*Different lowercase letters in the same column indicate a significant difference.
** Different lowercase letters in the same column indicate a significant difference (no overlap of the confidence intervals)
*** 50S: more than 50% of cement adhered on the substratum;
50C: more than 50% of cement adhered on the crown.
COE: cohesive failure: composite die fracture.

observed. However, the Weibull modulus (*m*) was higher in the CTRL group compared with the CB and EFB groups (overlap of confidence intervals). The most common type of failure was 50S (more than 50% of cement adhered to the substratum) (Figure 3).

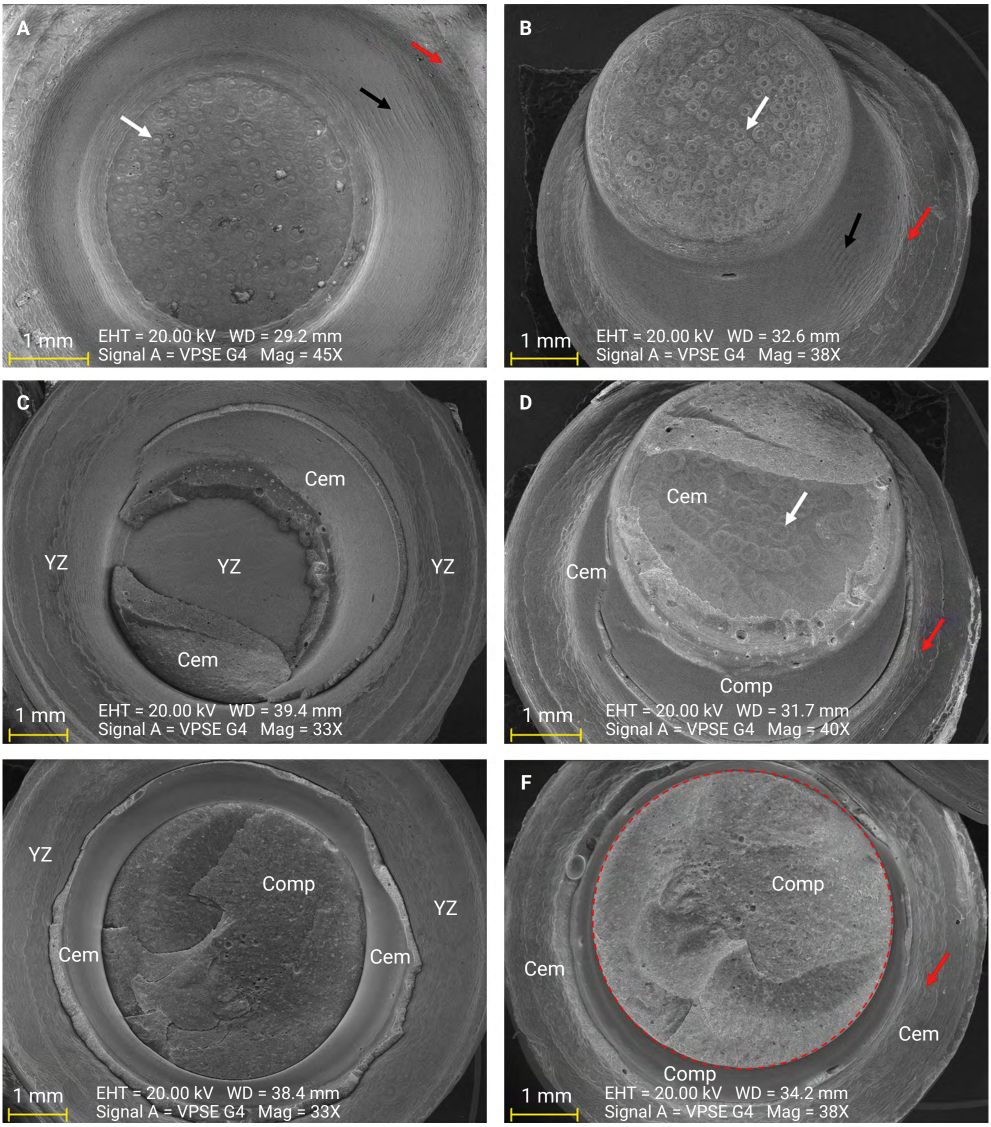

Figure 3. Representative scanning electric microscopies. A. Zirconia crown of the Coarse bur group (white arrow: circular machining marks on the internal occlusal surface; black arrow: axial machining marks on the axial internal surface; red arrow: semicircular machining marks on crown shoulder). B. Composite core of the Coarse bur group (it is possible to note that the resin cement layer is adhered totally on the core and the machining marks are reproduced on the cement layer) – 50S failure. C. Zirconia crown of the CTRL group (YZ: zirconia and Cem: cement) – cement partially adhered on crown. D. Composite core of the CTRL group (major part of cement adhered on composite surface) and machining marks on the layer cement – 50S failure. E. Zirconia crown of the Extra fine bur group – Cohesive failure (part of the core fracture into crown. F. Composite core of the Extra fine group (red circle: fractured occlusal third; cement adhered on the composite shoulder with semicircular machining marks).

DISCUSSION

The retentive strengths of the three groups were found to be statistically similar (Table 1). Therefore, our formulated research hypothesis was rejected.

Other studies have used bond strength tests with simplified geometry (shear or tensile bond strength on flat surfaces) to evaluate bonding to aged composites[36-39]. However, these studies have shown conflicting results. In relation to the surface treatment with burs, our results align with other studies that showed no effect of burs on composite-composite bonding[36,37]. In contrast, Valente et al.[38] and Costa et al.[16] showed that surface roughening with diamond burs improved the tensile bond strength to new composites. However, these studies used intermediate agents between the aged and fresh composite layers, which could have enhanced the adhesion. Bonstein et al.[39] suggested that surface treatment with only a diamond bur on aged composites is simple, efficient, and does not require additional dental materials or instrumentation. Other methods of surface roughening were tested, including sandpapers[7,24,40], abrasive stone[11], and pumice[41], but for these studies the increased bonding is associated with surface grinding, followed by the application of a primer/adhesive. We chose to test burs for their finishing abilities (i.e., surface treatments) because the method is simple, has low cost and is available in the dental office. Notably, we did not apply any intermediate agent since a self-adhesive resin cement was chosen to lute the Y-TZP crowns. This cement is easier and less technical to use, and promotes similar bond strength to conventional luting resin cements[42-44].

Most failures were classified as 50S (more than 50% of cement adhered to substratum) (Table 1). These findings agree with those of both Amaral et al.[4] and Rippe et al.[6], who also used composite cores finished with fine diamond burs and observed that failure occurred between the cement and zirconia (adhesive failure). A main explanation for a non-significant result could be the association of resin materials (e.g., composite resin and resin cement) with similar chemical compositions[7], thus favoring a bond between them. It is possible that the rougher surface produced with an extra-fine bur and coarse bur had no effect on retentive strength because of the similar compositions of resin cement and composite resin. In contrast, other studies demonstrated that the majority of cement was adhered to the intaglios of zirconia crowns after thermocycling[32,44,45]. However, dentin substrate was used in these studies.

In addition, failure analysis showed that the cement remained attached on the internal occlusal surface of the zirconia crown for some samples in the Extra-fine and Coarse Bur groups (Figure 3). This result possibly occurred because the occlusal surface of the composite core was not prepared and, therefore, the cement remained adhered on ground axial surfaces of the composite. Notably, this result was also observed by Palacios et al.[44]. Amaral et al.[4] and Rippe et al.[6] did not evaluate the roughness of the composite core on zirconia crown retention. However, both of these studies presented failure patterns similar to those observed in our study, which used composite cores and resin cements. Hence, independently of surface treatment, factors including the type of substratum, resin cement, and taper preparation can be more important than surface roughness in influencing the retention of zirconia crowns.

Taper preparation is another factor that could have affected the retention values. Kaufman et al.[46] examined the effect of variation of the convergence angle (1°, 5°, 10°, 15° and 20°) on crown retention and showed that retention increases as the convergence angle decreases. In our study, we utilized the total convergence angle of 12° and, consequently, the retentive effect may have been higher than both bonding and roughness effects. This convergence angle could have contributed to cohesive failure as observed by this study, Amaral et al.[4], and Rippe et al.[6].

Despite the similar retention strengths depicted by our findings, the Weibull modulus of control group (CTRL) was higher (higher reliability) than the EFB and CB groups (Table 1). Ayad et al.[47] stated that excessive roughness could lead to trapped air between the cement and tooth preparation, which could cause adhesive failure; this event could have occurred in the current study. Furthermore, the standard deviation of the control group was lower than in the EFB and CB groups, possibly due to the fact that the procedure could have promoted heterogeneous morphological surface patterns on the treated cores.

There were some limitations of our study. First, unreal retention values were generated with cohesive failures of the composite cores. As a result, these data were removed from the statistical analysis to avoid overestimation or underestimation of the retention values. In a prior study, cohesive failure occurred before reaching the maximum load supported by adhesive interfaces[44]. In the current study, cohesive failures varied from 15% to 30%, depending on the group (Table 1). It is important to emphasize that if this type of failure had not occurred, the retention values would probably be higher. These failures may be associated with taper preparation — if the convergence angle had been greater, maybe the cohesive failures would not have occurred. Secondly, composite preparations were created using highly standardized procedures. In clinical practice, however, dental tissue will be present at the chamfer preparation when restoring endodontically treated teeth with posts and composite cores. Therefore, it is difficult to compare our results with those in the current literature. Indeed, most studies employ different methodologies including varying geometries of the preparation, as well as different taper preparations, resin cements, and substrate. Further studies should be performed with other types of aging, composite-core surface treatments, luting cements (e.g., zinc phosphate, glass ionomer, resin modified glass ionomer, and resin cement of different compositions), adhesive techniques, and taper preparations. Finally, tests applying intermittent loading and fatigue investigations should also be conducted.

In conclusion, the retention of zirconia crowns cemented with self-adhesive resin cement was not affected by grinding using diamond burs with different grit sizes on composite resin preparations with a convergence angle of 12º.

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