

RESEARCH AND EDUCATION

Bond strength durability of self-adhesive resin cements to zirconia ceramic: An in vitro study



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In recent years, the use of zirconia ceramics in prosthetic dentistry has increased rapidly as a result of its favorable esthetics, biocompatibility, and mechanical properties.^{1,2} Zirconia restorations can be luted with conventional cements³; however, resin cements show a long-term durable bond to zirconia after airborne-particle abrasion.⁴⁻⁶ Conventional adhesive resin cement procedures for luting glass-ceramic-based restorations include hydrofluoric acid etching followed by silane treatment.⁷ However, this protocol is not recommended for zirconia because it does not contain a glass phase to be selectively etched.^{8,9} The best surface treatment protocol for achieving a durable long-term

ABSTRACT

Statement of problem. How contamination, cleaning, and artificial aging affect the bond strength of self-adhesive resin cements to zirconia ceramics is unclear.

Purpose. The purpose of this in vitro study was to assess the durability and bond strength of different self-adhesive resin cements to zirconia ceramics subjected to contamination, cleaning, and aging.

Material and methods. A total 192 zirconia ceramic squares were airborne-particle abraded with 50 μm Al_2O_3 at a pressure of 100 kPa. The specimens were then divided into 4 main experimental groups ($n=48$) according to the type of self-adhesive resin. Specimens in the subgroups ($n=16$) were exposed to 3 different treatment methods: alcohol bath cleaning only, contamination with saliva and alcohol bath cleaning, and contamination with saliva and cleaning with Ivoclean followed by alcohol bath cleaning. Bonded specimens were stored in distilled water (37°C), either for 3 days with no thermocycling or for 150 days interrupted by 37 500 thermocycles between 5°C and 55°C. After storage, the bond strength was determined using a universal testing machine. Results were analyzed statistically, using nonparametric tests.

Results. After saliva contamination, the tensile bond strength for all specimens decreased significantly ($P<.001$). Furthermore, after saliva contamination and during 150 days of water storage with thermocycling, all specimens debonded spontaneously. However, use of the cleaning medium (Ivoclean) significantly increased the tensile bond strength for almost all specimens ($P<.05$).

Conclusions. Saliva contamination significantly negatively influenced the bond strength and durability to zirconia ceramic. Ceramic cleaning using Ivoclean significantly improved the bond strength to saliva contaminated zirconia ceramics. (*J Prosthet Dent* 2019;121:477-84)

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Clinical Implications

Use of a newly developed cleaning medium appears to be a promising approach to improve the bond strength of self-adhesive resin cement to saliva-contaminated zirconia ceramics. However, avoiding any saliva contamination of the conditioned zirconia ceramic is best.

chemical bond to zirconia is abrading the intaglio surface with alumina particles under low air pressure and priming with 10-methacryloyloxydecyl dihydrogen phosphate monomer (MDP).¹⁰⁻¹⁴ High initial bond strength values have been reported when using MDP-containing resin cements because of effective bonding between MDP acidic groups and zirconium oxide.^{6,10,15,16}

Recently, MDP-containing self-adhesive resin cements have been introduced as effective agents for improving bonding to zirconia restorations.¹⁷⁻¹⁹ Self-adhesive cements accelerate the clinical procedure because of the absence of etching and/or adhesive steps.^{19,20} In addition, self-adhesive resin cements have a higher shear bond strength²¹ and better compressive strength²² and marginal seal than conventional luting cements.^{23,24} However, self-adhesive cements have a low pH,²⁵ and the acid groups join with calcium hydroxyapatite to form a stable bond between the methacrylate network and tooth.²⁶

Pretreated restorations are typically evaluated in the mouth, which leaves them contaminated with evaluation paste, blood, and saliva.²⁷ Saliva contamination has a negative influence on the bond strength of a restoration to tooth surface.^{10,28,29} Airborne-particle abrasion of the intaglio surface of zirconia restorations with Al₂O₃ particles is considered the only cleaning method that allows reliable adhesion after saliva contamination.²⁸ The use of a product (Ivoclean; Ivoclar Vivadent AG) composed of a hypersaturated solution of zirconia particles in sodium hydroxide to clean the intaglio surfaces of the zirconia may enhance the bond strength of adhesive resin cement to zirconia. The manufacturer claims that application of this paste to saliva-contaminated zirconia effectively cleans saliva-contaminated bonding surfaces. However, the cleaning efficacy of such cleaning solutions on saliva-contaminated zirconia in terms of resin zirconia bonding is unknown (Ivoclar Vivadent AG. Ivoclean: Scientific documentation. 2011).

The purpose of this *in vitro* study was to evaluate the durability and bond strength of different self-adhesive resin cements to zirconia ceramic subjected to contamination, cleaning, and aging. The null hypothesis was that self-adhesive resin cements, cleaning strategies, and

artificial aging do not affect the tensile bond strength (TBS) to zirconia ceramic.

MATERIAL AND METHODS

A list of materials used in this study is presented in Table 1. In total, 192 squares (10×10×4 mm) of densely sintered zirconia ceramic (Zenostar Zr Translucent Medium; Wieland Dental+Technik GmbH & Co KG) were tested. Specimens were polished in an automated grinder polisher (EcoMet/AutoMet 250 Pro; Buehler), using rotating silicon carbide paper (SiC grinding paper; Buehler GmbH) to 600 grit under cool water and constant pressure. Subsequently, specimens were divided into 4 experimental groups (n=48) as follows, according to the types of self-adhesive resin cements being investigated (Fig. 1): SPC (SpeedCem; Ivoclar Vivadent AG); RUC (RelyX Unicem2 Automix; 3M ESPE); PSA (Panavia SA Cement Plus Automix; Kuraray Noritake); and BSE (Bifix SE; VOCO). All groups were divided into 3 subgroups (n=16). Specimens in the first subgroup (non-contaminated group) were only airborne-particle abraded with 50 μm Al₂O₃ at 100 kPa for 15 seconds at 10 mm. Afterward, specimens were ultrasonically immersed in 99% isopropanol bath for 3 minutes prior to bonding.

Specimens in the second subgroup (saliva-contaminated group) were first treated in the same manner as their counterparts in the first subgroup. Then they were contaminated with saliva. Saliva was collected from 1 healthy author (A.A.) who had abstained from eating and drinking for 1.5 hours prior to the collection process. By using a microbrush, saliva was distributed for 10 seconds, and the saliva layer was left for 60 seconds to take effect. The contaminated surface was then washed with water spray for 15 seconds and dried by applying a gentle oil- and water-free compressed air stream. The test specimens were ultrasonically cleaned in 99% isopropanol bath for 3 minutes prior to bonding.

Specimens in the third subgroup (contaminated and cleaned group) were first treated in the same manner as their counterparts in the second subgroup, except for the last step (alcohol bath cleaning protocol). Instead, specimens were first cleaned with a cleaning medium (Ivoclean; Ivoclar Vivadent AG). The cleaning medium was applied by using a microbrush and then distributed over the contaminated surface for 10 seconds. The layer was left for 20 seconds to take effect. Subsequently, the cleaned surface was washed with water spray for 15 seconds. Thereafter, specimens of the third subgroup were ultrasonically cleaned in 99% isopropanol bath for 3 minutes prior to bonding. The alcohol supernatant was blown off with a gentle compressed air stream (for all subgroups), and specimens were allowed to dry for 3 minutes.

Table 1. Composition and manufacturer information of materials used

Material used	Composition	Manufacturer	Batch No.
SpeedCem	Base: dimethacrylates, glass fillers (base only), silicon dioxide initiators, stabilizers and pigments. Catalyst: dimethacrylates, ytterbium trifluoride, co-polymer, glass fillers (base only), silicon dioxide, adhesive monomer, initiators, stabilizers and pigments	Ivoclar Vivadent AG	T 12 246
RelyX Unicem2 Automix	Base: methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers, initiator components, stabilizers, rheological additives Catalyst: methacrylate monomers, alkaline fillers, silanated fillers, initiator components, stabilizers, rheological additives, pigments	3M ESPE	575 033
Panavia SA Cement Plus	Paste A: 10-methacryloyloxydecyl dihydrogen phosphate (MDP), bis-phenol A diglycidylmethacrylate (Bis-GMA), triethyleneglycol dimethacrylate (TEGDMA), hydrophobic aromatic dimethacrylate, dl-camphorquinone, benzoyl peroxide, initiator, silanated barium glass fillers, silanated colloidal silica Paste B: Bis-phenol A diglycidylmethacrylate (Bis-GMA), hydrophobic aromatic dimethacrylate, hydrophobic aliphatic dimethacrylate, accelerators, pigments, surface treated sodium fluoride, silanated barium glass filler, silanated colloidal silica	Kuraray Noritake	880 012
Bifix SE	Base: dimethacrylates (Bis-GMA, UDMA, Gly-DMA) fillers: glass, co-initiator, photoinitiator, polyfunctional adhesive monomers (phosphate monomers), stabilizers. Catalyst: dimethacrylates, fillers, SC initiator.	VOCO	1432 436
MultiCore Flow	Dimethacrylates, inorganic fillers, ytterbium trifluoride, initiators, stabilizers, pigments cont. composite	Ivoclar Vivadent AG	T 21 661
Ivoclean	Zirconium oxide, water, polyethylene glycol, sodium hydroxide, pigments, additives	Ivoclar Vivadent AG	T 27 107

Acrylic resin tubes (192 tubes) with an inner diameter of 3.3 mm were filled with dual-polymerizing composite resin (MultiCore Flow; Ivoclar Vivadent AG) (Fig. 2). After 7 minutes of mixing, the filled tubes were bonded at their tube bonding side with the specified self-adhesive resin cements to the ceramic squares using an alignment apparatus. A detailed description of the alignment apparatus has been previously published.^{7,30} All self-adhesive resin cements were applied with a mixing tip. Excess cement was removed from the bonding margins using foam pellets, and an oxygen-blocking gel (Liquid Strip; Ivoclar Vivadent AG) was applied with a syringe along the bonding margins to prevent the formation of an oxygen-inhibited polymerization layer. Subsequently, the bonding margins were light polymerized from 2 opposite sides for 20 seconds each and at 0.5 cm from the halogen polymerizing light source (ELIPAR 2500; 3M ESPE). To ensure complete polymerization, the specimens were subjected to an additional 90 seconds of light polymerization in a xenon strobe light-polymerizing unit (Dentacolor Uni XS; Kulzer GmbH). Thereafter, bonded specimens were stored in a dry-heat oven (Memert) at 37°C for 7 minutes.

Each bonded subgroup (n=16) was divided into 2 subgroups (n=8) according to the applied artificial aging procedure. One subgroup was stored for 3 days in 37°C distilled water without thermocycling, whereas the other subgroup was stored for 150 days (long-term storage) in 37°C distilled water interrupted by 37 500 thermocycles between 5°C and 55°C with a dwell time of 30 seconds.

TBS tests were performed at a crosshead speed of 2 mm/min in a universal testing machine (Z 010/TN2A; Zwick GmbH & Co KG), using a chain loop alignment.^{7,30} The debonded interfaces of the zirconia ceramic specimens were examined using light microscopy (Wild Makroskop M 420) at ×20 magnification to calculate the debonded area. This area was assigned to adhesive failure at the ceramic surface or cohesive failure in the self-adhesive resin cement or in the tube filling composite resin. Observed areas of each failure mode were calculated and expressed as a percentage of the total bonding surface area for each test group.

Representative specimens were then examined using scanning electron microscopy (SEM) (XL 30 CP'; Philips) with an acceleration voltage of 15 kV and working distance of 10 mm (Fig. 3). Data were statistically analyzed using statistical software (IBM SPSS Statistics, v21.0; IBM Corp). Data were not normally distributed (Shapiro Wilk test), so statistical analysis was conducted using the Kruskal-Wallis test, followed by multiple pairwise comparisons of groups and subgroups with the Mann Whitney *U* test ($\alpha=.05$ corrected using the Holm Bonferroni method).

RESULTS

Medians of TBS (MPa) of the tested groups are shown in Table 2. Almost all clean specimens showed relatively high initial TBS, which decreased significantly after 150 days of water storage with thermocycling. After saliva contamination, TBS for all specimens significantly

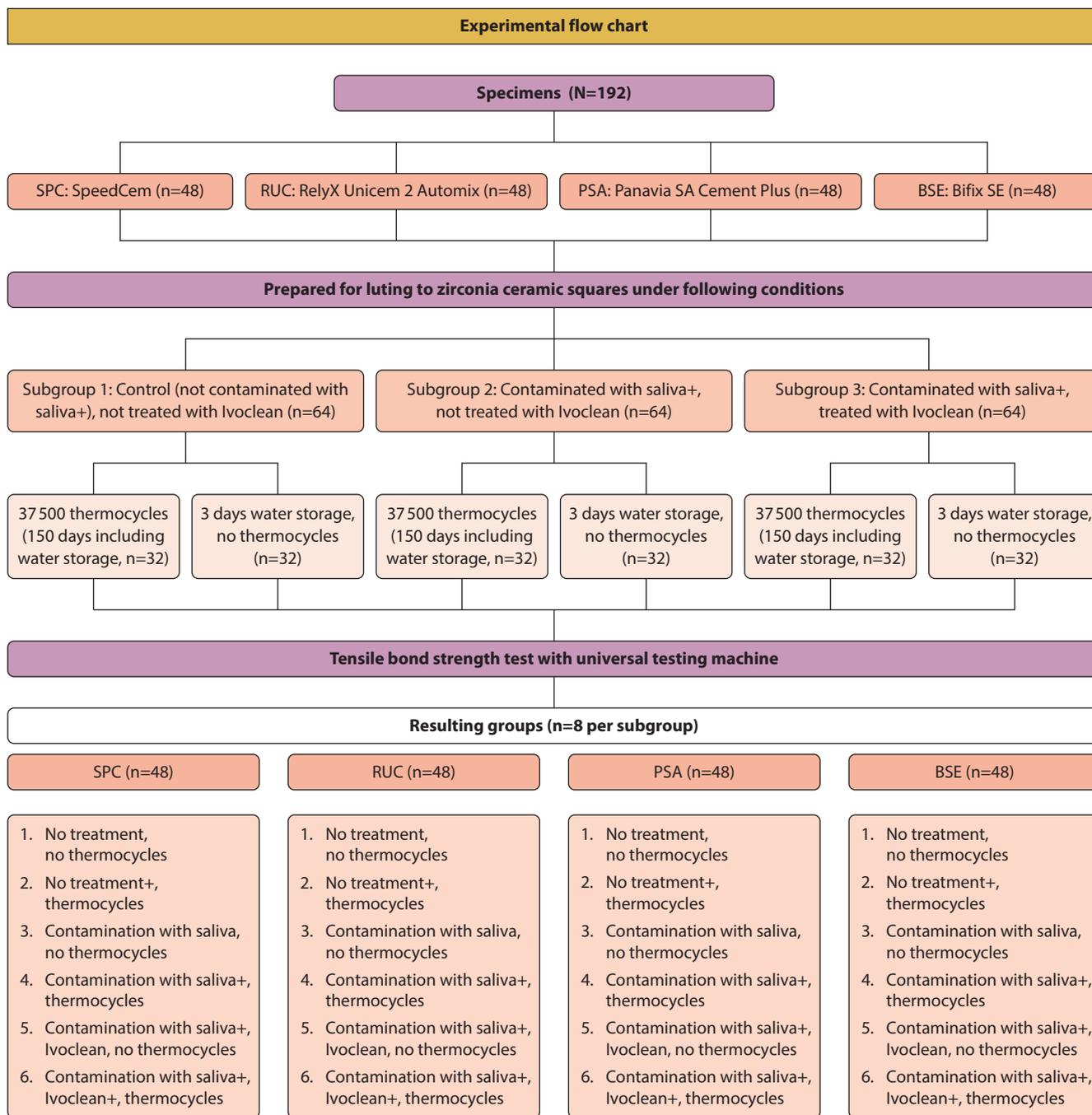


Figure 1. Studied groups and subgroups flow.

decreased. However, after saliva contamination and during 150 days of water storage with thermocycling, all specimens debonded spontaneously. Using the cleaning medium (Ivoclean; Ivoclar Vivadent AG), the TBS significantly increased for all specimens ($P \leq .05$).

Failure mode examination was conducted using light microscopy at $\times 20$ magnification and calculated in percentages of the bonding areas for all groups (Table 3). Initially, after 3 and 150 days of water storage, the failure modes that were not subjected to saliva contamination

were mostly cohesive in the self-adhesive resin cement or tube filling composite resin for all groups, except for BSE, in which the failure mode after 150 days of water storage and thermocycling was completely adhesive (between zirconia and self-adhesive resin cement). In all groups with saliva contamination and without treatment, the failure modes were mostly adhesive for all specimens after 3 and 150 days of water storage. After 3 days of water storage, the failure modes with saliva contamination and cleaning medium treatment were mostly cohesive for

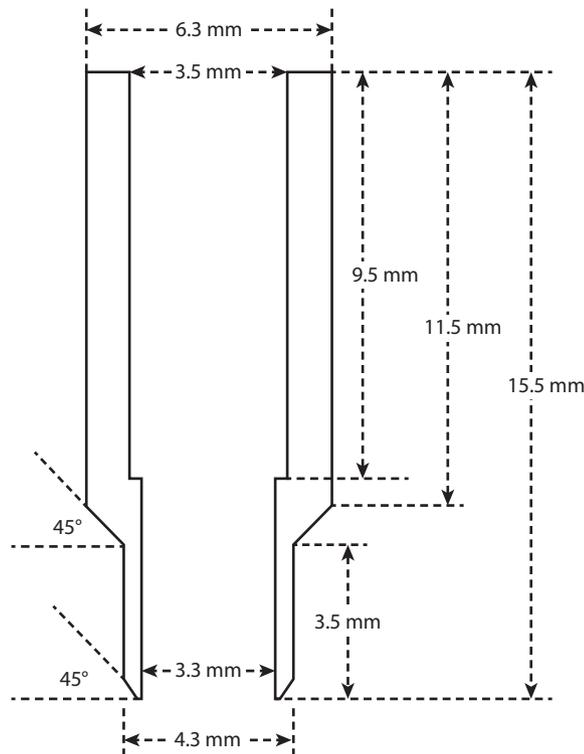


Figure 2. Schematic and dimensions of acrylic resin tube.

all groups. However, after 150 days of water storage and thermocycling, the failure modes with saliva contamination and cleaning medium treatment were mostly equally distributed between cohesive and adhesive failure, except for the BSE group, in which the failure mode after 150 days of water storage and thermocycling was completely adhesive (between zirconia and self-adhesive resin cement). The examination of typical specimens using SEM verified the failure modes detected with light microscopy in all groups; SEM photographs with typical examples of adhesive and cohesive failure modes can be seen in [Figure 3](#).

DISCUSSION

The purpose of this *in vitro* study was to evaluate the long-term durability of bonding to zirconia by using different self-adhesive resin cements and different zirconia surface pretreatments. Self-adhesive resin cements were chosen because they have the advantages of ease of handling, good mechanical properties, good esthetics, and improved adhesion to teeth and ceramic substrates.¹⁷ Long-term water storage and thermocycling are well-established artificial aging methods used for laboratory bond strength tests. The combination of these 2 important parameters to simulate oral conditions can affect the durability of resin bond strength to zirconia ceramic.³¹ Laboratory bond tests after long-term oral condition simulation should be performed before clinical

recommendations can be provided. Therefore, in this *in vitro* study, the effects of artificial aging on the bond strength durability of 4 self-adhesive resin cements to zirconia subjected to contamination and cleaning procedures were evaluated. In this study, airborne-particle abrasion was used because this method cleans the bonding surface and increases roughness, surface area, and surface energy and therefore the wettability of zirconia surfaces.^{11,16} Moreover, airborne-particle abrasion may generate hydroxyl groups on the zirconia surfaces, facilitating the chemical reaction with phosphate monomer containing self-adhesive resin cement.^{11,13}

The first part of the null hypothesis was partially accepted (except for the BSE group); the type of self-adhesive resin cement had no significant effect on TBS. This result may be attributed to the presence of phosphate monomer in self-adhesive resin cements. Hydroxyl groups in phosphate monomer-containing luting resin cements may react with the hydroxyl groups on the zirconia ceramic surface.³² Kern and Wegner¹⁶ investigated bonding to Y-TZP ceramic by using various bonding systems. They concluded that durable bonding to Y-TZP can be achieved by using luting agents containing a phosphate monomer. In the meantime, it is generally accepted that primers, adhesives, and resin luting agents containing a phosphate monomer promote durable bonding to zirconia ceramics.⁶ Differences in chemical and physical properties of self-adhesive resin cements may affect the bonding mechanism and bonding durability to zirconia ceramic.^{19,24}

Integration of adhesive phosphate monomers in the chemical composition of self-adhesive resin cements promotes chemical bonding to zirconia ceramic.^{6,11,16} Bifix SE cement revealed the lowest TBS, although it contains phosphate monomers. From a physical perspective, the viscosity of BSE cement might have hindered the resin material flowing into the irregularities of the airborne-particle abraded zirconia surface; that is, it could not wet the entire bonding surface efficiently, thereby reducing the bonding sites and consequently the intimate interaction with the bonding surface.³³ Another reason for low TBS might have been the low surface energy parameters of the luting material.³² From a chemical perspective, the functional phosphate monomer incorporated into BSE cement might have had less efficacy (chemical affinity) to establish a strong chemical bond to ZrO_2 than the functional phosphate monomers incorporated in the other investigated self-adhesive resin cements, such as the MDP contained in Panavia SA Cement Plus.^{14,32} This factor, in turn, might have manifested in markedly lower initial bond strength to zirconia surface. Moreover, purity, and concentration of the functional phosphate monomer might have influenced the chemical interaction of Bifix SE cement with zirconia surface.³⁴

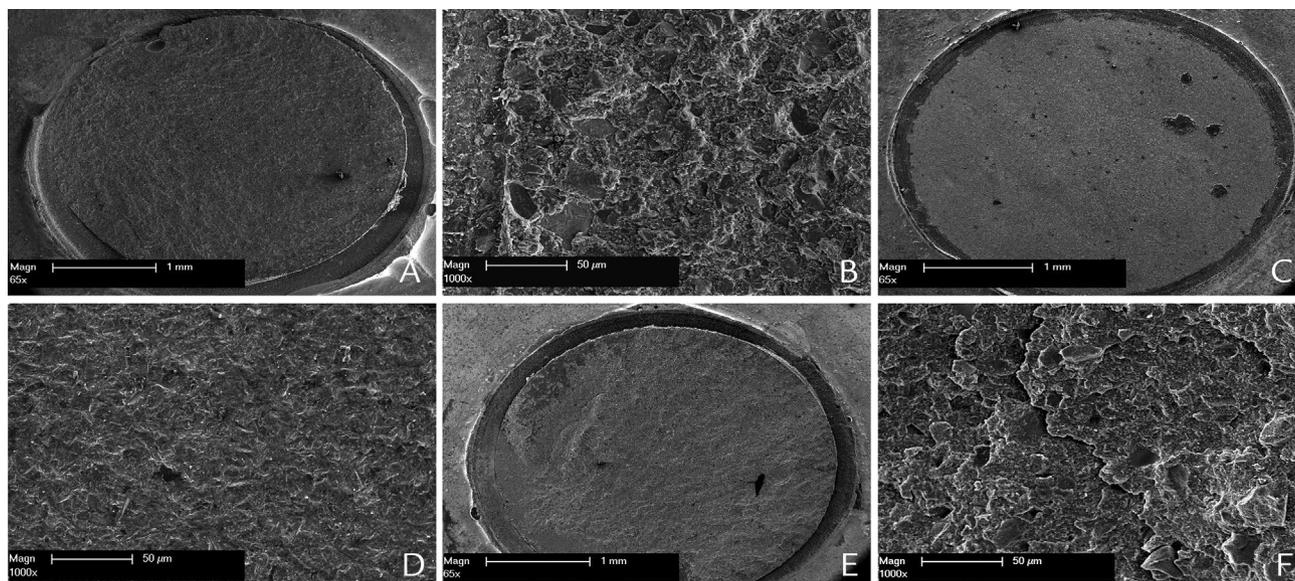


Figure 3. Scanning electron micrographs of debonded specimens. A, Without contamination, demonstrating cohesive failure (original magnification $\times 65$). B, High-magnification image (original magnification $\times 1000$). C, Saliva contamination without cleaning, demonstrating adhesive failure (original magnification $\times 65$). D, High-magnification image (original magnification $\times 1000$). E, Saliva contamination and Ivoclean application, demonstrating mostly cohesive failure (original magnification $\times 65$). F, High-magnification image (original magnification $\times 1000$).

A synergistic coupling of physical and chemical factors might have eventually resulted in the low TBS of BSE. The TBS values for all self-adhesive resin cements were not significantly different when measured under the same aging conditions (except for BSE cement). This result was consistent with a preliminary report that also showed no significant difference between self-adhesive cements measured under the same aging condition.²⁰ However, significant differences were found among the aging conditions for the same cement (Table 2). The highest TBS for all cements was observed after 72 hours of water storage, that is, with no artificial aging.

Water storage and thermocycling lowered the TBS compared with the values observed at 72 hours (Table 2), which agrees with the findings of previous studies.^{10,11,35} This result may be attributed to the fact that long-term water storage and thermocycling deteriorate the bonding interface. In comparison with conventional resin cements, self-adhesive resin cements are more hydrophilic due to the high content of acidic phosphate functional monomers; as a result they show higher water sorption and, consequently, may be more prone to hydrolytic degradation.³⁶ Of particular importance is the resin cement-zirconia interface. Water molecule diffusion into the bonding interface may weaken the bond strength by means of hydrolytic degradation. Additionally, thermal stress induced by the difference in coefficients of thermal expansion between zirconia and luting resin cement during thermocycling could favor further hydrolytic degradation of the bonding interface.³¹ Therefore, the second part of the null hypothesis was rejected because

Table 2. Medians of tensile bond strength (MPa) of tested self-adhesive cements without and with contamination and cleaning

Saliva Contamination	Resin Cement	Water Storage and Thermocycling		P*
		3 Days WS	150 Days WS/TC	
No saliva contamination	SPC	27.6 _z ^{ABa}	20.7 _z ^{Ab}	.038
	RUC	28.7 _z ^{Aa}	15.8 _z ^{Ab}	.002
	PSA	29.2 _z ^{Aa}	14.2 _z ^{Ab}	<.001
	BSE	19.5 _z ^{Ba}	0.0 _z ^{Bb}	<.001
p**		.024	<.001	
Saliva contamination with alcohol cleaning only	SPC	2.8 _z ^{Ba}	0.0 _z ^{Aa}	.077
	RUC	0.0 _z ^{Ba}	0.0 _z ^{Aa}	1
	PSA	0.0 _z ^{Ba}	0.0 _z ^{Aa}	1
	BSE	7.3 _z ^{Aa}	0.0 _z ^{Ab}	.001
p**		<.001	1	
Saliva contamination with Ivoclean treatment and alcohol cleaning	SPC	33.1 _z ^{Aa}	8.5 _z ^{Ab}	.001
	RUC	17.7 _z ^{Ba}	8.1 _z ^{Ab}	<.001
	PSA	18.6 _z ^{Ba}	9.3 _z ^{Ab}	.05
	BSE	14.6 _z ^{Ba}	0.0 _z ^{Bb}	<.001
p**		<.001	.01	

BSE, Bifix SE; PSA, Panavia SA Plus; RUC, RelyX Unicem 2 Automix; SPC, SpeedCem; TC, thermocycling; WS, water storage. *Mann-Whitney *U* test. **Kruskal-Wallis test. Significance determined at .05 and corrected for multiple testing using Holm-Bonferroni method. Within each column, considering each saliva contamination status individually (comparison by used cement), different superscript uppercase letters indicate statistically significant differences ($P \leq .05$). In each column, considering each cement individually (comparison by saliva contamination status), different subscript Greek letters indicate statistically significant differences ($P \leq .05$). Within same row, different superscript lowercase letters indicate statistically significant differences ($P \leq .05$).

artificial aging significantly affected the TBS to zirconia. The TBS obtained from self-adhesive resin cements to zirconia ceramic before and after artificial aging agreed with the results of previous studies.^{14,27,28}

Table 3. Ratio of adhesive to cohesive bonding failure mode as identified with light microscopy at magnification $\times 20$ (% of bonding area)

Saliva Contamination	Group	3 Days		150 Days	
		Adhesive	Cohesive	Adhesive	Cohesive
No saliva contamination	SPC	14%	86%	15%	85%
	RUC	6%	94%	16%	84%
	PSA	13%	87%	23%	77%
	BSE	26%	74%	100%	0%
Saliva contamination with alcohol cleaning only	SPC	98%	2%	100%	0%
	RUC	100%	0%	100%	0%
	PSA	100%	0%	100%	0%
	BSE	98%	2%	100%	0%
Saliva Contamination with Ivoclean treatment and alcohol cleaning	SPC	21%	79%	47%	53%
	RUC	22%	78%	63%	37%
	PSA	25%	75%	53%	47%
	BSE	34%	66%	100%	0%

BSE, Bifix SE; PSA, Panavia SA Plus; RUC, RelyX Unicem 2 Automix; SPC, SpeedCem.

The third part of the null hypothesis was rejected because contamination with saliva significantly reduced the bond strength ($P < .05$). This result was in agreement with those of previous studies.^{10,27,28} Saliva contamination may deposit an organic adhesive coating, which is resistant to cleaning with water and isopropanol, on the bonding surface of restorative materials.²⁷ The Ivoclean medium was recommended by the manufacturer for cleaning saliva-contaminated zirconia surface (Ivoclar Vivadent AG. Ivoclean: Scientific documentation. 2011).

The manufacturer of the cleaning medium claims it absorbs phosphate contaminants and leaves behind a clean zirconia surface. Cleaning the contaminated surface of all groups with the cleaning medium yielded initial TBS results that were generally lower than those of uncontaminated groups. The decrease in TBS for all contaminated and cleaned groups was more remarkable after 150 days of artificial aging, which was consistent with the findings of a previous study.²⁹ According to Ishii et al,²⁹ this may be attributed to the presence of residual agglomerated small particles of the cleaning medium on the zirconia ceramic surface.

The failure modes of the tested groups were investigated by optical microscopy and SEM. For groups with only airborne-particle abrasion, mostly cohesive failure modes were detected after 3 days (Table 3). Moreover, cohesive failure modes were still dominant for these untreated groups after 150 days of water storage with thermocycling (except for the BSE group), suggesting even stronger chemical bonding to the zirconia surface, despite the significant decrease in bond strength after artificial aging (Table 3, Fig. 3A, B). Values obtained by microscopic inspection of bonding failure mode (Table 3) were consistent with the results obtained by the TBS test (Table 2). This may support the fact that investigated

self-adhesive resin cements, except for BSE, showed strong and durable bond strength to clean zirconia substrates. However, groups which were contaminated with saliva showed nearly complete adhesive failure after 3 days of water storage without thermocycling (with a small amount of residual luting resin on the adhesively failed surfaces) and complete adhesive failure modes (100%) after 150 days of water storage with thermocycling (Table 3) (Fig. 3C, D). This may be attributed to the lack of chemical bonding to the ceramic surface, caused perhaps by the presence of an insulating contamination layer that was not removed by the alcohol cleaning procedure.²⁷

With cleaning media, all groups showed mostly cohesive failure mode after 3 days of water storage (Fig. 3E, F). Cohesive failure mode representing values obtained for the groups treated with the cleaning medium were consistent with the TBS test results of these groups after 3 days of water storage. After 150 days of water storage with thermocycling, a decrease was found in the cohesive failure mode and an increase in the adhesive failure mode values of the groups treated with the cleaning medium. These findings clearly reflected the decrease in TBS of these groups. The findings obtained in the present study can be used to compare the cements tested and the findings of other studies with similar methodology. Clinical studies are needed to confirm the findings of this in vitro study.

CONCLUSIONS

From the findings of this in vitro study, the following conclusions were drawn:

1. No significant differences in TBS to zirconia were observed in 3 of the 4 self-adhesive cements tested in the study.
2. The aging process significantly affected the TBS of the 4 tested self-adhesive resin cements to zirconia.
3. Cleaning the contaminated surface of all groups with the cleaning medium significantly improved the TBS of the 4 tested self-adhesive resin cements to zirconia. However, it did not restore the TBS to the same level as uncontaminated specimens.

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