Microleakage of various cementing agents for full cast crowns

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Summary
Objectives. To evaluate microleakage and marginal gaps in full cast crown restorations bonded with six different types of cementing agents.

Methods. Sixty non-carious human premolars and molars were prepared in a standardized manner for full cast crown restorations. The mesial and distal margins were located in dentin, while the vestibular and palatal/lingual margins were located in enamel. Crowns were made from a high-gold alloy using a standardized technique. The specimens were randomized to six groups of cementing agents: one zinc-phosphate cement (Harvard cement), one conventional glass-ionomer cement (Fuji I), one resin-modified glass-ionomer cement (Fuji Plus), two standard resin cements (RelyX ARC, Panavia F), and one self-adhesive universal resin cement (RelyX Unicem). After 4 weeks of storage in distilled water at 37 °C, the specimens were subjected to 5000 thermocycles ranging from 5 to 55 °C. Then, they were placed in a silver nitrate solution, embedded in resin blocks, and vertically cut in buccolingual and mesiodistal direction. Subsequently, the objects were evaluated for microleakage and marginal gap using a high-resolution digital microscope camera.

Results. A number of inter-group differences were statistically significant. RelyX Unicem showed the smallest degree of microleakage both in enamel and in dentin. Panavia F and RelyX Unicem were associated with significantly larger marginal gaps than all other cementing agents. No association was observed between microleakage and marginal gap other than a weak direct correlation when using Harvard cement on enamel.

Significance. The cementing agents investigated revealed different sealing abilities. These differences were not associated with specific types of materials.

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Introduction

In vitro studies of microleakage are an initial screening method to assess the maximum theoretical loss of sealing ability in vivo [1]. The occurrence of microleakage along the interface has been
related to pulpal problems [2,3], hypersensitivity, and secondary caries [4], the latter being the most common reason why restorations are replaced [5].

Few studies have dealt with microleakage in full cast crowns based on different types of cementing agents [6-10]. Moreover, the methodologies and cementing agents used in these studies have been too diverse to allow direct comparison of the data. But it is possible to analyze different types of commercially available cementing agents that can be used for long-term cementation of fixed restorations. These include zinc-phosphate cements, conventional glass-ionomer cements, resin-modified glass-ionomer cements, standard resin cements, and a recently developed material described as self-adhesive universal resin cement. The objective in developing this cement was to combine the ease of handling offered by glass-ionomer cements with the favorable mechanical properties [11], attractive esthetics [12], and good adhesion of resin cements [13].

A review of the literature by Raskin et al. [14] showed that 62.5% out of 144 studies on microleakage performed between 1992 and 1998 evaluated microleakage in Class V cavities, while only 4.3% evaluated microleakage and marginal gaps as study parameters involved in crown restorations. These latter include only a limited number of studies [9,10] investigating the correlation between microleakage and marginal gaps in full cast crowns; no such correlation was found. However, the significance of the marginal gaps of full cast restorations and their clinical consequences remain to be determined.

The objective of the present in vitro study was to investigate microleakage and marginal gaps associated with cementing agents in full cast crowns following artificial aging. Other questions to be examined were (1) whether various types of cementing agents produce the same sealing ability for definite bonding of indirect restorations and (2) in how far microleakage results differ depending on whether the margins of the restoration are placed in dentin or in enamel. A final objective was to determine whether there was a connection between microleakage and marginal gaps in full cast crowns.

**Materials and Methods**

**Specimen preparation**

A total of 60 freshly extracted non-carious permanent human molars with fully developed roots were selected for this study. All teeth were stored in distilled water at room temperature immediately after extraction. Calculus and residual periodontal tissue were removed using a surgical knife, scaler, and curette. Subsequently, the teeth were conservatively polished using a rotating brush and pumice.

The preparations for the full cast crowns were performed using a suitable design and a converging angle of around 6° to achieve optimal retention and resistance properties. The occlusal and axial surfaces were reduced by approximately 1.2 and 0.8 mm, respectively. The cervical preparation margins were designed as circular chamfers using torpedo-shaped diamond burs and water-cooling (Gebr. Brasseler, Lemgo, Germany; No. 878.314, size 012). The preparations were finished with the help of magnifying loupes (magnification ×3.5; Zeiss, Oberkochen, Deutschland; serial #53-20) using fine and extra-fine diamond burs (Gebr. Brasseler, Lemgo, Germany; No. 8878.314 and 878EF.314, size 012). Subsequently, a final check of the preparations was performed. The mesial and distal margins were located in dentin, while the vestibular and palatal/lingual margins were located in enamel.

For the model dies, impressions of the prepared teeth were taken with Impregum Penta (3M ESPE, Seefeld, Germany) and poured with Type IV resin-stabilized extra-hard stone (esthetic-base 300; dentona AG, Dortmund, Germany; lot #51001742) following the manufacturer's mixing instructions. The stone was allowed to set for 40 min and then removed from the impression. The resultant stone dies were trimmed and covered with stone hardener (Classic Hardener Spacer clear; Kerr Lab, Belle de St Claire, France) followed by two layers of die spacer (Classic Cement Spacer blue; Kerr Lab, Belle de St Claire, France) above the preparation margin. The preparation margin was marked with a non-graphite pencil under a stereomicroscope at ×32 magnification (Zeiss, Oberkochen, Germany; Stemi 2000-C, serial #200403753). Subsequently, red cervical wax and blue modeling wax (YETI Dentalprodukte, Engen, Germany) were used to model full crowns of 0.5 mm thickness. Four round reference marks approximately 1.5 mm in diameter were applied in the mesial, distal, vestibular and lingual/palatal segments centrally around 3 mm above the preparations located in enamel and dentin. Five wax copings each were embedded in a #3 muffle ring with phosphate-bonded investment (Precibalite plus; Dentona AG, Dortmund, Germany; lot #0501101). After setting, the muffle was heated and a centrifugal casting performed using a Type IV high-gold casting alloy (Portadur P4; Wieland Edelmetalle GmbH, Pforzheim, Germany;
relative constituents: Au 68.5%, Ag 12.0%, Cu 12.0%, Pt 6.9%, Zn 0.5%, Ir 0.1%; lots #4492 and 4269).

The castings were divested, trimmed and seated using well-established procedures routinely used by dental laboratories for crown restorations. The fit of the castings was checked with silicone (Fit Checker; GC, Munich, Germany) and improved if necessary. Any points visibly pressed into the silicone were relieved using a small (0.08 mm in diameter) rotary instrument. The marginal fit of all castings was verified on the prepared residual teeth under a stereomicroscope (×32 magnification) and with an extra-fine probe (EXD5; Hu-Friedy, Chicago, IL, USA). Subsequently, the interior surface of the gold frameworks was sandblasted with Al₂O₃ (Hasenfratz, Grafing, Germany; average grain size, 105 µm; pressure, 0.18 MPa; distance, 10 mm; duration, 10 s).

Our experimental set-up included one zinc-phosphate cement (Harvard cement), one conventional glass-ionomer cement (Fuji I), one resin-modified glass-ionomer cement (Fuji Plus), two standard dual-cure resin cements (RelyX ARC, Panavia F), and one recently developed dual-cure self-adhesive resin cement (RelyX Unicem) (Table 1). All cementing agents were processed at room temperature (23 °C) strictly following the manufacturers’ instructions. Two cements (GC Fuji Plus and RelyX Unicem) were supplied in pre-measured capsules. Upon activation, these materials were mechanically triturated with the rotational mixing machine (CapMix; 3M ESPE, Seefeld, Germany) for the time recommended by the manufacturers (10 or 15 s). RelyX ARC was supplied in pre-measured delivery systems. Panavia F was mixed on a mixing block, using a hard plastic spatula, at a base-to-catalyst paste ratio of 1:1 for approximately 20 s. An oxygen-blocking gel (Oxyguard II; Kuraray, Osaka, Japan; lot #00373A) was applied for 3 min when Panavia F was used. Fuji I was manually mixed at a powder-to-liquid ratio of 1.8–1.0 for around 20 s. The powder-to-liquid ratio of Harvard cement was determined by weighing according to the manufacturer’s instructions using an analytical balance (± 1 mg). Mixing was performed on a cool slab, over a wide area, to incorporate small increments of powder into the liquid for approximately 90 s (Harvard cement).

Before cementation, all 60 teeth were randomized along with their gold frameworks to six test groups (n=10). The interior surfaces of the crown restorations and the prepared teeth were cleaned with alcohol. All teeth, which were to receive the resin-modified glass-ionomer cement or a standard resin cement, were pretreated with dentin

<table>
<thead>
<tr>
<th>Materials</th>
<th>Type</th>
<th>Main composition</th>
<th>Adhesive system</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvard cement</td>
<td>Zinc-phosphate cement</td>
<td>P: zinc oxide, magnesia;</td>
<td>No adhesive system</td>
<td>Richter &amp; Hoffmann, Berlin, Germany</td>
</tr>
<tr>
<td>(Batch No. powder 2112498001, Batch No. liquid 2111000013)</td>
<td>L: phosphoric acid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuji I (Batch No. 0001251)</td>
<td>Conventional glass-ionomer cement</td>
<td>P: polyacrylic acid, aluminosilicate glass; L: polyacrylic acid, citric acid</td>
<td>No adhesive system</td>
<td>GC Corp., Tokyo, Japan</td>
</tr>
<tr>
<td>Fuji Plus (Batch No. 0009214)</td>
<td>Resin-modified glass-ionomer cement</td>
<td>P: aluminosilicate glass; L: HEMA, polyacrylic acid, TEGDMA</td>
<td>Fuji Plus conditioner</td>
<td>GC Corp., Tokyo, Japan</td>
</tr>
<tr>
<td>RelyX ARC (Batch No. CACA)</td>
<td>Resin cement</td>
<td>Bis-GMA, TEGDMA, silica and zirconium glass BPEDMA, MDP, DMA, barium, boron and silicate, NaF Phosphoric acid methacrylates, dimethacrylates, inorganic fillers, fumed silica, initiators</td>
<td>Single bond adhesive (Batch No. 4242) ED primer (Batch No. 00108B, Batch No. 00115B)</td>
<td>3M ESPE, Seefeld, Germany</td>
</tr>
<tr>
<td>Panavia F (Batch No. base 00124A, Batch No. catalyst 00046A)</td>
<td>Resin cement</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RelyX Unicem (Batch No. 0001)</td>
<td>Self-adhesive universal resin cement</td>
<td>Phosphoric acid methacrylates, dimethacrylates, inorganic fillers, fumed silica, initiators</td>
<td>No adhesive system</td>
<td>3M ESPE, Seefeld, Germany</td>
</tr>
</tbody>
</table>

P, powder; L, liquid. Bis-GMA, bisphenol-A diglycidyl ether dimethacrylate; BPEDMA, bisphenol-A polyethoxydimeethacrylate; DMA, aliphatic dimethacrylate; HEMA, 2-hydroxyethylmethacrylat; MDP, 10-methacryloyloxy decyl dihydrogenphosphate; NaF, sodium fluoride; TEGDMA, triethylene glycol dimethacrylate.

a According to the information provided by the manufacturers.
adhesives as recommended by the manufacturers (Table 1). Dentin adhesives were not used for the zinc-phosphate cement, the conventional glass-ionomer cement, and the self-adhesive resin cement. Bonding was performed by loading the cementing agent into the interior surface of the restoration and applying finger pressure for 10 s. Then the frameworks were axially loaded at a constant weight of 58.8 N for 7 min [15]. Excess cement was removed with a scaler; marginal fit was checked both by visual inspection and with a probe.

All tooth-restoration specimens were stored in distilled water at 37°C for 4 weeks, then they were subjected to 5000 thermocycles ranging from 5 to 55°C (immersion time, 20 s; transfer time, 10 s). Subsequently, the root surfaces of the restored teeth were covered with two layers of nail varnish (ending 2 mm below the crown margin) and subjected to silver nitrate penetration [16]. Then they were placed into an unimolar silver nitrate solution (Crystal, Fisher Scientific, Fairfield, NJ, USA) for 6 h, followed by thorough rinsing, storage in a photochemical developer (Solutek Corporation, Boston, MA, USA) for 12 h, and exposure to a 150-W floodlamp for 6 h.

Next, the tooth-restoration specimens were embedded in a transparent resin matrix (Buehler Epoxide; Buehler, Lake Bluff, IL, USA), which was allowed to harden at room temperature for 24 h. Each resin block was cut twice in the buccolingual and the mesiodistal direction along the previously applied reference marks using a slow-speed diamond saw (Isomet; Buehler Ltd, Evanston, IL, USA) with water-cooling. In this way, each specimen featured eight surfaces (four in enamel and four in dentin) for analysis of microleakage and marginal gap. The cut surfaces were once again placed under a 150-W floodlamp for 5 min, such that all portions of the silver nitrate penetration acquired a black color.

**Evaluation of microleakage and marginal gap using a high-resolution digital microscope camera**

The microleakage in the area of the tooth–cement interface was defined as linear penetration of silver nitrate starting from the restorative crown margins [17] and was determined with a stereomicroscope (475052-9901; Zeiss, Oberkochen, Germany) and AxioCam HR digital microscope camera (Zeiss, Oberkochen, Germany; software module: Axio Vision 3.1). The images were taken at a resolution of 1300 × 1030 pixels. A micrometer scale (474026; Zeiss, Oberkochen, Germany) was placed diagonally across the image for calibration. The maximum potential calibration-related error due to the width of mapped lines was ±0.709 or ±0.475% depending on the magnification factor relative to the absolute measured values. Depending on the magnification, 2.42 or 3.64 μm/pixel were obtained. Metric assessment of distances was performed using micrometers (μm) as units. A randomly selected image including 10 measurements was analyzed to determine the potential mapping error due to the definition of microleakage length. Given a measured length of 1 mm, a maximum mapping error of ±0.01 mm was obtained irrespective of the magnification factor.

Marginal gaps were measured as defined by Holmes et al. [18] using the stereomicroscope (4730129901; Zeiss, Oberkochen, Germany) and digital microscope camera. The selected magnification was based on 1.21 μm equaling one pixel. Based on the absolute values measured, the maximum calibration-related error was ±0.154%. A randomly selected image including 10 measurements was analyzed to determine the potential mapping error due to the definition of marginal gap length. Given a length of 40 μm, a maximum mapping error of ±0.18 μm was obtained.

**Statistical analysis**

Descriptive representation of continuous variables was based on mean values, SD, and minimum–maximum values. In addition, a number of tests (skewness test, kurtosis test, and omnibus test) were used to analyze whether the frequency distribution of the random sample differed significantly from the normal distribution. Since, the bulk of data was not characterized by a normal distribution, a non-parametric Kruskal-Wallis test was used to analyze differences in the various groups of cementing agents, comparing the obtained test parameters (Bonferroni-corrected p values). A non-parametric Wilcoxon’s test was used to evaluate the differences between enamel and dentinal substrates. The selected level of statistical significance was p < 0.05. Spearman’s correlation coefficient (R) was used to assess the correlation between two continuous variables.

**Results**

**Microleakage with preparation margins in enamel**

Fig. 1 illustrates the mean values and SD for the microleakage findings obtained with the various cementing agents. The smallest degree of
Microleakage was observed with the dual-cure self-adhesive resin cement (RelyX Unicem; 0.70 ± 0.61 mm), followed by the conventional glass-ionomer cement (Fuji I; 0.71 ± 0.32 mm), and the resin-modified glass-ionomer cement (Fuji Plus; 0.77 ± 0.48 mm). The greatest degree of microleakage was observed with the zinc-phosphate (Harvard) cement (1.59 ± 0.64 mm). The Kruskal-Wallis test revealed statistically significant differences between the zinc-phosphate (Harvard) cement on one hand and all other agents (all $p < 0.01$) with the exception of standard resin cement (RelyX ARC) on the other. A significant difference was also established between one standard resin cement (RelyX ARC) and the self-adhesive resin cement (RelyX Unicem) ($p = 0.019$).

### Microleakage with preparation margins in dentin

Fig. 2 illustrates the microleakage findings with preparation margins located in dentin. The smallest degree of microleakage was observed with the self-adhesive resin cement (RelyX Unicem; 1.01 ± 0.54 mm), followed by the resin-modified glass-ionomer cement (Fuji Plus; 1.39 ± 0.49 mm), and the conventional glass-ionomer cement (Fuji I; 1.41 ± 0.90 mm). Statistically significant differences were observed between the zinc-phosphate (Harvard) cement and both the conventional glass-ionomer cement (Fuji I, $p = 0.006$) and the self-adhesive resin cement (RelyX Unicem, $p < 0.0001$), between the conventional glass-ionomer cement (Fuji I) and the standard resin cement (RelyX ARC, $p = 0.002$), between the resin-modified glass-ionomer cement Fuji Plus and the standard resin cement RelyX ARC ($p = 0.0281$), between the standard resin cement RelyX ARC and the self-adhesive resin cement RelyX Unicem ($p < 0.0001$), and between the standard resin cement Panavia F and the self-adhesive resin cement RelyX Unicem ($p < 0.0001$).

### Microleakage with preparation margins in enamel versus dentin

All test groups revealed significant differences in microleakage between enamel and dentin. Microleakage was invariably more pronounced in dentin than in enamel (Table 2).

### Marginal gap

The average marginal gap in the specimens ranged from 47.70 ± 17.92 μm for the zinc-phosphate (Harvard) cement up to 74.59 ± 29.15 μm for the self-adhesive resin cement (RelyX Unicem; Fig. 3). The difference between one of the standard resin

<table>
<thead>
<tr>
<th>Material</th>
<th>Enamel (mm)</th>
<th>Dentin (mm)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harvard cement</td>
<td>1.59 (0.64)</td>
<td>2.01 (0.70)</td>
<td>0.0054</td>
</tr>
<tr>
<td>Fuji I</td>
<td>0.71 (0.32)</td>
<td>1.41 (0.90)</td>
<td>0.000003</td>
</tr>
<tr>
<td>Fuji Plus</td>
<td>0.77 (0.48)</td>
<td>1.39 (0.49)</td>
<td>0.000008</td>
</tr>
<tr>
<td>RelyX ARC</td>
<td>1.11 (0.68)</td>
<td>2.19 (1.04)</td>
<td>0.0000001</td>
</tr>
<tr>
<td>Panavia F</td>
<td>0.95 (0.59)</td>
<td>2.11 (1.35)</td>
<td>0.000001</td>
</tr>
<tr>
<td>RelyX Unicem</td>
<td>0.70 (0.61)</td>
<td>1.01 (0.54)</td>
<td>0.0098</td>
</tr>
</tbody>
</table>

Inter-group differences were evaluated by Wilcoxon’s test and were statistically significant in all groups ($p < 0.05$).
cements (Panavia F) and the self-adhesive resin cement (RelyX Unicem) was not statistically significant. Both, however, differed significantly from all other cementing agents (all \( p < 0.01 \)).

**Correlation between microleakage and marginal gap**

A weak direct correlation between microleakage and marginal gap was observed in the enamel of specimens in which the zinc-phosphate cement (Harvard) had been used for bonding (correlation coefficient, \( R = 0.41 \)). No such correlation was found in any of the other groups.

**Discussion**

It is well established that the type of cementing agent used for bonding has a bearing on microleakage [17,19]. It is also known that the composition and other special characteristics of cementing agents (e.g. the setting properties and the dentin adhesive used) determine the degree of leakage.

The smallest degree of microleakage, both in enamel and in dentin, was obtained with the self-adhesive resin cement (RelyX Unicem). Apparently, therefore, this agent is capable of generating an effective seal at the interfaces between restorative alloy, cementing agent, and dental tissue without requiring pretreatment of the prepared tooth surfaces. The formulation of RelyX Unicem contains specific multifunctional phosphoric-acid methacrylates able to interact with the tooth surface in multiple ways, such as by forming complex compounds with calcium ions or by different kinds of physical interaction like hydrogen bonding or dipole-to-dipole interactions. This variety of interactions seems to enable RelyX Unicem to generate self-adhesion to both enamel and dentin, resulting in an effective seal of the tooth-cement interface and hence in the lowest microleakage values in enamel and dentin of all luting agents examined.

The two standard dual-cure resin cements (RelyX ARC and Panavia F) were associated with a higher degree of microleakage—both in enamel and in dentin—than the conventional glass-ionomer cement (Fuji I) and the resin-modified glass-ionomer cement (Fuji Plus). In general, different microleakage patterns may be caused by different factors, depending on the type of cementing agent used and the experimental conditions.

The greater leakage of the resin cements RelyX ARC and Panavia F compared to the conventional glass-ionomer cement Fuji I and the resin-modified glass-ionomer cement Fuji Plus might be thus attributed to polymerization shrinkage of the resin cements [20,21], combined with the coefficients of thermal expansion of the materials involved (i.e. tooth substance, cement, metal crown), during aging [22]. By contrast with the resin cements, conventional glass-ionomer cements like Fuji I are considered to be dimensionally stable during setting, and the hydrophilic formulation of resin-modified glass-ionomer cements like Fuji Plus can compensate for the initial setting contraction by subsequent expansion due to water uptake. This difference in chemical behavior might explain the different microleakage results found for the two standard resin cements, the conventional glass-ionomer cement, and the resin-modified glass-ionomer cement.

Microleakage was found to be most pronounced with the zinc-phosphate cement applied on preparation margins located in enamel. Zinc-phosphate cement on dentin showed the third-largest microleakage of all cementing agents. A similar trend was described by a number of authors [6–10] who compared several types of materials and observed the greatest degree of microleakage in full cast crowns bonded with zinc-phosphate cements. Possible reasons for these unfavorable results for zinc-phosphate cements include their lack of micromechanical and especially—by contrast with all other cements investigated in this study—the absence of chemical retention on dental tissue [23] and their high solubility [24]. Comparisons of the clinical performance with regard to microleakage around full cast crowns after 6 months in function showed that a zinc-phosphate cement (Flecks; Mizzy, Cherry Hill, NJ, USA) showed significantly higher values than a resin-modified glass-ionomer cement (Infinity; Den Mat Corp., Santa Maria, CA, USA) [25]. It must be noted, however, that Kydd et al. [26] have shown that...
crown restorations bonded with zinc-phosphate cement remained functional despite microleakage for over 20 years, with none of the tooth-crown interfaces revealing carious lesions. Other authors concluded that the cement dissolving at the marginal gap does not seem to have any serious consequences and does not give rise to carious penetration [27,28].

In the present study, microleakage occurred exclusively at the cement-enamel/dentin interface. This observation is confirmed by various studies in vitro and in vivo [9,17,25,26,29,30]. Although no microleakage occurred at the metal-cement interface, the use of metal primer should be taken into consideration clinically when metal restorations are cemented using polymer-based cements, because there is a chance of a better marginal seal when using metal primer [31,32]. However, this effect is mainly dependent on the combination of alloy composition, metal surface treatment [33], metal primer, and the cement used [31,32].

Our analysis of microleakage in enamel versus dentin revealed statistically significant differences in all study groups, i.e. the degree of microleakage was invariably higher with preparation margins in dentin than in enamel. This result is in keeping with the observations of other authors [8,9]. Although the retention mechanism on both dentin and enamel is micromechanical in nature, both substrates are dissimilar in composition and structure. The bond between the cementing agent and the dentinal hard tissue is compromised by the tubular microstructure, the higher content of organic material, and the intrinsic humidity of the dentinal substrate [34]. It must be noted, however, that bonding properties and tracer penetration may vary from location to location, depending on the structure and composition of the enamel or dentinal substrate. Major determinants include age, location, tissue health, and dietary factors [35,36].

To be able to perform an immediate relative comparison between the in vitro results of the study groups, margins were examined only after autopolymerization for all resin cements. One would have to take into consideration, however, that light-polymerization increases the bond between dual-cure resin cements and dental restorative materials [37]. Dual-cure resin cements should therefore be polymerized with a polymerizing light, especially if the crown margins are located supragingivally and are accessible.

The mean results in terms of marginal gap on storing the specimens in water for 4 weeks and subjecting them to 5000 thermocycles were least favorable for one standard dual-cure resin cement (Panavia F) and for the self-adhesive resin cement (RelyX Unicem). On the other hand, the second-most favorable marginal gaps were also obtained with resin cement (RelyX ARC). Consequently, the marginal gap quality of a given type of cementing agent may be co-determined by its specific physicochemical properties. Gemalmiez et al. [38] demonstrated that the marginal gap of porcelain inlays was larger when a dual-cure resin cement was used for bonding. White and Kipnis [39], who investigated the effect of five different luting agents on the marginal fit of cast single-crown restorations bonded to extracted premolars in vitro, observed no significant marginal gap differences in the pre-bonding stage (range 35.1–69.5 μm), but reported that significant differences did emerge after cementation. The smallest gaps were observed with a glass-ionomer cement (Ketac-Cem; 3M ESPE, Seefeld, Germany; 82.8±12.6 μm), the largest gaps with a microfilled resin cement (Thin Film Cement; Den Mat Corp., Santa Maria, CA, USA) using oxalate dentin bonding (333.1±45.9 μm).

This finding may conceivably be due to resin cements rapidly gaining viscosity in the process of curing. For this reason, White et al. [8] recommended that resin cements should be applied swiftly and carefully in clinical practice, and that indirect restorations should be inserted with considerable pressure.

The present study also showed that bonding of the restorations with the zinc-phosphate cement (Harvard cement), the conventional glass-ionomer cement (GC Fuji I), the resin-modified glass-ionomer cement (GC Fuji Plus), and one of the standard resin cements (RelyX ARC), involved no significant marginal gap differences. White et al. [29] demonstrated in vivo that the marginal gaps obtained with a zinc-phosphate cement (Flecks; Mizzy, Cherry Hill, NJ, USA) and a resin-modified glass-ionomer cement (Infinity; Den Mat Corp., Santa Maria, CA, USA) with or without dentin bonding (Tenure; Den Mat Corp.) did not significantly differ after 6 months of clinical function. The clinical implications of marginal gaps—i.e. how large they have to be to favor penetration of toxins and bacteria, pulpal damage and secondary caries—remain to be clarified.

The results obtained did not show any regular influence of marginal gaps on microleakage. One would have to assume that the quality of the marginal gap obtained under the experimental conditions outlined is not correlated with the microleakage results obtained. It should be pointed out that the results of the marginal gap were smaller than the maximum clinically acceptable
marginal gap size of 120 μm (as defined by McLean and Von Fraunhofer [40]) in all test groups. As in our own study, White et al. [9] did not find any correlation between marginal gaps and microleakage. Their study examined full cast crowns made of a non-precious alloy that had been cemented with a zinc-phosphate cement (Flecks; Mizzy, Cherry Hill, NJ, USA), a polycarboxylate cement (Durelon; 3M ESPE, Seefeld, Germany), a glass-ionomer cement (Ketac-Cem; 3M ESPE, Seefeld, Germany), a micro-filled resin with dentin bonding (Thin Film Cement; Den Mat Corp., Santa Maria, CA, USA), and a resin cement (Panavia Ex; Kuraray, Osaka, Japan). Nor did the study of Lindquist and Conolly [10] find any correlation between microleakage and marginal gap when using a zinc-phosphate cement (Flecks; Mizzy, Cherry Hill, NJ, USA) and a resin-modified glass-ionomer cement (Vitremer (now RelyX Luting); 3M ESPE, Seefeld, Germany). However, more research is needed to determine the relationships between restoration-associated diseases and the variables of microleakage, marginal opening, and host factors.

Although we used established protocols to simulate the oral environment, the real-life scenario is too complex to be fully reproduced by experimental set-ups of this type. On balance, it is reasonable to assume that the data obtained in the various study groups constituted a viable basis for comparison. In clinical practice, however, additional factors such as biocompatibility, thermal/electric conductivity, ease of use, and, most important, the specific requirements of each case (e.g. height of the residual tooth structure and preparation angle) must enter the equation to find out which cementing agent is most appropriate.

Conclusions

1. None of the cementing agents investigated in this study yielded a perfect seal at the bonding interface in enamel or dentin.
2. All cementing agents investigated were associated with higher degrees of microleakage when the tooth substrate was located in dentin.
3. The self-adhesive universal resin cement (RelyX Unicem) revealed the smallest degree of microleakage both in enamel and in dentin.
4. After artificial aging differences in the marginal gap quality were observed.
5. An association between marginal gap and microleakage was not observed.

References