A REVIEW OF

Luting Agents, Properties and Bioactivity

Steven R. Jefferies, MS, DDS, PhD; Håkan Engqvist, PhD, MS;
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ABSTRACT

Luting agents have developed considerably since the introduction of zinc phosphate more than a hundred years ago. While zinc phosphate may still be regarded as the benchmark for other luting agents, specific benefits of contemporary luting agents are superior. These include the ability to form an adhesion zone at the tooth-luting agent interface, more esthetic materials, and thin film thicknesses that are suitable for current all-ceramic restorations. Luting agents must meet a number of criteria, including adequate physical properties for long-term success. Minimally invasive dentistry also has placed new demands on restorative materials in general, including luting agents. Recent research has focused on the ability of materials to form a biomimetic layer at the interface and to mineralize tooth structure.

EDUCATIONAL OBJECTIVES

The overall goal of this article is to provide readers with information on the properties and functionality of luting agents. On completing this article, the reader will be able to:

1. List the available permanent luting agents and their uses
2. Review the mechanisms of adhesion for the various luting agents
3. Describe biomimetics as it relates to luting agents and describe the process involved in mineralization adjacent to the tooth-luting agent interface
4. Review the relative properties of luting agents and their applicability.

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Restorative materials and luting agents have developed exponentially since the introduction of the first modern dental cement, zinc phosphate, in 1879. Almost a century later, additional luting agents became available. New materials and techniques gradually led to the use of esthetic restorative materials, as well as adhesive techniques and luting agents compatible with esthetics. Since then, minimally invasive techniques have generated new demands for restorative properties at a macro- and micro-level, and there is a desire for minimally invasive bioactive luting materials. A bioactive material is defined as one whose use results in the formation of an
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An example of a simulated body fluid would be a solution containing inorganic phosphate at a physiologic pH, such as phosphate-buffered saline. Bioactivity is also relevant with respect to implants, and is found in ISO 23317: In Implants for surgery - In vitro evaluation for apatite-forming ability of implants materials, 2007.

With respect to permanent luting cements, materials available include zinc polycarboxylate, zinc phosphate, glass ionomers and resin-modified glass ionomers, resin composites, and a more recently introduced GIC-modified bicericam material that has been found to exhibit bioactivity (Table 1). Although compomers are also available, these can be considered a subset of composite resin luting agents — they incorporate features of glass ionomers and a composite resin adhesive technique for retention.

Ideal properties of luting agents

Ideally, a luting agent would offer biocompatibility; excellent adhesion and bond strength to enamel and dentin; an appropriate film thickness; compatibility with indirect restorative materials; and the ability to form an apatite-like material as a surface layer when in the presence of a simulated body fluid. An example of a simulated body fluid would be a solution containing inorganic phosphate at a physiologic pH, such as phosphate-buffered saline. Bioactivity is also relevant with respect to implants, and is found in ISO 23317: In Implants for surgery - In vitro evaluation for apatite-forming ability of implants materials, 2007.

With respect to permanent luting cements, materials available include zinc polycarboxylate, zinc phosphate, glass ionomers and resin-modified glass ionomers, resin composites, and a more recently introduced GIC-modified bioceramic material that has been found to exhibit bioactivity (Table 1). Although compomers are also available, these can be considered a subset of composite resin luting agents — they incorporate features of glass ionomers and a composite resin adhesive technique for retention.

### Ideal properties of luting agents

- Compatibility with all indirect restorative materials
- Biocompatibility
- Lack of toxicity
- Excellent adhesion and bond strength
- High compressive, flexural, and tensile strengths
- Fracture resistance
- Long-term stability
- Lack of solubility in water
- Low/no water sorption
- Easy/no mixing
- Suitable working and setting times
- Self-setting or dual-cure
- No shrinkage during setting
- Hydrophilic with good flow properties
- Suitable film thickness for all restorations
- Non-exothermic setting reaction
- Does not result in post-operative sensitivity
- Mineralization properties
- Biomimetic
- Bactericidal or bacteriostatic
- Esthetic
- Radiopaque

### TABLE 1. Timeline for introduction of materials used as luting agents

<table>
<thead>
<tr>
<th>Material</th>
<th>Year of introduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zinc phosphate cement</td>
<td>1879</td>
</tr>
<tr>
<td>Zinc polycarboxylate cement</td>
<td>1968</td>
</tr>
<tr>
<td>Glass ionomers</td>
<td>1971</td>
</tr>
<tr>
<td>Resin composites</td>
<td>1950s</td>
</tr>
<tr>
<td>Resin-reinforced glass ionomers</td>
<td>1995</td>
</tr>
<tr>
<td>Compomers</td>
<td>2000s</td>
</tr>
<tr>
<td>GIC-modified bioceramic cement</td>
<td>2009</td>
</tr>
</tbody>
</table>

### TABLE 2. Ideal properties for a luting agent

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- Bactericidal or bacteriostatic
- Esthetic
- Radiopaque
restorative materials; lack of toxicity; bacteriostatic or bactericidal properties; esthetics; lack of low solubility in water and low/no water sorption; short- and long-term stability; bioactivity, biomimetics and mineralization; versatility; and ease-of-use. From the patient’s perspective, luting agents should not only be biocompatible but also pain-free at the time of, and following, placement of the indirect restoration (Table 2).

The selection of a luting agent is based on its properties, clinical preference, and the type of restoration to be luted. Zinc polycarboxylate cement offers adhesion and a low exothermic reaction; however, it has a film thickness that may make it unsuitable as a luting agent with modern indirect restoratives. This cement offers a relatively weak bond, and is now mainly used as a liner or as a temporary luting agent for provisional restorations.

Zinc phosphate

Zinc phosphate cement is still considered the benchmark for luting agents; however, it has limitations. These include a lack of chemical adhesion, as well as its acid-based, exothermic setting reaction. The liquid contains phosphoric acid (pH 1.5), water, and aluminum phosphate (+/- zinc phosphate); the powder consists mainly of zinc oxide. During setting, the pH reaches 3.5 and after 24 hours the cement is fully set at a pH of 6.7. Following its application, the dentinal smear layer and plugs are dissolved, opening up the dentinal tubules. In addition, any phosphoric acid not involved in the setting reaction can then enter the tubules due to the hydraulic pressure associated with cementation. This acid-based, exothermic setting reaction can cause pulpal irritation, which usually resolves when secondary dentin is deposited in response to the pulpal insult. Zinc phosphate also is soluble intraorally. It is suitable for cast posts and cores, and metal/PFM single-unit crowns or 3-unit bridge restorations with adequate retention form.

Glass ionomer and resin-modified glass ionomer cements

Glass ionomer cements (GICs), discovered in 1971, consist of fluoroaluminosilicate glass and a polyacrylic (polyalkenoic) acid component that also contains small amounts of itaconic/tartaric acid as setting reaction accelerators. GICs are water-based and therefore hydrophilic, improving contact with the tooth surface. The acid-based setting reaction involves gelation — the polyacrylic acid interacts with the fluoroaluminosilicate glass particles, releasing calcium fluoride and aluminum ions that cause gelation and setting over a 24-hour period. Additionally, the polyacrylic and metal ions in the GIC cross-link during setting.

Advantages of glass ionomers include their moisture tolerance and self-adhesion; no etchant/bonding agent is required. They offer low solubility, good translucency, and fluoride release.

In resin-modified glass ionomer cements (RMGICs), smaller fluoroaluminosilicate particles are present and some of the polyacrylic acid is replaced with hydrophilic acrylate or methacrylate monomers such as hydroxyethyl methacrylate; these monomers with free radical double bonds are added to the fluoroaluminosilicate. These differences result in greater strength and fracture resistance for RMGICs, and a faster initial set with light-cured polymerization of the monomers in addition to the traditional GIC setting reaction.

The clinical performance of GIC and RMGIC has been found to be equivalent or superior to the benchmark (zinc phosphate), while a comparative 4-year study of zinc phosphate, GIC, and resin composite cement also found equivalent performance. RMGICs are suitable for indirect restoration retention except when preparations have poor retention and resistance forms. For all GICs and RMGICs, maturation over time results in increased strength. These materials can be used for cast or PFM restorations, as well as zirconia and alumina crowns. They should not be used for low-strength all-ceramic restorations.

Composite resin luting agents

Composite resin luting agents are currently the most frequently used, consisting of a filler component and a monomer component (bis-GMA, TEGDMA, or DMA). They are
self-cured, light-cured, or dual-cured. The increased retention offered by resin composite luting agents is an advantage compared to RMGIC/GIC materials for indirect restorations with a poor retentive form.15

All composite resins set through polymerization, which introduces adverse polymerization shrinkage. Such shrinkage has been minimized through the use of various techniques, including nanofillers, chemical ring-like structures in the polymerized material, and the use of other chemicals that reduce shrinkage.

There are three options for composite resin luting cement bonding: 1) Use of a separate etch-and-rinse (total-etch) adhesive system; 2) Use of a self-etch adhesive system that requires application of a primer/bonding agent or separate primer and bonding agents; or, 3) Use of a self-adhesive dual-cured resin composite that does not require separate etching or bonding.

With a total-etch technique, the enamel margins should be etched for longer than the dentin (typically, 30 seconds versus 15 seconds) to prevent overetching the dentin. In dentin, the etchant removes the smear layer and demineralizes the dentin, leaving exposed collagen fibrils that will be penetrated by the bonding monomer. Self-adhesive composite resins contain adhesive monomers; they have a pH that is suitable for etching enamel and dentin, and then decreases rapidly in acidity. Unlike etch-and-rinse luting agents, the self-adhesive cements do not remove the smear layer. It has been recommended that a selective etch first be performed on enamel margins to improve bonding with self-etch and self-adhesive cements.

Composite resin luting agents offer excellent bond strength. In one study, this ranged from 4.8 MPa to 7 MPa for self-etch luting agents and up to 28 MPa for total-etch luting agents.16 Bond strengths were confirmed to be lower with use of single-step adhesives than with multi-step adhesive systems in a more recent study.17 A separate study also found the compressive strength of total-etch luting agents to be greater than for self-etch luting agents, but found the flexural strength to be lower.18 In comparing the bond strength of copings luted with RMGIC, self-adhesive composite resin, or a self-adhesive cement, and subsequently thermocycled, or comparing retention with seven self-adhesive cements without prior thermocycling, self-etch and self-adhesive composite resin cements exhibited higher retention rates in two studies.19,20 In comparison to GIC, RMGIC, and zinc phosphate, total-etch and self-etch luting agents were found in a separate study to offer significantly greater bond strengths.21

Self-cure or dual-cure agents can be used for ceramic restorations that are too thick to adequately transmit light. Self-adhesive composite resin luting agents are light-cured at the margins while the area under the restoration self-cures. Composite resin luting agents are compatible with ceramic crowns, ceramic and composite inlays and onlays, porcelain veneers, and resin-bonded fixed partial dentures. Most self-cure and some dual-cure composite resin luting agents also may be used to lute metallic indirect restorations, especially if there is ample remaining dentin thickness in the preparation.

Postoperative sensitivity

GICs and RMGICs are associated with few reports of postoperative sensitivity,22 which is a more frequent complaint with the use of resin composites. Although sensitivity has been considered to be more of a risk with total-etch adhesives, which remove the smear layer and plugs, a recent study found no differences between the various modalities of resin composite bonding.23 It has been suggested that sensitivity may, at least in part, be associated with dessication of the tooth during cementation. Therefore, using an exact technique is important not only for proper bonding but also to reduce postoperative complications. In a 4 year period, 1560 of 4400 restorations placed with self-adhesive cements were evaluated at recall. Of these, occasional sensitivity was reported in <1.8% of restorations, with marginal staining — indicative of microleakage — evident in 4.2%.24

Glass ionomer-modified bioceramic cement

A glass ionomer-modified bioceramic luting agent was introduced in 2009. It is mixed with distilled water and sets through an acid-base reaction as well as a traditional GIC adhesive reaction. While on placement this new luting agent
has a pH of 4, it neutralizes 1 hour after setting, then reaches and maintains an alkaline pH of 8.5 4 hours after setting. *In vitro* testing has confirmed that the physical properties of this new luting agent are at least equivalent to other contemporary luting agents. Retention was found in one study to be equivalent to a self-adhesive composite resin and superior to another self-adhesive composite resin, a compomer, and zinc phosphate (P<0.01). Compressive strength was found in a separate *in vitro* study to be comparable to a self-adhesive composite resin at 24 hours and to increase over time (30 days).

Excellent retention also was confirmed in a more recent study, where the force required to rupture luting agents from cast gold alloy copings was greater for the glass ionomer-modified bioceramic cement than for compomer or zinc phosphate, and slightly less than that of a self-adhesive cement. With respect to all-ceramic copings, a statistically significantly greater force was required to separate the glass ionomer-modified bioceramic luting cement compared to self-adhesive composite resin cement (Fig. 1). At 3-year recall in a small *in vivo* study, no restoration retention failures were observed.

The acid-base reaction and rapid attainment of an alkaline pH eliminates or substantially reduces the possibility of postoperative sensitivity. Studies have confirmed almost a complete absence of pulpal irritation, oral mucosal irritation, or skin sensitization with use of this cement. In a 3-year study of restoration placement in 17 patients, while 7 patients reported pre-cementation sensitivity, post-placement sensitivity was reduced, and at 1, 2, and 3 years sensitivity was completely absent for all recalled patients. Gingival inflammation also decreased from baseline, with an 88% reduction by year 3 (P<0.05), also indicative of biocompatibility.

This new luting agent is suitable for metal, PFM and high-strength, all-ceramic crowns and bridges (zirconia, alumina and lithium disilicate); gold inlays and onlays; and metal posts. It should not be used for veneers or fiber posts. An overview of luting agent compatibility can be found in Table 3.

### Ion Exchange, Adhesion, Nanotechnology, and Bioactivity

As research has continued, materials have been developed that increasingly fulfill the desired properties for luting...
agents. The basic role of demineralization and remineralization, the nature of the adhesion zone, nanotechnology, and bioactivity are all important concepts in this regard.

**Demineralization/remineralization and mineralization**

In the context of luting agents, there are two relevant aspects: the first is the caries process and preventing secondary caries at restoration margins, while the second relates to the adhesion zone.

**Caries process and management**

During the caries process, cariogenic bacteria metabolize fermentable carbohydrates and produce acid. Once the pH decreases sufficiently to reach the critical level, tooth structure is demineralized. In the presence of a sufficient quantity of calcium, phosphate, and fluoride ions, the area is supersaturated with these ions, helping to prevent demineralization. Should the concentration gradient be insufficient to prevent demineralization, the ions present at the surface help to remineralize the demineralized areas. In the case of deep dentin lesions, after removal of soft carious dentin an affected area of dentin remains that can be remineralized through the application of suitable agents.\(^{29,30}\) This is the basis for indirect pulp capping, which is intended to promote the generation of tertiary (regenerated) dentin as the odontoblasts supply calcium and phosphate. Viable collagen fibrils must be present to act as a scaffold for newly forming apatite crystals.\(^{31}\) At the same time, since the area is sealed from the external environment, new bacteria cannot gain access to the demineralized dentin and for the limited number of bacteria already present there is no accessible source of fermentable carbohydrates. The above is also the basis for stepwise excavation of deep carious lesions and the preservation of pulpal health.\(^{32}\) The use of glass ionomers, calcium hydroxide, and mineral trioxide aggregate (MTA) have been found to result in dentin remineralization.\(^{33-35}\)

**The adhesion zone**

During creation of an adhesive zone for composite resin cements, a low-pH etchant will demineralize the exposed surface. In dentin, this results in loss of inorganic structure that leaves behind exposed organic collagen fibrils. These fibrils are evident on micrographs after etching associated with the use of resin composite materials. Composite resin adhesives include hydrophilic monomers to encourage penetration of the adhesive through the depth of etched, demineralized dentin and to envelop the exposed collagen fibrils. Based on recent research on the microscopic structure of dentin at the nano level, complete penetration may be prevented by intermolecular spaces containing water between subfibrils as well as by fluid movement within the dentinal tubule system.\(^{36-39}\) The adhesive interface also has been found to be more variable in caries-affected dentin than noncarious dentin.\(^{40}\) If exposed collagen fibrils remain (ie, that were not penetrated during adhesion), etchant-activated dentin matrix metalloproteinases, derived from odontoblasts, hydrolyze these fibrils. Over time, this leads to bond degradation (Fig. 2). This is the basis for the inclusion of MMP inhibitors in etchants, such as chlorhexidine or benzalkonium chloride, to preserve the integrity of the dentin-adhesive interface.\(^{41,42}\) In vitro, bond degradation has been shown to have the potential for stress redistribution and reduced load-bearing capacity of all-ceramic restorations over several years.\(^{43}\) Bond degradation also may occur as a result of water sorption and hydrolytic breakdown of ester linkages of methacrylate resins.\(^{38}\)

It should be noted that the potential for bond degrada-
tion is material-specific. One etch-and-rinse resin composite incorporates chemicals in the adhesive that encourage adhesion through the creation of a bond between the calcium in hard tooth structure and the esters in the bonding agent. Self-etch composite resins bonds have been found to degrade more and to be weaker than with total-etch techniques. Researchers have proposed several methods that could prevent bond degradation, including the use of ethanol to wet-bond dentin while displacing all water, cross-linking agents, alternative materials, and bioactive remineralization.

Nanotechnology

The first use of nanotechnology in dental restorative materials was the incorporation of nanofillers into composites to improve strength and wear resistance, and to reduce polymerization shrinkage; nanofillers also have been used in glass ionomers. Most recently, nanotechnology has been used to investigate the mineralization of dentin at the cement-tooth interface for restorative materials and luting agents. Experimentally, the use of calcium silicate with etch-and-rinse adhesives and glass ionomers has been found to result in mineral deposits in the hybrid layer, with demonstrated reductions in microleakage, microhardness, and moduli of elasticity. Natural nanotechnology also can play a role to increase bond strength; with MTA and glass ionomer-modified bioceramic cements, the setting reaction results in nanograins bonding together to provide material strength. Hydroxyapatite nanoparticles have been added to glass ionomers experimentally and found to increase bond strength and overall strength after 30-day storage in distilled water; nanoparticles of amorphous calcium phosphate also have been investigated in vitro.

A bioactive approach to luting

A bioactive approach has been presented with a glass ionomer-modified bioceramic luting cement. Bioactive mineralization occurs by two different mechanisms: A negative surface charge attracts calcium ions to the surface where apatite formation begins, and the release of ions to the saliva induces hydroxyapatite formation. Early in vitro testing demonstrated the formation of hydroxyapatite after

![Figure 3. Process of bioactive mineralization](image)

![Figure 4. SEM showing hydroxyapatite formation on sample with GIC-modified bioceramic cement](image)
7 days when glass ionomer-modified bioceramic luting cement was immersed in physiologic phosphate buffered saline solution over a 30-day period. The layer consisted of randomly arranged, nanosized crystals (19-30 nm), with similar ratios of calcium to phosphorus as found in standard hydroxyapatite. In separate in vitro testing, the level of phosphate in buffered saliva was significantly less by day 7 after immersion of this bioactive luting agent, indicating use of phosphate for the hydroxyapatite formation observed at the samples’ surfaces.

The pH profile of glass ionomer-modified bioceramic is essential and conducive for intraoral apatite formation. As noted earlier, the pH is acidic at the time of placement, and then rapidly rises within 1 hour before reaching an alkaline pH of 8.5 within 4 hours. This alkaline pH promotes precipitation of nanocrystals and the formation of an interface mineralized zone, and is favorable for bioactive regeneration of dentin. An alkaline pH is also known to advantageously degrade already-exposed collagen fibrils, which enables greater mineralization as the structure becomes more porous and infiltration of calcium and other hydroxyapatite precursor ions is encouraged (Fig. 3). The mineralization observed with glass ionomer-modified bioceramic luting cement has been found to result in a durable seal at the cement-tooth interface. In vivo, this bioactive material releases an excess of calcium ions, which results in an area of supersaturation that promotes mineralization. Nanocrystals of calcium aluminate hydrate are precipitated at the tooth-cement interface during hardening of the cement, act as biomimetic precursors, and over time apatite continues to form in vivo in the presence of phosphate.

Preventing secondary caries

Secondary caries is the most frequent reason for the replacement of restorations, making its prevention of great importance for clinicians and patients. Maintaining bond integrity prevents microleakage and the ingress of cariogenic bacteria at the margins, while lowering the cariogenic microbial load also reduces the risk. Given that cariogenic bacteria are causal for primary and secondary caries, and that Streptococcus mutans bacteria contain esterases that can variably biodegrade composite resins and resin adhesives, biofilm reduction is advantageous.

Biofilm adheres well to rough composite surfaces, therefore using nano filled restoratives that are smoother and possess high polishability helps to reduce the presence of bacteria. Another strategy is to use materials that reduce bacterial growth and biofilm formation and/or that possess antibacterial properties. Antibacterial agents researched for use with composite resin materials include chlorhexidine, benzalkonium chloride, and quaternary ammonium. Numerous studies have researched the positive influence of chlorhexidine in vitro and in vivo on composite resin bond integrity. In vitro research using bonding agents containing antibacterial nanoparticles of silver and remineralizing nanoparticles of amorphous calcium phosphate demonstrated significantly reduced biofilm viability and acid production, while maintaining dentin bond strength. In an in vitro study comparing

<table>
<thead>
<tr>
<th>TABLE 4. Potential strategies for secondary caries prevention</th>
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<tbody>
<tr>
<td><strong>Method</strong></td>
</tr>
<tr>
<td>Nanoparticles/ nanofillers</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Biofilm-inhibiting materials</td>
</tr>
<tr>
<td>Incorporation of antibacterial agents</td>
</tr>
<tr>
<td>Silver nanoparticles</td>
</tr>
<tr>
<td>Fluoride release from luting agent</td>
</tr>
<tr>
<td>Bioactive materials that create a crystalline interface</td>
</tr>
</tbody>
</table>
the bacterial load present on various luting agents compared to control (methyl methacrylate), glass ionomer-modified bioceramic cement exhibited statistically significantly lower levels of colony-forming units compared to other agents at day 1 (P<0.05) and no differences to most luting agents at day 7. A further strategy is the use of materials that incorporate and release fluoride (Table 4).

GICs, RMGICs, GIC-modified bioceramic, and fluoride-releasing composites all have been shown to release fluoride, with the release profiles depending on the specific material. GIC and fluoride-releasing composite resin more effectively reduced adjacent demineralization than a composite resin in an in vitro study, with the GIC resulting in the least demineralization. In a systematic review of GICs and RMGICs, no statistically significant differences in their caries preventive effects were found. A quantitative systematic review of 6 trials was inconclusive, finding either no differences between RMGIC and composite resin, or demonstrating superior caries prevention with the RMGIC. In an in vitro study of open sandwich restorations, GIC and RMGIC were found to increase enamel hardness vs. composite resin, while the GIC also increased dentinal hardness and was most effective in reducing enamel and dentin demineralization during cariogenic challenges. Based on a review of studies published between 1980 and 2004, these materials act as fluoride reservoirs. However, results are equivocal with respect to, specifically, their impact on secondary caries prevention.

In a 2013 review of 3-year results in a small study encompassing 17 patients with 38 restorations luted with fluoride-releasing glass ionomer-modified bioceramic cement, no loss of marginal integrity or staining was observed, and no secondary caries were observed at any restored site. A separate in vitro study found significantly less microleakage using this luting agent compared to a glass ionomer-resin composite luting agent (compomer) (P<0.01), while another found equivalent (P>0.05) and statistically significantly lower levels of microleakage for glass ionomer-modified bioceramic and RMGICs compared with compomer (P<0.05) (Fig. 6). The case shown here (Figs. 7-10) demonstrates the use of GIC-modified bioceramic luting cement. The patient had originally presented with extensive restorations with second-
ary caries and discoloration, as well as requiring an implant that had been placed and had received a custom-fabricated abutment. After preparation of the five anterior teeth (Fig. 7) and impression-taking, PFM crowns were fabricated for the five anterior teeth and a zirconia crown was fabricated for the implant. GIC-modified bioceramic luting cement was used to place the definitive restorations. The luting cement was first activated and mixed in accordance with the manufacturer’s instructions, and then injected directly into the crowns (Fig. 8). The crowns were seated and stabilized until the cement had reached a rubbery stage (about 2 minutes post-mixing). The excess cement easily and cleanly peeled away with an explorer (Fig. 9). The restorations were stabilized for a further 4 minutes before inspecting the area for any residual excess. The final restorations can be seen in Figure 10.
The second case shown here (Figs. 11-15) demonstrates the use of the same GIC-modified bioceramic luting agent. The patient had presented with two failing indirect restorations that had poor marginal fit, carious margins, and adjacent gingival bleeding (Fig. 11). After discussion with the patient, these restorations were removed and the preparations adjusted for the new all-ceramic restorations. Digital impressions were taken and provisional restorations placed. The all-ceramic zirconia crowns were CAD/CAM designed and fabricated in the laboratory. At the seating appointment, the provisional restorations were removed and the sites cleaned of any residual provisional cement (Fig. 12). Cementation was performed using a GIC-modified bioceramic luting agent. Stabilization was achieved until the cement became rubbery (Fig. 13), at which point the excess cement was easily removed by peeling it away with an explorer (Fig. 14) and the restorations further stabilized for several minutes. The final restorations provided the patient with an esthetic and functional result that was compatible with oral health (Fig. 15).

Conclusions

Research over the last few decades led to significant improvements in the functionality and esthetics of both restorative materials and luting agents. There has been a focus on researching and providing clinicians with luting agents that offer excellent marginal sealing, long-term bonding and durability, biocompatibility, lack of toxicity, ease-of-use, and esthetics. In selecting a luting agent, its properties and compatibility with the restorative material must be assessed. Most recently, nanotechnology and biomimetic bioactivity have been researched and introduced. Advances have been considerable, offering benefits for the clinician and patient alike.

Acknowledgments

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References


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CEQuiz

1. The first modern dental cement, zinc phosphate, was introduced in ____________.
   a. 1879
   b. 1899
   c. 1919
   d. 1939

2. ____________ is one of the ideal properties for a luting agent.
   a. Biocompatibility
   b. Long-term high bond strength
   c. Ease-of-use
   d. all of the above

3. The selection of a luting agent is based on ____________.
   a. its properties
   b. clinical preference
   c. the type of restoration to be luted
   d. all of the above

4. Zinc phosphate ____________.
   a. is considered the benchmark for a luting agent
   b. sets by an exothermic, acid-based setting reaction
   c. is suitable for cast posts and cores as well as metal/PFM single units and 3-unit bridges
   d. all of the above

5. The setting reaction for GICs ____________.
   a. involves the interaction of polyacrylic acid with fluoroaluminosilicate particles
   b. results in polymerization
   c. involves cross-linking between the polyacrylic acid and metal ions in the GIC
   d. a and c

6. Self-adhesion and moisture tolerance are advantages of ____________.
   a. etch-and-rinse composite resins
   b. GICs and RMGICs
   c. zinc polycarboxylate
   d. zinc phosphate

7. Postoperative sensitivity is most frequently associated with the use of a ____________ luting agent.
   a. GIC
   b. calcium aluminate/GIC
   c. composite resin
   d. RMGIC

8. Etch-and-rinse composite resin luting agents ____________.
   a. are not suitable for low-strength ceramics
   b. offer excellent bond strength and compressive strength
   c. result in adhesion through a process of chelation
   d. all of the above

9. A GIC-modified bioceramic luting agent ____________.
   a. is mixed with distilled water
   b. sets through an acid-base and a traditional GIC adhesive reaction
   c. changes from an acidic pH to a pH of 8.5 over a period of 4 hours
   d. all of the above

10. In a small in vivo study of a GIC-modified bioceramic luting agent, at 3-year recall which of the following was observed?
    a. no restoration failures
    b. no sensitivity
    c. gingival inflammation was reduced compared to baseline
    d. all of the above

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11. Nanotechnology has been used in dental restorative materials to ______________.
   a. improve the strength and wear resistance of composite resin restorations
   b. reduce polymerization shrinkage
   c. investigate the mineralization of dentin at the cement-tooth interface
   d. all of the above

12. Experimentally, the use of calcium silicate with etch-and-rinse adhesives and glass ionomers has been found to result in ______________.
   a. mineral deposits in the hybrid layer
   b. mineral deposits in the material at the restoration-luting agent interface
   c. preferential absorption of fluoride
   d. all of the above

13. Numerous studies have researched the positive influence of ______________ on composite resin bond integrity.
   a. chlorhexidine
   b. chloride
   c. ethers
   d. all of the above

14. The alkaline pH found after setting of a GIC-modified bioceramic luting cement ______________.
   a. advantageously degrades already-exposed collagen fibrils
   b. promotes precipitation of nanocrystals and the formation of a mineralized zone at the tooth-luting agent interface
   c. encourages infiltration of hydroxyapatite precursor ions
   d. all of the above

15. ______________ is the most frequent reason for the replacement of restorations.
   a. Restoration fracture
   b. Discoloration
   c. Secondary caries
   d. none of the above

16. ______________ is a strategy to help prevent secondary caries.
   a. Using materials that reduce bacterial growth and biofilm formation
   b. The inclusion of nanoparticles in restorative materials
   c. Using a fluoride-releasing restorative material
   d. all of the above

17. With respect to composite resin adhesives, ______________.
   a. hydrophilic monomers are included to encourage penetration of the adhesive
   b. the adhesive interface has been found to be more variable in caries-affected dentin than noncarious dentin
   c. one etch-and-rinse adhesive includes chemicals that encourage adhesion through the creation of a bond between the calcium in hard tooth structure and the esters in the bonding agent
   d. all of the above

18. In an in vitro study, a reduced level of bacterial colony-forming units was found immediately following the use of a ______________.
   a. methyl methacrylate
   b. GIC-modified bioceramic cement
   c. zinc phosphate cement
   d. zinc polycarboxylate cement

19. Research over the last few decades led to significant improvements in the ______________ of luting agents.
   a. functionality
   b. esthetics
   c. cementum interface
   d. a and b

20. Most recently, ______________ have been explored and introduced into luting agents.
   a. nanotechnology and biomimetics
   b. bioreduction and macrotechnology
   c. anti-compression agents
   d. all of the above
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EDUCATIONAL OBJECTIVES

- List the available permanent luting agents and their uses
- Review the mechanisms of adhesion for the various luting agents
- Describe biomimetics as it relates to luting agents and describe the process involved in mineralization adjacent to the tooth-luting agent interface
- Review the relative properties of luting agents and their applicability

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6. A B C D
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11. A B C D
12. A B C D
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