Long-term success of indirect restorations is associated with accurate luting procedures, among other factors. Resin cements have been recommended for luting densely sintered, high-strength oxide ceramics, such as zirconia, in order to improve the retention and sealing of indirect restorations. The use of phosphate monomer–containing composite cements in association with specific surface pre-treatments (such as airborne-particle abrasion or silica-coating) of zirconia-based prostheses is currently suggested to develop satisfactory bonding to coronal dentin. Other classes of commonly used cements, such as resin-modified glass-ionomers (RMGI), have demonstrated lower initial and long-term bond strengths to zirconia than phosphate monomer–containing composite cements.

Purpose: To evaluate the amount of residual cement (ECL) around the margins of zirconia crown copings after careful luting and cleaning procedures and to investigate these factors in relation to two tested luting materials. Materials and Methods: An experimental model of a maxillary arch was selected for this in vitro study. The maxillary first molar was prepared to receive an all-ceramic, single, full-crown restoration with a finish line located 1 mm below the artificial gingiva. After scanning of the prepared tooth, 20 paired zirconia coping–abutment assemblies were CAD/CAM fabricated. A slot in the model allowed for insertion and removal of the assemblies for each new test. Specimens were divided into two groups according to the cementation procedure: half (n = 10) were luted using a resin-modified glass-ionomer (RMGI) (Ketac-Cem Plus) (GI group), and the other half with a dual-curing self-adhesive resin agent (RelyX Unicem 2) (UN group). The substructures were loaded with cement, and a customized preseating device was adopted for preliminary reduction of excess. The zirconia copings were finally seated on their respective abutments located on the simulation model. A blinded investigator attempted to remove all excess cement with clinically available instruments. The amount of excess cement left in situ after cleaning procedures was weighed in grams. Dislodging forces of luted coping-abutment assemblies were obtained by using pull-off tests in a universal testing machine (crosshead speed of 0.5 mm/minute) after 24 hours of water storage. Means and standard deviations were calculated for ECL and for retention force values, and Mann-Whitney and ANOVA tests were carried out to detect significant differences (α = .05) among groups. Results: Cement remnants were found in all specimens despite the cleaning procedures, with a typical distribution in interproximal areas. Mean ECL values for the GI and UN groups were 0.0079 ± 0.0060 and 0.0107 ± 0.0081, respectively. No statistically significant differences were found between tested cements (P = .3284). Removal stress values (MPa) were significantly higher (P = .0313) for the UN group (12.4 ± 6.5) than for the GI group (6.57 ± 4.69). Conclusion: Similar amounts of undetected cement remnants were discovered around the esthetic margins of zirconia crown copings regardless of cement type. The luting procedure using the self-adhesive resin cement provided significantly higher early retention values than the RMGI material.

hand, the use of RMGI cements might be attractive due to their handling properties (eg, automix formulations and tack curing options), technique simplicity (reduction of steps for tooth/prosthetic conditionings), or for cases of subgingival margins (relative moisture conditions). RMGI cements might represent an alternative for zirconia cementation in selected restorative cases or when retention is not critical. Despite their benefits for retention, resin cements may raise other clinical challenges during luting procedures, as partial or incomplete removal of excess material flowing outside the marginal areas of restorations has been documented. Polymerized resin remnants may be found on unprepared areas of the tooth or settle down on root cement and dentin. In other cases, unwanted adhesion to prosthetic frameworks/substructures is possible. For example, suboptimal removal of excess luting materials has been clinically described on the adjacent tissues and abutments of cement-retained implant prostheses. Excess cement at tooth-restoration interfaces promotes bacterial adhesion and biofilm development due to surface irregularities and increased roughness. Soft tissue inflammation and dental hard tissue demineralization are potential problems related to increased plaque accumulation on surface discontinuities. Recent histologic findings have revealed an increased number of inflammatory cells and periodonto-pathogens associated with cement-retained implant restorations. Large amounts of luting agent might be extruded at marginal areas, as reported by some studies on cement-retained implant prostheses. According to the results of Al-Johany et al, 84% (33.48 ± 1.55 mg) of the total loaded cement might be expressed at crown-abutment interfaces when the intaglio surface of the restoration is half-filled. In research by Zaugg et al, zirconia crowns were filled in their occlusal half, but the cement was then distributed with a microbrush on all inner surfaces. With this technique, 65.7% of the total loaded material was extruded at the margins. In other words, depending on the selected luting technique, the clinician should be prepared to clean up extensive, unnecessary amounts of extruded cement; but, unfortunately, there might be some left behind. The type of cement and its inherent properties might have an influence on the amount of excess material expressed at the crown margin. More relative cement excess has been produced with the glass-ionomer cement—possibly due to its lower viscosity—than with the tested adhesive composite material. A study on excess cement removal from titanium abutments revealed more remnants for a resin cement with respect to zinc phosphate or conventional glass-ionomer materials, suggesting differences regarding their ease of removal.

New cementation techniques have been proposed for cement-retained implant restorations in order to reduce the amount of residual excess cement. Usually these techniques are based on presenting the restoration loaded with a luting agent on abutment replicas or intaglio surface duplication. With these proposed devices/techniques, preliminary extraoral cementation is possible. Similar techniques could also be applied for the cementation of traditional tooth-supported all-ceramic prostheses. Information regarding the removal of excess cement from zirconia-based, all-ceramic crowns is limited and mainly focused on luting to standardized implant abutments; however, the abutments usually differ in shape and size from the configuration of natural abutments/teeth preparations. In addition, the effect of different classes of luting agent on excess cement removal should be further explored.

The aim of this in vitro study was to evaluate the removal of excess cement from computer-aided design/computer-assisted manufacture (CAD/CAM)–produced zirconia copings cemented on molar abutments using two different types of luting agent. An experimental model was developed to assess the amount of remnants left in situ after luting and cleaning procedures. In addition, the retention force of the copings was measured with uniaxial dislodgment tests in a universal testing machine. The same ease of removal and retentive performances were hypothesized for the two luting materials.

**MATERIALS AND METHODS**

**Mouth Simulation Model**

An experimental stone model replicating the maxillary arch was selected for the study. The mouth model originally had anterior and posterior removable teeth made of stone with a gingival replica around them. The removable teeth had root-like portions with coulisses on the interproximal surface (one for each side) to ensure proper insertion and coupling into the model slots. The maxillary first molar was prepared for a single full-coverage all-ceramic crown restoration. A bur mounted on a high-speed handpiece was used to perform axial (1.0 to 1.5 mm) and occlusal (1.5 to 2.0 mm) reductions; the final abutment had an axial height of approximately 4 mm and a measured surface area of 117.8 mm². A chamfer finish line of approximately 0.8-mm width was selected for the cervical margin area. The finish line was placed within 1 mm below the margin of the artificial gingiva to simulate a slight intrasulcular position of prosthetic margins. The experimental model with gingival replicas, slots, and abutment (duplicated in zirconia material, as described below) is shown in Fig 1.

**Zirconia Coping Fabrication**

The prepared molar abutment with its corresponding root-like portion was scanned (S600 ARTI, Zirkonzahn),...
and 20 new zirconia abutments (n = 10 for each cement group) with simulated roots were produced using CAD/CAM technology. For each abutment, a corresponding zirconia coping was digitally designed, milled (presintered Prettau Zirconia, Zirkonzahn), and finally sintered. The copings were designed to be 0.5 mm thick with a predefined 50-μm internal cement space, and the axial portion was elongated to host a 4-mm–diameter hole. This tunnel-like space enabled the insertion of a tool for removal of the coping during retention testing. A hole of the same size was also present on the simulated root to hold the samples in the universal testing machine. Fabricated copings that had macroscopic deficiencies were discarded and remade. The marginal adaptations of the copings were verified by the dental technician using a stereomicroscope at ×40 magnification (Leica M400 E, Leica Microsystems) at eight selected locations along the coping’s circumference. Marginal gaps < 120 μm were required for clinical acceptability. During fitting evaluations, a 30-N constant pressure was applied to the copings by means of a calibrated spring compressed by a clamp. This device allowed standardization of the measurements and maintained the copings on their respective abutments.\textsuperscript{21} The internal surface was conditioned according to the manufacturer’s instructions with standardized airborne-particle abrasion\textsuperscript{3} by means of 50-μm aluminum oxide particles (Al\textsubscript{2}O\textsubscript{3}) applied for 20 seconds (working distance of 10 mm and a pressure of 2.8 bar/0.28 MPa). The copings were ultrasonically cleaned with isopropyl alcohol and dried.
of paste-paste, hand-mixed polyvinyl siloxane impression material (Aquasil Soft Putty/Regular Set, Denstply Sirona). For each coping, one corresponding putty index was obtained. The copings were ultrasonically cleaned (isopropyl alcohol) and dried after separation from their respective indices.

The tested luting agents were extruded with their dedicated automix syringe tip on the intaglio surfaces of the copings and uniformly distributed with the aid of a brush. The exact amount of cement was not quantified, as the cementation protocol tried to imitate a

### Table 1  Characteristics of the Tested Luting Agents

<table>
<thead>
<tr>
<th>Cement Group</th>
<th>Type</th>
<th>Manufacturer</th>
<th>Batch no.</th>
<th>Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>RelyX Unicem 2 Automix</td>
<td>Self-adhesive resin luting agent</td>
<td>3M ESPE</td>
<td>574774</td>
<td>Methacrylate monomers containing phosphoric acid groups, methacrylate monomers, silanated fillers, initiator components, rheologic additives, alkaline fillers, pigments</td>
</tr>
</tbody>
</table>
| Ketac Cem Plus Automix | Resin-modified glass-ionomer luting agent | 3M ESPE | 765914 | Paste A: Fluoroaluminosilicate (FAS) glass, proprietary reducing agent, HEMA, water, opacifying agent  
Paste B: Methacrylated polycarboxylic acid, BisGMA, HEMA, water, potassium persulfate, zirconia silica filler |

NA = 0.

**Enrollment of an Experienced Operator for Excess Cement Removal**

A senior instructor with more than 10 years of experience in prosthodontics was selected from the department (D.A.). The task consisted of removing as much excess cement as possible over the entire tooth/coping area within a predefined maximum time limit. A stainless steel explorer (Dentsply Sirona), dental floss (VITIS, Dentaid), and Super Floss (Curaprox) were provided to remove the excess material. Preliminary cementations were carried out with the aim of familiarization with the experimental model. Procedures for luting and cement removal were the same as those described in the subsequent part of the study. Three main guidelines were proposed to the selected operator for estimating the near-end or conclusion of the task: (1) achievement of a smooth surface when probing the sulcular area on the vestibular and lingual sides (with longitudinal and vertical movements of the explorer along the margins of the copings); (2) achievement of a clean dental floss surface and absence of roughening after use; and (3) no direct visualization of remnants under inspection with light and magnification. The maximum time limit of 6 minutes was chosen considering the self-curing times of the tested cements (Table 1).

**Luting of the Copings and Excess Cement Removal**

Two different luting agents were selected for the study: a self-curing RMGI (Ketac Cem Plus Automix, 3M ESPE) (GI group) and a dual-curing self-adhesive resin cement (RelyX Unicem 2 Automix, 3M ESPE) (UN group). Table 1 shows the composition of the cements. A single operator performed the luting procedure (up to the tack-curing polymerization step) but was not involved in the removal of excess material; instead, clean-ups were carried out by the previously selected operator. A pre-cementation device (Fig 2) was used to improve film thickness standardization and to reduce the amount of excess. The internal configuration of each coping was replicated, seating the framework on a small amount of paste-paste, hand-mixed polyvinyl siloxane impression material (Aquasil Soft Putty/Regular Set, Denstply Sirona). For each coping, one corresponding putty index was obtained. The copings were ultrasonically cleaned (isopropyl alcohol) and dried after separation from their respective indices.

The tested luting agents were extruded with their dedicated automix syringe tip on the intaglio surfaces of the copings and uniformly distributed with the aid of a brush. The exact amount of cement was not quantified, as the cementation protocol tried to imitate a

**Fig 2** Preseating device produced by direct shaping of polyvinyl siloxane material (putty consistency) on the intaglio surface of the coping. This device allowed preliminary removal of excess cement.
real clinical scenario. The copings filled with cement were first seated on their respective putty indices. After this preliminary step, the copings were seated on the abutment (which was already inserted in the model slot with the gingival mask) using finger pressure; thereafter, a constant vertical load (30 N) was applied and maintained throughout the luting procedure. When the setting cement reached a rubbery consistency, the previously selected operator, who was blinded to the material, attempted to remove the excess.

According to the manufacturer’s guidelines, for the GI group, the gel state of the cement was achieved with tack light-curing option (light curing 5 seconds per surface; polymerization light unit Bluephase C8, Ivoclar Vivadent). Established time (6 minutes) for the clean-up procedure was monitored from this point using a digital stopwatch. Samples were left to self-cure following the cleanup procedure. Complete setting was reached about 8 minutes after mixing the cement at 37°C (2.5 minutes of working time + 5 minutes of setting); however, extended setting time (doubled to 10 minutes) was provided due to the extraoral room temperature of approximately 21°C.

For the UN group, as prescribed by the manufacturer’s guidelines, a tack light-curing option of 2 seconds per surface was carried out. After subsequent removal
of excess cement, a complete light-curing polymerization of 20 seconds per surface was performed. Ten additional minutes were allowed for setting of the self-adhesive cement.

The specific task of excess cement removal was carried out applying the criteria proposed during the preliminary trials. In order to enhance the precision and visualization of remnants, the preselected prosthodontist wore galilean dental loupes (HDL 2.5 Macro, Orascoptic) at ×2.5 magnification during removal of excess. Due to deterioration from the cleaning steps, the artificial gingival mask was replaced for each new procedure. An illustration of the luting steps is shown in Fig 3.

Assessment of Cement Left In Situ After Cleaning Procedures

Several weight measurements were taken during the cementation procedure on the experimental model using a high-precision analytical balance with a readability of 0.0001 g (Entris Model 1241-15, Sartorius). For each sample, a baseline measurement (preluting, without any cement) of the abutment/coping/gingival mask (ACG) assembly was carried out (W1 value). The weight of each single component was also obtained. The pre-cementation weight of the abutment/coping complex was recorded in grams (R1 value). After completion of the luting and cleaning procedures, the ACG assembly was extracted from the model and measured again (W2 value). The cement left in situ (ECL), expressed as weight in grams, represented the primary outcome variable and can be regarded as: (1) the amount of excess cement flowing outside the marginal areas minus (2) the amount of cement removed by the cleaning procedure. The ECL was calculated by using the following formula:

\[ ECL = (W2 - W1) - \text{(the amount of cement retained inside the crown-abutment complex [RC])} \]

For each sample, the RC was evaluated after the coping-abutment separation using the uniaxial dislodgment test.

Uniaxial Retention Tests

The specimens (coping/abutment) were stored in distilled water at 37°C for 24 hours after the luting procedures. The copings were subjected to uniaxial dislodgment forces until failure using a universal testing machine at a 0.5-mm/minute crosshead speed. The dislodgment force (N) of each zirconia coping was recorded, and the removal stress (MPa) was calculated for each group using the surface area of the prepared molar (dislodgment force/mm²). Following coping dislodgment, the predominant nature of failure was also examined by a calibrated observer using a stereomicroscope. The failure modes were classified as follows:

- **Type 1:** Cement remaining on the intaglio surface of the crown
- **Type 2:** Cement remaining on both crown and abutment surfaces
- **Type 3:** Cement remaining on the abutment surface

After separation of the coping from its respective abutment, the excess cement still present in the marginal areas was accurately removed under a microscope at ×40 magnification (Leica M400 E) using a scalpel blade. The coping and abutment complex was weighed again (R2 value [grams]), and the RC was obtained from the difference (R2 – R1).

**Statistical Analyses**

Means and standard deviations (SDs) were calculated for ECL, dislodgment force, and removal stress. The data were analyzed using statistical software (SPSS for Mac OS X, ver. 25.0, IBM). Normal distribution regarding excess cement remnants and retention strength values was confirmed (Shapiro-Wilk normality test: \( P = .0629 \) and \( P = .2474 \), respectively).

One-way analysis of variance (ANOVA, significance at \( \alpha = .05 \)) was used to detect differences among tested cements for ECL and removal stress. The data for characterization of the distribution of the remnants and type of failure were given as descriptive information. Linear regression was performed to analyze the potential relationship between ECL and retention strength values.

**RESULTS**

Cement remnants were found in all specimens despite the cleaning procedures. Residue was also found on the internal sides of the gingival masks (Fig 4). Vestibular, palatal, and interproximal areas were analyzed to assess the presence/absence of remnants (Table 2). Mesial and distal sides were mainly affected (> 80% of all surfaces, regardless of cement type), with minor involvement of other surfaces.

ECL values ranged from 0.0002 to 0.0282 g, with an overall mean of 0.0094 ± 0.0072 g. The mean and SD ECL values for GI and UN groups were 0.0079 ± 0.0060 g and 0.0107 ± 0.0081 g, respectively (Table 3). For ECL, no statistically significant differences were found between tested cements (\( P = .3284 \)). Mean ECL values represented a proportion of 50.3% and 52.2% of the cement retained inside the coping-abutment assemblies (RC values) for GI and UN groups, respectively.

Removal stress values (MPa) were significantly higher (\( P = .0313 \)) for the UN group (12.4 ± 6.5) than for the GI group (6.57 ± 4.69). Linear regression analysis failed to show any correlation between ECL and retention strength values (\( P = .8729 \)).
No fractures of zirconia copings or abutments were recorded during retention tests. All specimens exhibited type 2 failures, with visible areas of zirconia (on both the coping and abutment) free of cement (Fig 5). Major amounts of luting material (> 75%) were found attached to the inner surfaces of the copings.

**DISCUSSION**

**Incomplete Removal of Excess Cement**

The issue of excess cement removal for a single all-ceramic zirconia crown has been highlighted by the present study, as a deep cleaning of extruded luting material appeared difficult to achieve. Accurate removal of excess should be pursued clinically, especially for definitive luting agents that are suggested for tooth-bonded zirconia-based prostheses. In contrast to the intraoral solubility of interim/temporary (mainly zinc oxide–based) materials, long-term washout of permanent resin cements is very low. The obtained postcleaning values (7 to 10 mg) were relatively similar to the weight of remnants reported by Linkevicius et al. for groups with subgingival finish lines (in the range of 5 to 6 mg). Compared to the extruded but uncleaned cement

### Table 2  Distribution of Cement Remnants from Retrieved Coping-Abutment Assemblies

<table>
<thead>
<tr>
<th>Presence of remnants by surface (No. of surfaces with remnants/total no. of surfaces [%])</th>
<th>Interproximal</th>
<th>Vestibular</th>
<th>Palatal</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>RelyX Unicem</td>
<td>18/20 (90)</td>
<td>3/10 (30)</td>
<td>2/10 (20)</td>
<td>23/40 (57.5)</td>
</tr>
<tr>
<td>Ketac Cem Plus</td>
<td>17/20 (85)</td>
<td>4/10 (40)</td>
<td>4/10 (40)</td>
<td>25/40 (62.5)</td>
</tr>
</tbody>
</table>

### Table 3  Statistical Comparison of Amount of Excess Cement Left In Situ After Cleaning Procedures

<table>
<thead>
<tr>
<th>Mean ± standard deviation (g; mg)</th>
<th>Range (g; mg)</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>RelyX Unicem</td>
<td>0.0107 ± 0.0081; 10.7 ± 8.1</td>
<td>0.0007–0.0282; 0.7–28.2</td>
</tr>
<tr>
<td>Ketac Cem Plus</td>
<td>0.0079 ± 0.0060; 7.9 ± 6.0</td>
<td>0.0002–0.0187; 0.2–18.7</td>
</tr>
</tbody>
</table>

---

**Fig 4** (a) Example of unremoved cement remnants attached to the specimen despite the accurate cleaning procedures. (b) In some cases, cement remnants were also observed on the inner surface of the gingival mask.

**Fig 5** Fracture of a debonded specimen after pull-off test. The cement remained on both the crown and abutment surfaces, with some areas free of luting material.
reported by some studies on implants (in the range of 35 to 50 mg), these postcleaning values might appear relatively small; however, the influence of an exact amount of residual cement on tissue response has not yet been established.

Cement removal was facilitated by a number of conditions in this in vitro research, including a dry field, enhanced illumination, and the ability to observe the copings from multiple sides. In addition, the operator who removed the excess cement was a skilled prosthodontist with the opportunity to become familiarized with the model. When in vivo conditions and demanding/complex rehabilitations are encountered, a higher amount of remnants should be expected. Several factors have been associated with partial removal of excess cement, such as margin locations and emergence profiles. The studies of Linkovicius et al. evaluated the amount of undetected cement (using weighing) for intrasulcular margins. Even if their studies were based on implant abutments, the unremoved excess material was significantly increased on the crowns and soft tissues for deeper (up to 3 mm) finish-line locations. In the present study, undetected cement excess might be partially explained by the 1-mm subgingivally placed crown margin; in addition, a good color-matching of the cements with zirconia copings and abutments decreased the visibility of the remnants. The anatomy of subgingival areas may play a role in excess cement removal; for example, Sancho-Puchades et al. reported that concave subgingival areas may retain more excess cement than a convex emergence profile. In clinical situations, root developmental grooves, concavities, or furcation areas close to the crown-tooth interface are favorite places for cement accumulation. In the present study, the efficiency of cleaning was reduced in interproximal areas, as has been previously reported.

Wasiluk et al. also used dental floss for cement removal, and the authors also discovered major amounts on mesial and distal sides with respect to facial/lingual surfaces. Regardless of the factors of influence and distribution, no difference was found in the ECL among the examined groups, and the tack-curing technique used to achieve the gel state facilitated excess removal and was available for the two tested materials. It may be speculated that the two cements have a similar ease of removal, and, consequently, comparable remnants were found after cleaning.

Significance of the Preseating Device
The exact amount of loaded cement was specifically measured and reported by some other in vitro studies with the main purpose of evaluating the amount of excess material expressed at the margins considering different luting techniques. Measurement of loaded cement is useful for calculating the proportion of luting agent expressed at the margins and might allow correlations with tensile strength values. However, the relationship between the amount of loaded and extruded cement is not clearly defined. Some authors have reported a positive correlation, while others have found no significant association. A limitation of the present study is the unknown amount of loaded cement; however, actual clinical conditions as described by other research were attempted. Al though a predefined amount of loaded cement would have ensured optimal standardization among specimens, the preseating device (customized to the intaglio surface of the coping) might represent a qualitative (at least partial) standardization of the loaded material, as it is able to displace a wide amount of unnecessary luting agent while leaving a thin and uniform film of cement over the internal surfaces. This study was mainly focused on the clean-up procedure and ease of cement removal. Exact measurements of loaded cement and extruded excess were not mandatory for calculation of ECL, which was the primary goal of this investigation.

Retentive Performance of Tested Cements
After luting, cleaning, and storage, the specimens were finally subjected to a uniaxial retention test, which is a pull-off test carried out on the long axis of the coping/abutment specimen. This test provided information regarding the retentive performance of the analyzed cements; moreover, the association of the pull-off results with the analysis of cement remnants was carried out to highlight a potential relationship between ECL and retention values. Unintended amounts of cement at marginal areas may have an influence on the retention values of the copings; however, the linear regression analysis failed to highlight any association (ie, the presence of different amounts of remnants at the coping/abutment interface was not related to retention of the copings). Low adherence of small amounts of set cements to unconditioned outer zirconia surfaces may partially explain these results. As reported by bond strength studies, unsatisfactory adhesion of resin-based materials to high-density zirconia without any chemical or mechanical pretreatment should be expected. In vitro bond strength tests usually demonstrate significant differences (before and after artificial aging) on the adhesive performances of composite and RMGI cements for luting zirconia substrates. When looking at the retention of single zirconia crowns, however, a number of pull-off studies (which are designed to be closer to clinical environmental conditions) have reported similarities among different classes of cements. Ernst et al. found no significant differences among a compomer cement, an RMGI cement, and a self-adhesive resin luting agent on pull-off values. According to their results, similar median retentive values...
were obtained for RelyX Unicem and RelyX Luting (4.7 and 4.8 MPa, respectively). Palacios et al also concluded that resin cements or a modified glass-ionomer material were equally effective for the retention of zirconia crowns (mean dislodgment stresses between 5.0 and 6.1 MPa) when using an airborne-particle abrasion surface treatment. In contrast to previous studies, Son et al, using a CAD/CAM procedure for strict abutment standardization, highlighted a difference between the two classes of cements. In this study, a significant difference was also confirmed between the RMGI and the self-adhesive resin cement. However, since this substrate was made of zirconia, a more suitable comparison of the results might be possible with pull-off studies on implants that have analyzed all-ceramic abutment coping interfaces. For an abutment height of 4.0 mm, after aging, slightly higher decementation forces were found for RelyX Unicem (590 ± 123 N) compared to Ketac Cem (522 ± 117 N). Zirconia-cement-zirconia interfaces are usually encountered on implant restorations with high esthetic demands (anterior or posterior areas) to reduce the gray appearance of metallic components through soft tissues. On cement-retained implant prostheses, a balance between retention and retrievability of the restoration might be desirable for maintenance: the availability of cements with different retention properties, as reported, could be clinically useful, as the tested materials could be chosen according to the specific rehabilitation needs.

Limitations and Future Directions
The present study has some limitations, specifically due to its in vitro design. Differences regarding the behavior of the experimental gingival mask and the actual periodontal attachment of a tooth should be considered in future studies. In addition, accurate removal of excess cement using other aids or technologies, such as fluorescence or ultraviolet-aided identification techniques, should also be explored. Considering the pull-off tests, long-term effects of aging on retention of the copings should also be evaluated.

CONCLUSIONS
Within the limitations of this study, similar amounts of undetected cement remnants were discovered around the esthetic margins of zirconia crown copings, regardless of cement type; preseating and cleaning procedures with clinically available instruments did not allow complete removal of excess cement; and the luting procedure using a dual-curing, self-adhesive resin cement provided significantly higher early retention values than an RMGI material.

ACKNOWLEDGMENTS
The authors report no conflicts of interest.

REFERENCES


Literature Abstracts

The Tooth On-a-Chip: A Microphysiologic Model System Mimicking the Biologic Interface of the Tooth with Biomaterials

The tooth has a unique configuration with respect to the biomaterials that are used for its treatment. Cells inside of the dental pulp interface indirectly with biomaterials via a calcified permeable membrane formed by the dentin matrix and several thousands of dentinal tubules (~2 μm in diameter). Although the cytotoxic response of the dental pulp to biomaterials has been extensively studied, there is a shortage of in vitro model systems that mimic the dentin-pulp interface and enable an improved understanding of the morphologic, metabolic, and functional influences of biomaterials on live dental pulp cells. To address this shortage, an organ-on-a-chip model system was developed that integrates cells cultured directly on a dentin wall within a microfluidic device that replicates some of the architecture and dynamics of the dentin-pulp interface. The tooth-on-a-chip is made out of molded polydimethylsiloxane (PDMS) with a design consisting of two chambers separated by a dentin fragment. To characterize pulp cell responses to the dental materials on-chip, stem cells from the apical papilla (SCAPs) were cultured in odontogenic medium, seeded onto the dentin surface, and observed using live-cell microscopy. Next, to evaluate the tooth-on-a-chip as a platform for materials testing, standard dental materials used clinically (2-hydroxyethylmethacrylate [HEMA], phosphoric acid [PA], and Adper Scotchbond [SB]) were tested for cytotoxicity, cell morphology, and metabolic activity on-chip and compared against standardized off-chip controls. All dental materials had cytotoxic effects in both on-chip and off-chip systems in the following order: HEMA > SB > PA (P < 0.05), and cells presented consistently higher metabolic activity on-chip than off-chip (P < 0.05). Furthermore, the tooth-on-a-chip enabled real-time tracking of gelatinolytic activity in a model hybrid layer (HL) formed in the microdevice, which suggests that dental pulp cells may contribute to the proteolytic activity in the HL more than endogenous proteases. In conclusion, the tooth-on-a-chip is a novel platform that replicates near-physiologic conditions of the pulp-dentin interface and enables live-cell imaging to study dental pulp cell response to biomaterials.


Compliance with Supportive Periodontal/Peri-implant Therapy: A Systematic Review

This systematic review aimed to assess the degree of compliance with supportive periodontal/peri-implant therapy and to identify patient-related factors that could potentially play a role in patient compliance. Electronic and manual literature searches were carried out to assess patient compliance during maintenance. Main outcomes were compliance definition, degree of compliance, and patient-related factors. Owing to the heterogeneity of the data reported across the studies, descriptive statistics were performed to shed light on the compliance rate and patient-related factors. A total of 39 articles were included. No consensus regarding the definition of “compliance” was found in the analyzed literature. The percentage of full compliers and noncompliers ranged from 3.3% to 86.8% and from 1.69% to 64.4%, respectively. Smoking habit and history of periodontal disease were found to be associated with patient compliance. Inadequate information/motivation was found as the main patient-reported reason for noncompliance. Despite the high variability across studies, compliance with the supportive periodontal/peri-implant maintenance therapy was found to be unsatisfactory. Attitudes, psychologic traits, and construct associated with compliance remain largely unknown. Lack of information and motivation are paramount during the periodontal/implant therapy to increase patient compliance.


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