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Effect of the Photo-initiator System Contained in Universal Adhesives on Radicular Dentin Bonding

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Clinical Relevance

The photo-initiator system based on an advanced polymerization system may be an alternative that can be used to overcome the disadvantages of radicular dentin, especially for the apical third.

SUMMARY

Objectives: The purpose of this study was to evaluate the effects of universal adhesives with different photo-initiator systems applied in etch-and-rinse (ER) and self-etch (SE) modes on dentin interaction (push-out bond strength [PBS], nanoleakage [NL], and degree of conversion [DC] within the hybrid layer) in the different root thirds after fiber post cementation.

Methods and Materials: Roots of endodontically prepared human premolars were randomly divided into six groups according to one of three adhesive systems (Scotchbond Universal [SBU], Ambar Universal [AMB], and Ambar Universal APS [AMB-APS]) and two adhesive strategies (ER and SE) for each system. Posts were cemented, and PBS was tested at 0.5 mm/min. The NL was evaluated by scanning elec-

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tron microscopy. DC was measured using micro-Raman spectroscopy. The data were analyzed by three-way analysis of variance and Tukey tests (α=0.05).

Results: AMB-APS showed similar performance in all root thirds ($p>0.05$) and higher values of DC, especially in the apical third ($p<0.0001$). AMB and SBU showed the lowest values in the apical third ($p<0.0001$).

Conclusions: The APS photo-initiator system contained in universal adhesives is a feasible alternative for improving radicular bonding procedure.

INTRODUCTION

Fiber post cementation has become a very popular alternative with clinicians for endodontically treated teeth. The success of cementation depends on the strong bond to tooth substrates,[1,2] and a suitable dentin bonding is needed for infiltration of resin monomers on etched substrates and subsequent polymerization.[3,4] However, in radicular dentin, there are several limitations, such as typical histological morphology in the apical third[5] and a high C-factor within the root canal[6] impairing the bonding on this substrate.[7] Furthermore, the polymerization process inside the root canal, which is a prerequisite for adequate bonding, is impaired because of the difficulty in controlling humidity and solvent evaporation of the adhesive system.[8,9] In addition, lower bonding performance can be caused by the reduced radiant exposure achieved in the apical third,[10] making radicular dentin bonding a challenge.

Some authors have proposed alternatives for increasing the success of fiber post cementation into radicular dentin by reducing the required light intensity for the polymerization of the material inside of the radicular dentin.[11,12] However, the most commonly employed photo-initiator systems for the polymerization of resin-based materials are based on a camphorquinone (CQ)/amine system. Basically, a photosensitizer molecule (CQ) can absorb light directly, and a co-initiator (typically a tertiary amine) interacts with the activated photo-initiator to generate a reactive free radical. These reactive free-radical species attack monomer molecules and initiate polymerization.[13] However, CQ and amines are hydrophobic, which are antagonistic to the adhesive solutions. These solutions contain hydrophilic components required for the interaction with tooth substrates, promoting the resin infiltration on the wet dentin surface.[14] This problem encourages research efforts to identify alternative co-initiators as substitutes for amines to improve the photo-initiator systems without impairing the polymerization reaction and the bonding ability of dental adhesives.[15-17]

Furthermore, it was previously demonstrated that in the hydrophilic-rich phase of simplified adhesives, photo-initiator systems (CQ/amines) are present in limited concentrations in the hydrophobic phase. This effect could compromise the photo-polymerization of the hydrophilic-rich phase and result in loosely cross-linked regions, facilitating diffusion of the oral fluid into the resin-dentin interface.[18] Therefore, more-hydrophilic photo-initiator systems added into adhesive systems could be an interesting alternative for improving the polymerization on the apical third and, consequently, the bonding performance in radicular dentin. However, to the best of our knowledge, this approach has not been previously evaluated.

Thus, this study investigated the use of three universal adhesives with different photo-initiator systems (applied with etch-and-rinse [ER] and self-etch [SE] strategies) on the interaction with radicular dentin (push-out bond strength [PBS], nanoleakage [NL] evaluation, and degree of conversion [DC] within the hybrid layer). The different root thirds were also evaluated. The null hypotheses tested were that the evaluated bonding characteristics of post-to-radicular dentin are not affected by 1) adhesive strategies (ER and SE), 2) different universal adhesives, or 3) different root thirds.

METHODS AND MATERIALS

Sample Preparation

After approval by the local ethics committee (protocol 2.408.873), 66 caries-free human mandibular premolars (root length of about 14 mm measured from the cementoenamel junction), extracted within the past 6 months, were selected. The dental crowns were removed by a diamond saw (Isomet 1000, Buehler, Lake Bluff, IL, USA). A single operator, a specialist in endodontics and experienced in all the techniques used in this study, performed the root canal preparation and obturation according to Vilas-Boas and others.[19] Root canals were prepared 1-mm shorter than the apical foramen with Reciproc R40 (VDW, München, Germany) and irrigation using 1% sodium hypochlorite (10 mL in total). Subsequently, the smear layer was removed using 5 mL of 17% EDTA for three minutes and flushed with 10 mL of distilled water. Canals were dried with absorbent

Table 1: *Universally Used Adhesive Systems (Manufacturer/Batch Number), Detailed Composition, and Application Mode, According to the Adhesive Strategy*[a]

Adhesive System (Manufacturer/ Batch No.)	Composition	Strategies	
		Self-etching	Total Etching
AMB-APS (FGM, Joinville, SC, Brazil/070817)	10-MDP, methacrylic monomers, photo-initiator APS, CQ, silica nanoparticles, ethanol, co-initiators, and stabilizers	1. Apply two layers with a micro brush for 20 s (10 s each layer) 2. Evaporate the adhesive solvent by using gentle air for 10 s 3. Light-cure for 10 s to 1200 mW/cm^2	1. Phosphoric acid etching in enamel for 15 s 2. Rinsing with water spray to remove the acid 3. Evaporation of the adhesive solvent, using gentle air 4. Application of the adhesive system to the self-etching mode
AMB (FGM, Joinville, SC, Brazil/200416)	10-MDP, hydrophilic methacrylic monomers, ethanol, silanized silicon dioxide, CQ, co-initiators, and stabilizers	1. Apply two layers with a micro brush for 20 s (10 s each layer) 2. Evaporate the adhesive solvent, using a gentle air for 10 s 3. Light-cure for 10 s to 1200 mW/cm^2	1. Phosphoric acid etching in enamel for 15 s 2. Rinsing with water spray to remove the acid 3. Evaporation of the adhesive solvent using gentle air 4. Application of the adhesive system to the self-etching mode
SBU (3M Oral Care, St Paul, MN, USA/ 1630600505)	10-MDP, HEMA, bis-GMA, decamethylene dimethacrylate, ethanol, silane-treated silica, water, copolymer of acrylic and itaconic acid, CQ, dimethylaminobenzoate(–4)	1. Apply the adhesive actively for 20 s and, if necessary, reapply the adhesive system 2. Air dry for 5 s until the adhesive does not move and the solvent evaporates completely 3. Light-cure for 10 s to 1200 mW/cm^2	1. Phosphoric acid etching in enamel for 15 s 2. Rinsing with water spray to remove the acid 3. Evaporation of the adhesive solvent using gentle air 4. Application of the adhesive system to the self-etching mode

Abbreviations: bis-GMA: bisphenol A-glycidyl methacrylate; CQ: camphorquinone; HEMA: 2-hydroxyethyl methacrylate; 10-MDP: 10-methacryloyloxydecyl dihydrogen phosphate.
[a] *All adhesive systems were applied according to the manufacturers' instructions.*

paper points (VDW). Then, the canals were filled with AH Plus (Dentsply Ind Com Ltd, Petropolis, RJ, Brazil) using the single-cone technique (R40, Reciproc). The cervical opening was sealed (glass-ionomer cement Maxxion R, FGM, Joinville, SC, Brazil) and the teeth were stored at 37°C in 100% humidity for seven days.

Fiber Post Cementation

The filling material was removed from the coronal 10 mm of the canal (leaving 4 mm of gutta-percha in the apical third of the root) using #3 Largo burs (Dentsply Maillefer, Ballaigues, Switzerland). The post space was prepared using a #2 bur (White Post DC, FGM) with a 10-mm length, followed by irrigation (10 mL of distilled water) and dried with absorbent paper points. The specimens were randomly divided into six groups (n=12) according to one of three adhesive systems (Scotchbond Universal [SBU], 3M Oral Care, St Paul, MN, USA; Ambar Universal [AMB], FGM; and Ambar Universal APS [AMB-APS], FGM) and two adhesive strategies (ER and SE) for each system. Product information and modes of application are detailed in Table 1.

Before cementation, glass fiber posts were horizontally sectioned in the coronal region with a water-cooled diamond cutting instrument to reduce the post length to 13 mm. While 10 mm was cemented inside the root canal, the coronal 3 mm served as a guide to standardize the distance of the light-curing device from the cervical root area. All posts were cleaned with gauze immersed in 70% alcohol for five seconds.

After the adhesive application, a dual-cure resin cement (All Cem, shade A2, FGM) was inserted with a Centrix syringe (NOVA DFL, Rio de Janeiro, RJ, Brazil); the posts (DC 2, FGM) were inserted immediately and light polymerized for 40 seconds (1200 mW/cm^2, Valo, Ultradent Products, Lake City, UT, USA).

Specimen Preparation and Measurement

After storage in water at 37°C for seven days, the specimens were sectioned perpendicular to the long axis into six 1-mm serial slices under water cooling (Isomet 1000, Buehler). Both sides of each slice were photographed at 40× magnification to measure the coronal and apical diameters of the posts to calculate

the individual bonding areas (Image J, National Institutes of Health [NIH], Bethesda, MD, USA).

Push-out Bond Strengths

The PBS test (n=8 teeth) was performed by measuring the bond strength of the fiber post to dentin. The cervical side of each test specimen was placed in contact with a support (Odeme, Joaçaba, SC, Brazil), which was coupled to the base of a universal test machine (Instron, 3342, Canton, MA, USA). Loading was performed at a crosshead speed of 0.5 mm/min^{-1} until the post was completely dislodged from the root slice. The maximum value obtained in kilogram-force was used to calculate the bond strength in megapascals (MPa) using the following formula: $A = \pi (R + r) \sqrt{h^2 + (R - r)^2}$, where π is the constant 3.14; r_1 and r_2 are the smaller and larger post space radii, respectively; and h is the height of the section in millimeters. The debonded specimens were observed under 40× magnification with a stereomicroscope loupe (SZ61, Olympus America Inc, Center Valley, PA, USA) to categorize the failure mode into six types: 1) adhesive at the post-cement interface, 2) adhesive at the cement-dentin interface, 3) adhesive mixed at the post-cement-dentin interface, 4) cohesive into dentin, 5) cohesive into cement, and 6) cohesive into post.

Nanoleakage Evaluation

For NL evaluation (n=2 teeth), the slices were immersed in 50 wt% ammoniacal silver nitrate solution for 48 hours and photo developed for eight hours under indirect fluorescent light. After polishing with a wet 600-, 1000-, 1200-, 1500-, 2000-, 2500-, and 4000-silicon carbide paper, each slab was ultrasonically cleaned, mounted, and sputter-coated in a vacuum evaporator (SCD 050, Balzers Union, Balzers, Liechtenstein), and the entire surface was examined using a scanning electron microscope (VEGA 3 TESCAM, Shimadzu, Tokyo, Japan). First, the slices were examined at a magnification of 600× to identify the center region, and then several micrographs were taken at a magnification of 1000×. The relative percentage of NL at the bonded interface was measured with the software Image J (NIH).

In Situ DC Within the Hybrid Layer

For the *in situ* DC determination (n=2 teeth), two bonded slices obtained by the sectioning that had not been used in the PBS were wet polished using 1500- and 2000-grit SiC papers and analyzed through micro-Raman spectroscopy (HORIBA Scientific, Kyoto, Japan) with a 638-nm diode laser, 100× objective, 600 lines/mm grafting centered between 800 and 1800 cm^{-1}, 100 mW of power, and accumulation time of 30 seconds with five coadditions. The spectra were obtained at the dentin-adhesive interface at three random sites (per slice) within the intertubular-infiltrated dentin. The spectra of uncured adhesives were taken as references, and DC was calculated according to Hass and others.[20] The ratio of double bonds of uncured and after curing (monomer to polymer) in the adhesive was calculated according to the following formula: DC(%) = (1 − [R cured/R uncured]) × 100, where R is the ratio of aliphatic and aromatic peak intensities at 1639 cm^{-1} and 1609 cm^{-1} in cured and uncured adhesives.

Statistical Analysis

The data of PBS, NL, and DC of all slices from the same tooth were averaged for statistical purposes. After evaluating the normality (Kolmogorov-Smirnov) and the equality of variances (Bartlett) tests, the data were evaluated by three-way analysis of variance (adhesive system vs adhesive strategy vs root third) and the Tukey test (α=0.05). All of the analyses were performed using the software SPSS (Statistical Package for the Social Science) version 17.0 (SPSS Inc, Chicago, IL, USA). In the case of NL results, the representative images were taken only after the data were collected.

RESULTS

In most specimens, the adhesive (at the cementum-dentin interface) and adhesive-mixed were detected in all experimental groups (data not shown). The obtained results for all bonding properties are shown in Table 2. For all properties, three-way analysis of variance (ANOVA) revealed a statistically significant effect for the cross-product interaction ($p<0.0001$). For all bonding properties, there was no significant difference between adhesive strategies for all of the evaluated adhesives ($p>0.05$).

Push-out Bond Strengths

Considering the PBS, for the adhesives SBU and AMB, the cervical third showed higher values than those of the apical third in both strategies ($p<0.0001$). The exception was AMB-APS, which showed no significant difference when radicular thirds were compared in both adhesive strategies ($p>0.05$). Significant and lower PBS values were

Table 2: *Means and Standard Deviations of Values Obtained by the Push-out Bond Strength (PBS), Nanoleakage (NL), and* In Situ *Degree of Conversion (DC) for All Experimental Conditions*[a]

Experimental Condition	PBS, MPa		NL, %		DC, %	
	ER	SE	ER	SE	ER	SE
AMB-APS						
Cervical	13.6 ± 4.5 AB	11.9 ± 6.2 AB	7.3 ± 1.3 a	7.2 ± 1.1 a	73.9 ± 2.5 [a]	78.6 ± 3.9 [a]
Middle	12.1 ± 5.7 AB	10.9 ± 3.6 BC	8.0 ± 1.7 ab	6.6 ± 1.6 a	65.2 ± 5.0 [b]	65.4 ± 6.2 [b]
Apical	13.6 ± 4.7 A	12.2 ± 3.4 AB	7.9 ± 1.1 ab	6.1 ± 1.1 a	63.3 ± 5.5 [b]	63.2 ± 5.5 [b]
AMB						
Cervical	15.9 ± 2.7 A	13.9 ± 5.5 A	7.1 ± 1.7 a	6.9 ± 0.9 a	71.0 ± 6.2 [a]	73.3 ± 5.6 [a]
Middle	12.3 ± 6.1 AB	10.6 ± 2.8 BC	9.9 ± 1.1 b	7.8 ± 2.2 ab	56.9 ± 6.5 [c]	56.4 ± 3.8 [c]
Apical	8.2 ± 3.3 BC	9.2 ± 4.0 BC	11.3 ± 1.6 c	11.1 ± 2.7 c	45.6 ± 7.8 [d]	52.9 ± 3.8 [cd]
SBU						
Cervical	13.4 ± 4.7 AB	13.6 ± 5.6 AB	8.3 ± 1.1 ab	7.7 ± 1.2 a	75.4 ± 2.3 [a]	74.1 ± 2.7 [a]
Middle	10.44 ± 4.6 BC	10.9 ± 4.4 BC	9.7 ± 1.0 bc	11.1 ± 1.2 c	51.6 ± 4.5 [c]	59.3 ± 6.5 [bc]
Apical	7.5 ± 2.8 C	7.3 ± 2.4 C	11.5 ± 1.1 c	12.2 ± 1.6 c	41.9 ± 1.9 [d]	43.1 ± 5.1 [d]

[a] *Different letters indicate a statistically significant difference for the comparisons inside each property (three-way ANOVA and Tukey test;* $p<0.0001$*). Different uppercase letters are valid for comparisons for PBS, lowercase letters for NL, and superscript lowercase letters for DC.*

observed for SBU and AMB in comparison with AMB-APS in the apical third ($p<0.0001$).

Nanoleakage Evaluation

Considering the NL evaluation (Table 2), the demonstrative scanning electron micrographs of each experimental group are shown in Figure 1. According to the three-way ANOVA (Table 2), for AMB and SBU, the cervical third showed lower NL values than those of the apical third ($p<0.0001$). However, the AMB-APS did not show any significant difference when thirds were compared in both adhesive strategies ($p>0.05$). Moreover, significant and higher NL values for SBU and AMB were observed in comparison with AMB-APS, especially in the apical third ($p<0.0001$).

In Situ DC Within the Hybrid Layer

For the *in situ* DC analysis (Table 2), the middle and apical thirds showed lower *in situ* DC values in comparison with the cervical radicular third for all of the evaluated adhesives ($p<0.0001$). However, AMB-

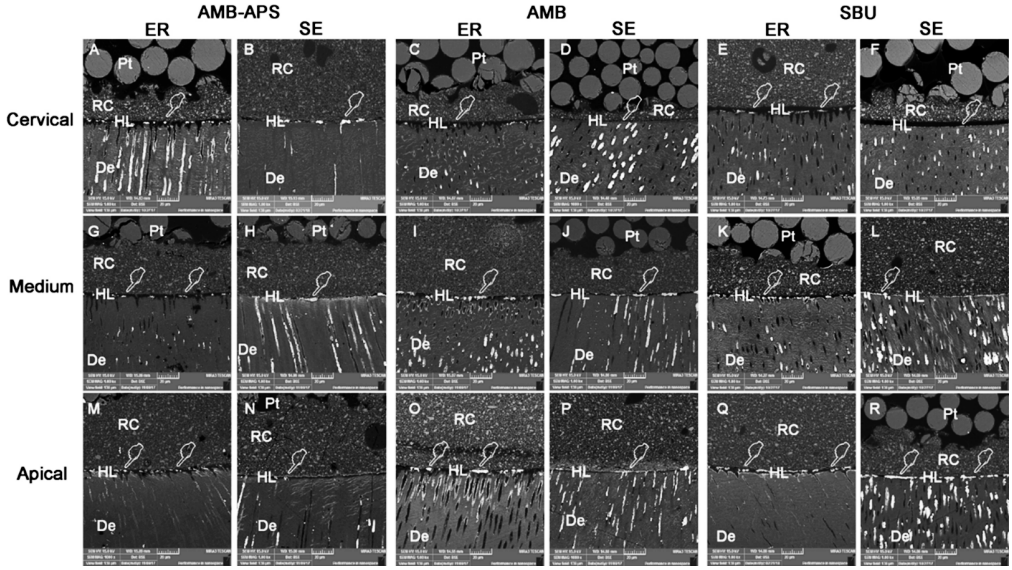

Figure 1. *Representative scanning electron photomicrographs (1000×) of fiber post to radicular dentin interfaces for all experimental groups. Higher silver nitrate uptake (hand indicator) can be observed on the apical third for AMB (figures O and P) and SBU (figures Q and R), in both adhesive strategies. In general mode, the AMB-APS showed the lowest silver nitrate uptake on fiber post-radicular dentin interfaces, especially on the apical third (figures M and N). Pt, post; RC, resin cement; HL, hybrid layer; De, radicular dentin.*

APS did not show any significant difference when middle and apical thirds were compared ($p>0.05$). Significantly higher *in situ* DC values were observed for AMB-APS in comparison with SBU and AMB, especially in the apical third ($p<0.0001$).

DISCUSSION

This study found different performance among the tested adhesives and root thirds. However, there was no difference between the adhesive strategies, leading us to accept the first null hypothesis.

Although mechanical interlocking remains the primary bonding mechanism in immediate bonding, chemical adhesion has become a key to overcome the long-term degradation of dentin-resin interfaces.[21] The phosphate-acid monomer (10-MDP) in all of the adhesives promotes chemical bonds to hydroxyapatite, forming hydrolytically stable calcium salts.[21,22] Considering the universal application concept behind these adhesives, bond strength should not be compromised by the application mode. Therefore, similar results between the adhesive strategies should be expected.[23] Our results confirm that both mechanisms (mechanical and chemical interaction) were able to promote efficient bonding to the tooth substrate, which is the reason for the similar performance between the strategies.

Regarding root thirds, the cervical third presented higher bond strength and *in situ* DC values as well as lower silver nitrate uptake when compared with the apical third for two of the three adhesives evaluated, leading to partial rejection of the second null hypothesis. This performance could be attributed to the better access or visibility for humidity control, suitable solvent evaporation prior to polymerization, and higher radiant exposure by the proximity of the light-curing source.[8,10,24,25] In contrast, the lowest values in the apical third could be explained by the contrary phenomena. The higher water content may cause phase separation of methacrylate adhesives during the photopolymerization, limiting the infiltration of bisphenol A-glycidyl methacrylate and consequently inhibiting the formation of an impervious, structurally integrated resin-dentin interface.[26] In fact, this could be confirmed by the highest NL and lower *in situ* DC values in the apical third. The water and arrested organic solvents within the adhesive layer prevent the approximation between reactive pendant species, making cross-linking reactions inside the hybrid layer more difficult.[27,28] Thus, the polymer backbone may have had its free space greatly augmented in a level directly related to the amount of organic solvent present during polymerization.[29] Consequently, the properties of the adhesive itself[30] and the final bond strength to the dentin substrate are affected.[31,32]

Furthermore, incompletely polymerized adhesive layers contribute to the creation of porous hybrid layers with reduced sealing ability,[33,34] contributing to higher silver nitrate uptake in the apical thirds. In addition, a lower radiant exposure was delivered to the apical third during the polymerization of the adhesive, and hence, fewer free radicals required for the polymerization process were promoted by the amine co-initiator.[35] All of these events certainly contributed to the decrease in *in situ* DC values[10,36] and, consequently, to the reduced bond strength and higher NL in the apical third, explaining the difference among the root thirds.

However, a closer view of all the evaluated universal adhesives showed several different results regarding the evaluated bonding properties, leading to partial rejection of the third null hypothesis. The SBU and AMB systems presented an intense reduction of adhesive properties on the apical third when compared with AMB-APS. The former contains CQ as the photosensitizer molecule and a tertiary amine as co-initiator (CQ/amine system) in the composition, whereas the AMB-APS contains the APS photo-initiator system (Advanced Polymerization System, FGM).

The entire photo-initiated polymerization process is sensitive to initiator and co-initiator systems, types of monomers, and the reaction medium.[14] Universal systems have acidic and hydrophilic monomers required for SE ability.[37] The 2-hydroxyethyl methacrylate (HEMA) contained in adhesive systems induced a notable reduction of photopolymerization and photoreactivity of systems based on CQ/amines,[14,38] such as SBU and AMB. Furthermore, the type of co-initiator affects the rate of polymerization and the final conversion level of hydrophilic adhesives in the presence of water,[14] as these effects were more intense in the apical third. Thereby, since SBU and AMB contain CQ/tertiary amine-based photo-initiator, which has limited polymerization ability in HEMA and water presence, the polymerization of the adhesive system was even more affected on the intrinsically wet apical third, resulting in the poorest bonding properties. This can be confirmed by the Raman results, which demonstrated a significant reduction of DC.

An earlier investigation quantified the components of methacrylate-based adhesive in the hydrophilic-rich phase. This study showed that the

hydrophobic cross-linker and the widely used photo-initiator system, such as CQ and tertiary amines such as ethyl 4-(dimethylamino) benzoate, were present in limited concentrations. This could compromise the photo-polymerization of the hydrophilic-rich phase and result in loosely cross-linked regions, facilitating diffusion of the oral fluid into the resin-dentin interface.[18] Certainly, it would be related to a lower DC and bonding properties promoted by the CQ/amines–based adhesive on radicular dentin. The hydrophobic characteristics of the photosensitizer CQ and the aromatic co-initiator amines could undergo a higher incompatibility because of the humidity of the apical third in addition to the hydrophilic characteristics of adhesive systems. Consequently, the ability of photopolymerization promoted by CQ/amine–based systems was reduced.[38] This effect was the possible reason for the lower performance in the apical thirds for SBU and AMB in comparison with AMB-APS.

As previously mentioned, AMB-APS contained the APS photo-initiator system in its composition. According to the manufacturer, the APS photo-initiator system reduces the amount of CQ, which is balanced by the combination of several photo- and co-initiators acting synergistically. It would contribute to the reduction of incompatibility in the hydrophilic-rich phase promoted by the hydrophobicity of CQ/amines. In fact, a high *in situ* DC was shown in the apical third of the AMB-APS, demonstrating higher polymerization ability even in a wetter environment.

An indirect advantage of adhesives containing APS was recently shown by Oliveira and others.[39] One of the main disadvantages of CQ is its inherently yellowish-brown color, which significantly influences the color of the adhesive resin.[40] Nevertheless, the yellow color partially fades after curing, and the remaining yellow color may possibly cause problems in color matching.[41] Because there is a diminished amount of CQ in the APS system, it is possible to produce an adhesive system (AMB-APS) with higher color stability in comparison with CQ-based adhesives, especially when the final color of thin ceramic veneers is evaluated.[39]

Unfortunately, the exact composition of each universal adhesive is proprietary information. However, as previously shown, the addition of a third and more-hydrophilic component in the hydrophobic photo-initiator system seems an interesting approach.[14,42] In an earlier study, visible-light photo-initiator systems were investigated using formulations with the combination of hydrophobic (CQ) and several hydrophilic photosensitizers and hydrophilic co-initiators.[42] The authors showed that the addition of a third and more-hydrophilic component to a photo-initiator system reduced the detrimental effects of nanoscale phase separation. This means that, if active radicals are produced by both hydrophobic and hydrophilic initiators, these different phases can be polymerized effectively, consequently improving polymerization of both hydrophilic and hydrophobic domains.[42] Furthermore, the addition of other more hydrophilic co-initiators to a photo-initiator system increased the photopolymerization and photo-reactivity of hydrophilic monomers because of the ability to keep the energy level more stable during the excited state of CQ.[14]

Another hypothesis is that an APS photo-initiator system can keep this energy level more stable during excitation of CQ, as previously shown by Ilie and others.[43] According to these authors, this higher stability of the CQ molecule is an interesting form to recycle the CQ molecule and then potentialize its action.[43] Therefore, the outcome would be an increase in polymerization. The addition of hydrophilic components would become more compatible with wet substrates, as shown in the present study, not only in terms of higher *in situ* DC values and bond strength in the apical third but also in the reduction of silver nitrate uptake. Future studies need to be done to prove these hypotheses related to the APS photo-initiator system when associated with different adhesive substrates, and long-term studies should be conducted to evaluate the bonding performance of the post to radicular dentin.

CONCLUSIONS

The use of the APS photo-initiator system contained in universal adhesive systems showed an improvement in bonding properties (higher PBS, lower silver nitrate uptake, and higher *in situ* DC values), mainly in the apical third. This approach seems to be an interesting alternative to overcome the challenges of the radicular bonding procedure.

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Regulatory Statement

This study was conducted in accordance with all the provisions of the local human subjects oversight committee

guidelines and policies of the Ceuma University. The approval code issued for this study is 2.408.873.

Conflict of Interest

The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

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