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Abstract
The complexity of restorative dentistry has increased greatly in recent years, with the myriad of products used in "adhesive dentistry." So too has the "simple" matter of restoring access cavities after completion of endodontic treatment. This review discusses current methods of "bonding" to tooth structure, ceramic materials, and metals, with emphasis on those aspects that are important to endodontics. Specific materials, procedures and major decision making elements are discussed, as well as how to avoid problems in compatibility between endodontic and restorative materials.

Key Words
Access cavities, adhesive dentistry, endodontics, restorative dentistry

At the tomb of the unknown endodontist, there is a plaque that reads "Root canal treatment is not complete until the tooth has been restored." A recent article reviewed the overall topic of restoration of endodontically treated teeth (1). This review will address in detail the important issues when restoring access cavities through natural tooth structure and restorative materials with emphasis on major decision making elements, material selection and clinical procedures. It will focus on those aspects of adhesive dentistry that are important and unique to endodontics.

Contamination of the Root Canal System
One of the primary goals of root canal treatment is to eliminate bacteria from the root canal system to the greatest possible extent (2, 3). Bacteria have been shown to be the etiology for apical periodontitis (4) and to be the cause of endodontic failure (2, 3, 5). One of the goals in restoring the tooth after root canal treatment should be to prevent recontamination of the root canal system. Gross contamination can occur during the restorative process from poor isolation or poor aseptic technique. Contamination can also occur from loss of a temporary restoration or if leakage occurs. The same things can occur with a "permanent" restoration, but "permanent" materials tend to leak less than temporary materials (6). Exposure of gutta-percha to saliva in the pulp chamber results in migration of bacteria to the apex in a matter of days (2, 7-9). Endotoxin reaches the apex even faster (10).

The importance of the coronal restoration in successful endodontic outcomes is widely accepted and has been supported by studies by Ray and Trope (11), Hommez et al. (12), Tronstad et al. (13), Iqbal et al. (14), and Siqueira et al. (2). However, studies by Ricucci et al. (15), Ricucci and Bergenholz (16), Heling et al. (17), and Malone et al. (18) indicate that contamination may not be as important a factor in failure as is commonly believed. Therefore, it must be concluded that the significance of bacterial contamination as a cause of endodontic failure is not fully understood. Because there is clearly no benefit to introducing bacterial contamination into the root canal system, and since it may be a contributing factor in endodontic failure, a basic premise of this review will be that every effort should be made to prevent contamination.

Temporization
To minimize the likelihood of contamination, immediate restoration is recommended upon completion of root canal treatment (19-21).

When immediate restoration is not possible, and the tooth must be temporized, a thick layer of temporary material should be used, preferably filling the whole chamber. The majority of restorative dentists prefer a cotton pellet in the chamber, however (22). If a cotton pellet or sponge is to be use, orifice barriers are recommended, to provide a second layer of protection against contamination in addition to the temporary material at the occlusal surface.

Recommended procedure for placing orifice barriers:
1. Countersink the orifice with a round bur.
2. Clean the orifices and floor of the pulp chamber thoroughly with alcohol or a detergent to remove excess cement and debris. Air abrasion provides a dentin surface that is free of films and debris.
3. Place a temporary or "permanent" restorative material in the orifices and over the floor of the chamber.
A bonded material such as composite resin or glass ionomer cement is preferred (23-27). Temporary materials may also be used (28). Mineral trioxide aggregate (MTA) may also be used (29). There is probably some benefit to using a material that is clear so that the restorative dentist can see the underlying obturating material if re-entry is needed into the canal system (1) (Fig. 1).

Results varied in studies that evaluated temporary materials for the access cavities (21, 30-36). The most common materials tested were zinc oxide eugenol (such as IRM, Dentsply Int.), zinc oxide/calcium sulfate (Cavit, Premier Corp.) or resin based materials including composite resin and resin modified glass ionomer materials. Generally, all of the temporary materials were adequate if placed in a thickness of 3 mm or greater (21, 33-36).

All temporary materials leak to some extent (20, 21, 37-40). The zinc oxide/calcium sulfate materials are more resistant to microleakage than the zinc oxide eugenol materials (21, 34), probably because of setting expansion and water sorption (33). Although the zinc oxide eugenol materials tend to leak more, they possess antimicrobial properties, making them more resistant to bacterial penetration (21, 34, 41). Both materials are simple to use. One study reported less leakage with the use of two materials in combination (42).

Resin based temporary materials must be bonded to provide an effective seal, because they undergo polymerization shrinkage of 1 to 3% (30, 43). This is offset somewhat by the fact that they swell as they absorb water (30). Generally, bonded resin materials provide the best initial seal, but lack antimicrobial properties (30). They require more steps and more time to place than materials such as IRM or Cavit. Bonded resins are recommended for temporization that is likely to last more than 2 to 3 wk (42, 44). Resin modified glass ionomer materials are also a good choice for long term temporization, because they provide a bond to dentin and enamel, and many have antimicrobial properties (44).

Teeth requiring temporary post/crowns are a particular challenge, because of the difficulty in obtaining a good seal (45, 46). To minimize
the chances of contamination of the obturating material, a barrier may be placed over it with a self-curing material. The post space should be restored as soon as possible and it may be beneficial to flush the post space with an antimicrobial irrigant when the temporary post is removed.

**Restoring Access Openings**

When an access opening is made through an existing restoration, several things should be considered. Removal of all existing restorations is desirable if possible, because it allows more complete assessment for the presence of cracks and caries (47). This is particularly recommended for old class 1 and class 2 restorations, because they are likely to be removed later anyway, in the process of preparing the tooth for a crown. Magnification and caries detector are helpful in identifying cracks and for complete removal of caries (48).

If the existing restoration is a crown or onlay that appears to be clinically satisfactory and replacement is not planned, the chamber and internal restorative materials should be examined carefully with magnification. Caries detector should be painted on the internal tooth surfaces. Any areas stained by the caries detector, particularly adjacent to restorations, should be examined carefully for softness or gaps (Fig. 2). Caries detector may also stain sound areas of dentin that have decreased mineral content (49). The key to the presence of caries is determined by whether the stained areas are hard or soft. Many times caries can be identified internally, necessitating replacement of the crown.

Access openings made through an existing restoration results in loss of retention (50–52) and strength (53). When the access opening is restored, loss of retention is reversed (51, 52). If a post is added, additional retention is gained (51).

Ideally, we would like to restore access cavities with a restorative material that provides a permanent, leak proof seal. Unfortunately, no such material is available. All materials that we use and restorations that place us to some extent. This includes intracoronal restorations including bonded resin and glass ionomer materials (38, 54) as well as the metal or ceramic extra-coronal restorations (55, 56). To minimize leakage, bonded restorations are recommended, regardless of the restorative material (6, 57).

Access openings are made through a number of different restorative materials, including gold alloys, base metal alloys and porcelain, as well as enamel and dentin. Bonding to each of these substrates present specific challenges which require specific strategies and materials. Often the access opening is prepared through two or three different substrates. The structural integrity of the tooth may also influence the choice of restorative materials. Each substrate will be addressed separately.

**Bonding to Enamel**

Enamel is often present along the margins of access preparations of anterior teeth. The resin bond to etched enamel is strong and durable. The technique dates back to 1955 (58). Etching of enamel with an acid such as 30 to 40% phosphoric acid results in selective dissolution of the enamel prisms and creates a surface with a high surface energy that allows effective wetting by a low viscosity resin. Microporosities are created within and around the enamel prisms that can be infiltrated with resin and polymerized in-situ (59). These "resin tags" provide micro-mechanical retention. Bond strengths are typically in the range of 20 megapascals (Mpa) (60). Megapascals are a measure of the force per unit area that is required to break the bond. Self-etching adhesive systems, which will be discussed in the section on bonding to dentin, etch ground enamel fairly well, but do not etch unground, aprismatic enamel effectively (61–63). Therefore, enamel margins should be beveled when using self-etching adhesive systems. It is critical to prevent contamination of etched enamel with blood, saliva or moisture (64). Properly etched enamel leads to staining at the margins of the restoration (65). A good enamel bond protects the underlying dentin bond which is less durable (66).

**Bonding to Metal-Ceramic and All-Ceramic Restorations**

Access cavities are often made through metal-ceramic or all-ceramic materials, so attaining an effective, durable bond is important when restoring them. The literature is unambiguous that the best method to bond to porcelain is to first roughen the surface by acid etching and then apply a silane coupling agent, followed by the resin (67–70). Bond strengths of 13 to 17 Mpa have been reported, and failure is often cohesive within the porcelain. Measuring the interfacial bond strength exceeds the strength of the porcelain itself (71–73). Bonding to porcelain was initially developed as a method for repair of fractured metal-ceramic crowns. Improvements in the technique allowed porcelain veneers to become a common clinical procedure. Etched ceramic materials form a strong, durable bond with resin (74).

Micro mechanical bonding can be attained by roughening the porcelain with a bur, air abrasion or etching with hydrofluoric acid. However, acid etching is the most effective method (73, 75, 76). The first to introduce acid etching of porcelain was Calamia in 1983 (77).

Adhesion between the resin and porcelain may be enhanced by the use of a silane-coupling agent. Silane acts as a surfactant to lower surface tension and forms double bonds with OH groups in the porcelain, forming a siloxane bond. At the other end of the silane molecule is a methacrylate group that copolymerizes with resin. The use of a silane-coupling agent with porcelain was first described by Rochette in 1975 (78).

**Hydrofluoric Acid**

Hydrofluoric acid provides greater surface roughness to porcelain than air abrasion or roughening with a bur (75). It works by dissolving the glass particles (leucite) within the porcelain (Fig. 3). Most of the porcelains used in metal-ceramic restorations are feldspathic porcelains that contain leucite. Some ceramic materials, such as low fusing porcelains, do not contain leucite and are not etched effectively by...
hydrofluoric acid (79). However, hydrofluoric acid is effective with most of the current ceramic restorative materials (80–83).

Hydrofluoric acid is usually provided in a 10% concentration in a syringe. It is very important to follow the manufacturer’s instructions, as an application time that is too short will produce an inadequate etch, while an application time that is too long may render the porcelain brittle and thus more prone to fracture (84).

**Silane**

Silane acts as a “coupling agent” enhancing the bond between the resin and ceramic materials. It is supplied premixed or as a two bottle system that is mixed at the time of use. It is applied to the etched surface and must be thoroughly air dried (85). A low viscosity resin adhesive is then flowed over the surface and polymerized. Once again, it is very important to follow the manufacturer’s instructions.

Silane has a limited shelf life. Storage in the refrigerator will extend its useful life, but it should be used at room temperature (86). The two bottle silanes have the longest shelf life (71). Silane that is past the expiration date or that contains precipitates should be discarded (86).

**Air Abrasion**

Air abrasion is sometimes recommended to clean the porcelain and provide surface roughness. Several companies sell “micro-etchers” that can be used chairside. Aluminum oxide particles are sprayed onto the surface at about 80 psi. Fifty micron particles have been shown to produce a more retentive surface than 100 µm particles (87). Two studies reported that air abrasion has a negligible effect on bond strength, however (76, 88). Etching and application of silane are the two most important steps.

**Cosmetics**

When restoring the access cavity of a ceramic crown, it is often a challenge to produce a good cosmetic result. Many times it is difficult to mask the underlying metal of a metal-ceramic crown. This is particularly true if the porcelain is thin. It is not uncommon to see the metal showing through the composite. The second challenge is to match the optical properties of the porcelain. This is true for metal-ceramic crowns as well as all-ceramic crowns. Most composites are too low in value (too gray and translucent) to effectively match the surrounding porcelain (Fig. 4).

Several products are available that may be used to mask the underlying metal before the restorative composite is placed. Most of these are composite resins that contain opaquers. They may be covered with more translucent composite materials. Several composites are available that are quite opaque and work well when restoring access cavities in metal-ceramic crowns. Composite stains can be used to accentuate pits and fissures to further enhance the cosmetic result (Fig. 5).

**Bonding to Metal**

The metal portion of metal-ceramic crowns is not usually significant when restoring access openings, so no extra procedures are necessary to deal with it. However, for crowns in which all or part of the occlusal surface is metal, adhesion may be desirable. Adhesion to metal is generally obtained by mechanical means. Surface roughness may be created with a bur or air abrasion, which provides micromechanical retention (89). Chemical adhesion is also possible with metals that form an oxide layer (90). Silane has no effect on bonding to metal (91).

Several studies have shown tin plating of metal enhances mechanical retention (92–96). Chromium plating also works well (96). Plating devices are available that can be used intraorally. Although effective, this...
procedure has never gained popularity. Metal primers are an alternative that enhances the bond between metal and resin. They have been shown to be effective and do not require any special equipment (97–99).

**Bonding to Dentin: Resin Materials**

Bonding to dentin with resin materials is more complex than bonding to enamel or porcelain. Dentin consists of approximately 50% inorganic mineral (hydroxyapatite) by volume, 30% organic components (primarily type I collagen) and 20% fluid (100). The wet environment and relative lack of a mineralized surface made it a challenge to develop materials that bond to dentin. Current strategies for dentin adhesion were first described by Nakabayashi in 1982 (101), but his ideas were not widely accepted for a number of years. Nakabayashi showed that resin bonding to dentin could be obtained by applying an acid to expose the collagen matrix and dentinal tubules, applying a hydrophilic (“water loving”) resin material to the demineralized surface and polymerizing the resin in situ. The collagen matrix and dentinal tubules, to a lesser extent, provide mechanical retention for the resin. Although not as durable and reliable as enamel bonding, steady improvements have been made in dentin bonding and in simplifying dentin-bonding procedures.

Most in vitro studies of dentin bonding report on bond strengths, microleakage, or both. Like enamel, bond strengths are usually reported in Mpa. Depending on the test method used, initial bond strengths can be obtained that are equal or greater to those of etched enamel. However, dentin bonding is not as durable as enamel bonding or as stable. It is well documented that bond strengths decrease with time and function. This has been shown in vitro (66, 102–109) and in vivo (110, 111). Microleakage is probably a more important issue to endodontics than bond strength. None of the current adhesive systems are capable of preventing microleakage over the long term (65, 112–117). There is not a direct relationship between bond strength and microleakage (116).

Dentin adhesive systems utilize an acid as the first step of the bonding process to remove or penetrate through the smear layer and demineralize the dentin surface. The smear layer covers the surface of ground dentin and consists of ground up collagen, hydroxyapatite, bacteria, and salivary components (59). Most dentin adhesive systems can be categorized as “etch and rinse” or “self etching,” based on the acid etching process (59).

**"Etch and Rinse" Adhesives**

Most of the “etch and rinse” adhesive systems utilize a strong acid such as 30 to 40% phosphoric acid. When phosphoric acid is applied to dentin, the surface is demineralized to a depth of about 5 μm. The acid is rinsed off after about 15 s, removing the smear layer and exposing the collagen matrix and network of dentinal tubules for resin bonding. A hydrophilic primer is then applied to the surface to infiltrate the collagen matrix and network of dentinal tubules, to a lesser extent, provide mechanical retention for the resin. Poor bond strengths and increased microleakage result from excessive etching (118). The same is true if residual carrier/solvent is left behind (119), which makes the bond more subject to hydrolytic breakdown (119).

**“Self Etching” Adhesives**

Most of the “self etching” products combine an acid with the primer. Rather than removing the smear layer, they penetrate through it and incorporate it into the “hybrid layer.” The acidic primer is applied to the dentin surface and dried with a stream of air. There is no rinsing step. A resin adhesive is then applied and polymerized, followed by the restorative material.

The “self etching” systems can be categorized as “strong” or “aggressive” (pH <1), “moderate” (pH 1–2) or “mild” (pH >2) (59, 120, 121). The strong “self etching” systems form a hybrid layer of approximately 5 μm in thickness, similar to phosphoric acid, whereas the mild systems form a hybrid layer of about 1 μm. There does not appear to be clinical significance to this difference in thickness, however (121). The “strong” systems generally produce a superior bond to enamel than the “weak” systems (59), particularly with unground enamel (61–63).

**Dentin Adhesive “Generations”**

Many of the “etch and rinse” adhesive systems require three steps (etch, primer, adhesive), and are known as “1st generation” adhesive systems. The “generation” of a dentin adhesive generally follows the order in which they were developed and each “generation” utilizes different bonding procedures. The “5th generation” adhesive systems are “etch and rinse,” followed by application of a combined primer and adhesive. These are sometimes referred to “single bottle” adhesive systems. Some require several applications of the primer/adhesive, however. The “6th generation” adhesives utilize an acidic (“self etching”) primer followed by an adhesive. The 5th and 6th generations are generally two step procedures, while the 7th generation combines everything (acid, primer and adhesive) into one step.

Many of the “self etching” products require fewer steps and less time than the “etch and rinse” products, and are considered to be less “technique sensitive” (59). There are still a number of questions about them, however, such as the unknown effects of incorporating partially dissolved hydroxyapatite crystals and smear layer into the hybrid layer. There is also the question of how much of the carrier/solvent remains behind. Because they are relatively new, there are currently no long-term...
clinical studies with the “self etching” adhesive systems. The three step adhesive systems generally perform better in in vitro testing than the adhesive systems that combine steps (59, 65, 66, 107, 121, 122), although the differences lessen with time as the bonds degrade (66, 107). The “self etching” adhesive systems are also less effective than the “etch and rinse” systems when bonding to sclerotic dentin and carries affected dentin (123, 124). They also have compatibility problems with some composite restorative materials, which will be discussed in the section on self-cure and dual-cure composites. The single step (7th generation) adhesives are a fairly recent addition to the market. At this point in their development, they produce consistently lower bond strengths in vitro than the others (59, 107, 121, 125) and are not compatible with self-cure or dual-cure composites (126). Most of the current research is directed toward improving the performance of the simplified adhesive systems, and they will probably continue to improve. Some of the common acronyms used in resin bonding are shown in Table 1. Examples of commercial dentin bonding systems are shown in Table 2.

**Wet Bonding**

Most adhesive systems utilize “wet bonding.” If the etched dentin surface is dried excessively, the collagen matrix collapses and prevents excessive microleakage (127-129). Excessive moisture has similar negative effects on adhesion (128, 129). An effective method to provide the proper amount of moisture is to dry the surface thoroughly and then rewet it with a moist sponge, so that the surface is damp, but there is no visible pooling (127, 130).

**Bonding to Dentin: Traditional Glass Ionomer Cements**

Glass ionomer cements are made primarily of alumina, silica and polyalkenoic acid and are self curing materials. Most glass ionomer cements release fluoride for a period of time after initial placement. They are the only restorative materials that depend primarily on a chemical bond to tooth structure (131). They form an ionic bond to the hydroxyapatite at the dentin surface (132) and also obtain mechanical retention from microporosities in the hydroxyapatite (133). Glass ionomer materials form lower initial bond strengths to dentin than resins, on the order of 8 Mpa. But unlike resins, they form a “dynamic” bond. As the interface is stressed, bonds are broken, but new bonds form. This is one of the factors that allow glass ionomer cements to succeed clinically, despite relatively low bond strengths. Other factors are low polymerization shrinkage and a coefficient of thermal expansion that is similar to tooth structure. Some glass ionomer materials also possess antimicrobial properties (134-136).

When placing glass ionomer cements, the surface is cleaned and then treated with a weak acid such as polymaleic acid (131). The acid removes debris from the dentin surface, removes the smear layer, and exposes hydroxyapatite crystals. It creates microporosities in the hydroxyapatite for mechanical retention, but there is minimal dissolution (131, 133). Because glass ionomer cements rely on ionic bonding to the hydroxyapatite, strong acids should be avoided because they cause almost total elimination of mineral from the dentin surface (137).

Traditional glass ionomer cements are not widely used for clinical procedures because they set slowly and must be protected from moisture and dehydration during the setting reaction, which in many cases is not complete for 24 h. They are also relatively weak and generally not as esthetic as other restorative materials.

**Bonding to Dentin: Resin Modified Glass Ionomer Materials**

Resin modified glass ionomer (RMGI) materials were developed to overcome some of the undesirable properties of the traditional glass ionomer cements. RMGI materials contain glass ionomer cement to which a light-cure resin is added. The purpose of the resin is to allow immediate light polymerization after the material is placed. The resin also protects the glass ionomer cement from dehydration, and improves the physical and mechanical characteristics and optical properties. True RMGI materials utilize similar bonding procedures as glass ionomer cements and do not require a dentin-bonding agent.

**Endodontic Issues in Dentin Bonding**

Some of the materials used in endodontics may have a significant impact on the bonding process. These issues apply not only to restora-

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**TABLE 1** Common abbreviations used in dental adhesive literature

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Abbreviation (chemical name)</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Bis-GMA</td>
<td>Bisphenol glycidyl methacrylate</td>
<td>Unfilled resin—The original acrylic matrix material in composite resins that are co-polymerized with the bisphenol acrylate monomer. May be used as an adhesive.</td>
</tr>
<tr>
<td>EDTA</td>
<td>Ethylenediaminetetraacetic acid</td>
<td>Chelating agent sometimes used to remove the smear layer and demineralize the dentin</td>
</tr>
<tr>
<td>HEMA</td>
<td>Hydroxyethyl methacrylate</td>
<td>Low viscosity hydrophilic acrylic monomer used in dentin adhesive systems</td>
</tr>
<tr>
<td>4-Meta</td>
<td>4-Methacryloxyethyl trimellitate anhydride</td>
<td>Low viscosity acrylic monomer used in dentin adhesives. Also used for metal bonding</td>
</tr>
<tr>
<td>MMA</td>
<td>Methyl methacrylate</td>
<td>Basic acrylic molecule</td>
</tr>
<tr>
<td>NPG-GMA</td>
<td>N-Phenylglycine glycidyl methacrylate</td>
<td>Low viscosity hydrophilic acrylic monomer used in dentin adhesives</td>
</tr>
<tr>
<td>PMDM</td>
<td>Pyromellitic acid dimethylmethacrylate</td>
<td>Low viscosity hydrophilic acrylic monomer used in dentin adhesives</td>
</tr>
<tr>
<td>TEG-DMA</td>
<td>Triethylene glycol dimethacrylate</td>
<td>Unfilled resin. Alternative composite matrix material for composites. Sometimes combined with Bis-GMA</td>
</tr>
<tr>
<td>UDMA</td>
<td>Urethane dimethacrylate</td>
<td></td>
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</tbody>
</table>

**TABLE 2.** Selected dental adhesive systems

<table>
<thead>
<tr>
<th>Adhesive</th>
<th>Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>All-Bond 2</td>
<td>Three step, etch and rinse, “4th generation”</td>
<td>Bisco</td>
</tr>
<tr>
<td>OptiBond Total Etch</td>
<td>Three step, etch and rinse, “4th generation”</td>
<td>Kerr</td>
</tr>
<tr>
<td>Scotchbond Multipurpose</td>
<td>Three step, etch and rinse, “4th generation”</td>
<td>3M</td>
</tr>
<tr>
<td>One Step</td>
<td>Two step, “single bottle,” etch and rinse, “5th generation”</td>
<td>Bisco</td>
</tr>
<tr>
<td>Prime&amp;Bond</td>
<td>Two step, “single bottle,” etch and rinse, “5th generation”</td>
<td>Dentsply</td>
</tr>
<tr>
<td>Clearfil SE</td>
<td>Two step, self-etching, “6th generation”</td>
<td>Kuraray</td>
</tr>
<tr>
<td>OptiBond Solo SE</td>
<td>Two step, self-etching, “6th generation”</td>
<td>Kerr</td>
</tr>
<tr>
<td>Prompt L-Pop 2</td>
<td>One step, self-etching, “7th generation”</td>
<td>3M/ESPE</td>
</tr>
<tr>
<td>I-Bond</td>
<td>One step, self-etching, “7th generation”</td>
<td>Kulzer</td>
</tr>
</tbody>
</table>
tion of access cavities, but also to the obturating materials that utilize adhesive resin technology, which will be discussed in a subsequent article.

Eugenol

In endodontics, eugenol containing materials are widely used in sealers and temporary filling materials. Eugenol is one of many substances that can prevent or stop the polymerization reaction of resins (138) and can interfere with bonding (139). If resin bonding is planned for a dentin surface that is contaminated with eugenol, additional clinical steps are needed to minimize the effects of the eugenol. The surface should be cleaned with alcohol or detergent to remove visible signs of sealer. Many temporary cements, whether they contain eugenol or not, leave behind an oily layer of debris that must be removed before bonding procedures (140, 141). Air abrasion is an effective method for cleaning the dentin surface (Fig. 7). Once it is clean, the dentin should be etched with an acid, such as phosphoric acid and then rinsed. The acid demineralizes the dentin surface to a depth of about 5 μm and removes the eugenol rich layer. Several studies have shown that the “total etch” (three step) procedure allows effective bonding to eugenol contaminated dentin surfaces (24, 142). An “etch and rinse” adhesive system should be used, because the “self etching” systems incorporate the eugenol rich smear layer into the hybrid layer, rather than removing it. Eugenol has no effect on glass ionomer cements (143).

Sodium Hypochlorite

Sodium hypochlorite is commonly used as an endodontic irrigant because of its antimicrobial and tissue dissolving properties (144). Sodium hypochlorite causes alterations in cellular metabolism and phospholipid destruction. It has oxidative actions that cause deactivation of bacterial enzymes and causes lipid and fatty acid degradation (144).

Several studies have shown that dentin that has been exposed to sodium hypochlorite exhibits resin bond strengths that are significantly lower than untreated dentin (145-149). One study reported bond strengths as low as 8.5 Mpa (147). Increased microleakage was also reported (150). This phenomenon probably occurs because sodium hypochlorite is an oxidizing agent, which leaves behind an oxygen rich layer on the dentin surface. Oxygen is another substance that inhibits the polymerization of resins (151). Morris et. al showed that application of 10% ascorbic acid or 10% sodium ascorbate, both of which are reducing agents, reversed the effects of sodium hypochlorite and restored bond strengths to normal levels. Lai et al. and Yu et al. reported similar results (149, 150). Because sodium hypochlorite is likely to remain the primary irrigant used in endodontics for the near future, and because adhesive resin materials are used routinely in restoring endodontically treated teeth, this issue will have to be addressed. Future adhesive resin products for endodontic applications may contain a reducing agent to reverse the effects of the sodium hypochlorite. A nonoxidizing irrigant would also solve this problem. Sodium hypochlorite and EDTA have also been shown to reduce the tensile strength and microhardness of dentin (152). These are particularly timely issues for endodontics as adhesive resin materials gain popularity as obturating materials.

Other Materials Applied to Dentin

Other materials that are applied to dentin during endodontic procedures have been tested for their effects on bonding. Not surprisingly, hydrogen peroxide leaves behind an oxygen rich surface that inhibits bonding (147, 148). Reduced bond strengths were shown after the use of RC prep (Premier) (146). Electro-chemically activated water has gained a following as an irrigating solution. It probably reduces bond strengths of adhesive resins because it has the same active ingredient as sodium hypochlorite, i.e. hypochlorous acid (153, 154). No loss of bond strength is reported from chlorhexidine irrigation before resin bonding (147, 155, 156) or placement of resin-modified glass ionomer materials (157). Caries detector did not affect resin bond strengths (158, 159), but chloroform and halothane resulted in significant loss of bond strength (160).

Restorative Materials

Silver Amalgam Alloy

Not surprisingly, silver amalgam alloy is the most common choice for restoring access cavities in metal crowns (161). The clinical technique is simple, with few steps, and provides a durable restoration. “Bonded amalgam” is often recommended (57) in which a resin adhesive is placed on the cavity walls before condensation of the amalgam alloy. The adhesive provides an immediate seal. When amalgam alloy is used without an adhesive, it leaks initially, but “self seals” with time as corrosion products form at the amalgam interface with tooth structure or other restorative materials (162). One strategy to use with amalgam alloy, that offers theoretical advantages, is to seal only the chamber floor and orifices with adhesive resin to provide initial protection of the root canal system from contamination. With time the amalgam restoration will corrode at the other interfacial areas and provide a seal that may be more durable than resin.

There is a theoretical advantage to using ad-mixture alloys over pure spherical alloys. Ad-mixture refers to a mixture of spherical and lathic cut particles. Ad-mixture alloys have slight setting expansion, which tends to reduce leakage (163), whereas spherical alloys shrink slightly while setting (165).

Composite Resin

Not surprisingly, composite resin is the most common choice for restoring access cavities in ceramic restorations (161). Composite can be bonded to tooth structure and most restorative materials, and can provide a good match of color and surface gloss. Bonded composite materials can also strengthen existing coronal or radicular tooth structure, at least in the short term (164, 165).

The limitations of composite resin as a restorative material are primarily related to polymerization shrinkage. Restorative resins are reported to exhibit shrinkage in the range of 2 to 6% during polymerization (43, 166). Less filler (such as found in “flowable” composites) results in more shrinkage (166, 167). Polymerization shrinkage causes stress on the adhesive bond that often results in gap formation (43). One study reported the percentage of dentinal gaps found in vivo was 14 to 54% of the total interface (168). Marginal deterioration of composite restorations expedites the loss of dentin adhesion (169).

Composite restorative materials come in several forms: light-cure, self- (chemical) cure or dual-cure. Light-cure materials consist of a

Figure 7. Example of the cleaning effect of sandblasting. Cleaning with alcohol and chloroform left a film on the dentin surface, shown in the first picture. Note how much cleaner the dentin appears in the second picture, after microabrasion (Courtesy of Dr. Fred Tsusui, Los Angeles).
Figure 8. (A) The access cavity is clean and ready to restore. (B) There was 10% hydrofluoric acid applied to the porcelain for 1 min and then rinsed thoroughly. (C) There was 37% phosphoric acid applied to the dentin and porcelain for 15 to 20 s. It demineralizes the dentin surface and cleans the porcelain. (D) The porcelain is thoroughly air dried and silane is applied and dried.

single paste and polymerization is initiated with a curing light. Self-cure materials consist of two pastes that are mixed together to initiate polymerization. Dual-cure materials also consist of two pastes that are mixed together to initiate polymerization, but may also be light activated. Dual-cure materials have the advantage of rapid polymerization in the areas irradiated by the curing light, but chemical polymerization occurs in areas the light can not reach.

Light-cure materials polymerize in a matter of seconds and generally have the best physical properties. However, they have several disadvantages. Because of the rapid polymerization, they tend to stress the adhesive bond to tooth structure more than the slower self-cure composites (167). The stress is sometimes so great that the restorative material debonds at the weakest interface (43, 170). For example, in class 5 composite restorations, they tend to debond at the interface with cementum, which forms a weaker bond than enamel (54). Because most curing lights can only effectively polymerize a thickness of 2 to 3 mm of composite material, cavities must be filled incrementally, a time consuming and tedious task. An access cavity may require 3 to 5 increments. Because curing lights lose intensity with distance, the light intensity may be greatly reduced at the floor of the chamber when curing through an access opening in a crown. In addition, it may not be possible to irradiate all areas inside an access cavity because of undercuts or difficulty in obtaining the proper angle with the light.

Self-cure materials may be bulk filled because they do not require penetration with a curing light. They polymerize more slowly than light-cure materials, allowing the material to flow during polymerization contraction, and placing less stress on the adhesive bond (43, 167). The
The problem with polymerization shrinkage is amplified in access cavities because of a concept known as C-factor or configuration factor (43, 167). C-factor refers to the ratio of bonded surfaces to free or unbounded surfaces. The higher the C-factor, the greater the stress from polymerization shrinkage (45). Restorations with C-factor higher than 3:1 are considered to be at risk for debonding and microleakage (170). In a class 5 restoration, the ratio might be 1:1. In an access cavity, the C-factor might be 6:1 or even 10:1. In a root canal system obturated with a bonded resin material, it might be 100:1 (45).

An incremental filling technique with light-cure composite resins partially overcomes the problem of C-factor. Incremental filling is possible because atmospheric oxygen prevents complete polymerization on the external surface of the resin. This oily surface is referred to as the

Figure 8 (continued). (E) A dentin primer is applied to all internal surfaces and air dried, and a dentin adhesive is applied to all internal surfaces and light polymerized. (F) A flowable composite is injected into the orifices and on the chamber floor and polymerized. This method minimizes voids between the restorative material and dentin. Because it is somewhat translucent, it makes location the canals easier if re-entry is necessary at a later time. (G) Incremental build-up, light composite over dark. Increments should be only 2 to 3 mm in thickness to allow adequate polymerization. (H) Application of opaque composite. This is often necessary when restoring metal-ceramic crowns that tend to be quite opaque.

same is true for dual-cure materials in the areas that are not irradiated by the curing light.
“oxygen inhibited layer (151).” Because of the unpolymerized surface layer, additional increments may be added and polymerized and a strong chemical bond is formed between increments (151). Incremental filling allows complete polymerization of each increment, and lessens the stress from polymerization shrinkage (171, 172) because the C-factor is more favorable for each increment than if the cavity was bulk filled. Another strategy to lessen the effects of C-factor is to use slow setting self-cured materials that flow during polymerization, thus reducing stress (31, 167).

If contamination occurs with blood or saliva during incremental filling, the bond between increments may be ruined. However, if the surface is rinsed, dried and a dentin adhesive is applied, there is no loss of bond strength (173).

Glass Ionomer Cement and Resin Modified Glass Ionomer Materials

Both types of glass ionomer materials may be bulk filled. Most of the RMGI materials are dual-cure. Traditional glass ionomer cements are self-cure and have very little polymerization shrinkage. Because resin is added to RMGI materials, they exhibit some polymerization shrinkage, although less than composite resins. Both types of glass ionomer materials are useful for bulk filling access cavities. Even though they bond to tooth structure, the bond strengths are too low to provide significant strengthening effect (174).

Material Incompatibilities

The “self etching” adhesive systems have generally been shown to result in low bond strengths when used with self-cure composites and
Clinicai Strategies

Most strategies for restoring access cavities require several steps and at least two layers of restorative material. Many approaches utilize an adhesive system and two restorative materials. The exception is unboned amalgam alloy.

Restoring Access Cavities with Tooth Colored Materials

Light-cure composite can be used to fill the entire access cavity if it is filled incrementally. This method will provide the strongest bond to tooth structure (181) and is the preferred method when it is necessary to maximize the tooth strengthening effects of the restoration. When executed with skill and knowledge of the materials, excellent esthetic results are possible (Fig. 8). However, this is a slow, time-consuming method. High initial bond strengths are also obtained with dual-cure composites that are placed incrementally and light polymerized (177). Moisture penetration can result in a phenomenon known in polymer chemistry as "emulsion polymerization," in which there is poor adaptation between the adhesive and restorative material (122). Moisture at the interface probably also contributes to the degradation of the bond over time (122).

A Simple Procedure for Composite Resin

The procedures are similar to those described with glass ionomer material, but a 4th generation dentin adhesive system is used on the dentin and a dual-cure composite is substituted for the glass ionomer material.

1. Treat the dentin and enamel, if present, with 30 to 40% phosphoric acid for 15 s.
2. Thoroughly rinse and dry the dentin then rewet with a moist sponge.
3. Apply primer and adhesive, following the manufacturer's instructions.
4. Bulk fill with a dual-cure or self-cure composite to within 2 to 3 mm of the cavo-surface margin and light cure.
5. Etch the ceramic material with 10% hydrofluoric acid, or other suitable etching gel for 1 min.
6. Rinse and dry.
7. Apply silane agent to the etched ceramic surface and air dry.
8. Apply phosphoric acid to the inside of the access cavity if restoring with composite. Etching with phosphoric acid adds no retention to porcelain, but it cleans the porcelain and enhances the silane adaptation (182).
9. Rinse and dry.
10. Apply silane to the etched ceramic surface and air dry.
11. Apply the dentin primer and adhesive to the glass ionomer material and etched ceramic and light cure.
12. Place the first increment of light-cure composite. The first increment should include the longest vertical wall and taper to the base of the opposing vertical wall.
13. Light cure for 40 s (time depends on type of light used).
14. Fill the remaining space with the second increment and light cure. The restoration should be slightly overfilled so it can be finished back to the margins.
15. Contour and adjust the occlusion.
16. Finish and polish the restoration.
Dual-cure composites that are bulk filled develop relatively low bond strengths to dentin, comparable to glass ionomer materials. Resin adhesives lose bond strength with time and function, whereas glass ionomer bond strengths are relatively stable. So there is little if any benefit to the use of dual-cure composites over glass ionomer materials for bulk filling the cavity.

Conclusions

1. Prevent contamination of the root canal system.
2. Restore access cavities immediately whenever possible.
3. Use bonded materials
4. The 4th generation (three step) resin adhesive systems are preferred because they provide a better bond than the adhesives that require fewer steps.
5. The “etch and rinse” adhesives are preferred to “self etching” adhesive systems if a eugenol containing sealer or temporary material was used.
6. “Self etching” adhesives should not be used with self-cure or dual-cure restorative composites.
7. When restoring access cavities, the best esthetics and highest initial strength is obtained with an incremental fill technique with composite resin.
8. A more efficient technique which provides acceptable esthetics is to bulk fill with a glass ionomer material to within 2 to 3 mm of the cavo-surface margin, followed by two increments of light-cure composite.
9. If retention of a crown or bridge abutment is a concern after root canal treatment, post placement increases retention to greater than the original.

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