The Material Science of Minimally Invasive Esthetic Restorations

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Abstract: The term *esthetic dentistry* usually conjures up mental images of porcelain crowns and veneers. To some dentists, the term *minimally invasive dentistry* evokes thoughts of observing early lesions, and postponing treatment until lesions are closer to the pulp. (The World Congress of Minimally Invasive Dentistry defines minimally invasive dentistry as those techniques which respect health, function, and esthetics of oral tissue by preventing disease from occurring, or intercepting its progress with minimal tissue loss.) It would seem these two niches within dentistry are on opposite ends of the spectrum; however, composite resin and glass ionomer restorative materials unite these two ideologies. Understanding the limitations, benefits, and science behind each material allows clinicians to produce highly esthetic restorations that can resist future decay, internally remineralize the tooth, and help protect adjacent teeth from cariogenic attack.

Learning Objectives:

After reading this article, the reader should be able to:

- discuss the properties of composite resins that affect their longevity.
- describe the benefits of using glass ionomer restorative materials.
- explain the chemistry at work within glass ionomer materials.
- implement the sandwich technique to reproduce a clinical crown with biomimetic properties.

Esthetic dentistry can be considered a combination of operative dental techniques and artistry. Minimally invasive (or minimum intervention) dentistry focuses on preserving natural tooth structure while intervening in the disease process. The myriad of dental materials available today makes it possible to achieve very esthetic results while preserving, not just healthy, but compromised tooth structure as well.

A perfect direct restorative material has not yet been created. Amalgam, although durable and time tested,[1] does not meet the esthetic requirements of today's patients and, because it does not reinforce tooth structure, should not be used to fill teeth that have been minimally prepared.[2] Composite resins are very esthetic and can be placed into the smallest of preparations, but even the most advanced bonding techniques do not result in margins that are totally sealed.[3] Glass ionomers are noted for their chemical adhesion to enamel and dentin,[4] but historically have been regarded as brittle and susceptible to occlusal wear.[5,6]

Despite the drawbacks associated with using composites and glass ionomers, they remain the best choice for clinicians who hope to conserve tooth structure. However, as with all dental materials, operative technique is paramount to a successful restoration. Clinicians who understand the chemistry of restorative materials are better able to minimize handling errors and provide patients with longer-lasting restorations.

COMPOSITE RESIN

Composite resin is quickly becoming the material of choice in many dental practices. In one US dental school, composite restorations are placed more than twice as frequently as amalgam in posterior teeth.[7] Although seemingly simple to use, all dentin bonding agents and composites are highly

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technique-sensitive and demand strict attention to detail. Even when placed properly, resin–dentin bond structures begin to show signs of bond strength degradation in less than 1 year.[8-11]

Resins are comprised of inorganic fillers, an organic polymer matrix, coupling agents, and chemicals to promote and/or modify the polymerization reaction. When composite resins are completely polymerized, they provide a durable substitute for missing tooth structure. In theory, once resin is completely light-cured, the resin matrix should not have any free monomers present. But the free radical addition polymerization reaction is never complete. According to Ferracane, 15% to 50% of the material remains unreacted.[12] The unreacted polymer matrix components, nonpolymerized monomers (ie, bisphenol A diglycidylether methacrylate [Bis-GMA], triethylene glycol dimethacrylate [TEGDMA], hydroxyethylmethacrylate [HEMA], etc), are highly cytotoxic[13] and have been implicated in allergic reactions to the material.[14,15] These remaining free monomers also are known to encourage growth of cariogenic bacteria, and may lead to secondary caries and/or degradation of the polymers.[13] Placing composite in small incremental layers and then thoroughly curing each layer helps to ensure that the material is cured properly.[16]

The process of bonding to enamel is fairly straightforward and often results in a long-lasting interface between the tooth and the restoration. When acid is applied to hydroxyapatite, microscopic porosities are created within the enamel and the surface energy of the tooth is increased.[17] Adhesive resin flows into the porosities and creates resin tags. As long as the etched enamel surface is kept clean and dry, a very predictable and strong bond is created.[17]

Dentin bonding is much more complex because dentin, by nature, has no affinity for composite resin. The chemistry involved in changing the hydrophilic dentin surface to hydrophobic substrate that will accept cross-linked monomers is a complex process and leaves room for many errors. A successful bond to dentin results when mineralized tooth structure is removed (acid etching), leaving behind a soft and delicate mesh network of collagen. The low-viscosity resin within the adhesive infiltrates this collagen network and,

Figure 1 Tooth No. 19 exhibited recurrent decay and failing amalgam, tooth No. 18 exhibited initial caries.

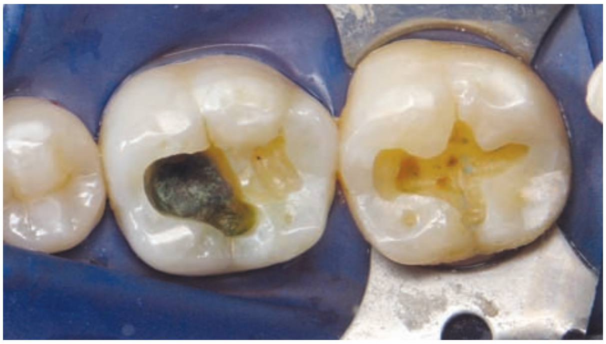

Figure 2 After removal of amalgam and caries, green caries indicator (Sable™ Seek®, Ultradent Products Inc, South Jordan, UT) revealed areas of infected dentin still remaining.

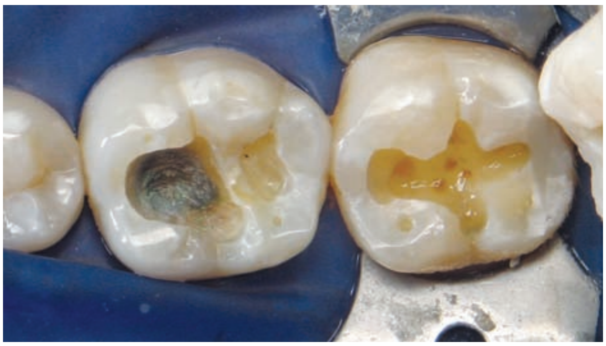

Figure 3 After removal of infected dentin, the tooth was ready for restoration using the closed sandwich technique.

Figure 4 The dentin was conditioned with polyacrylic acid for 10 to 20 seconds (Cavity Conditioner, GC America Inc).

Figure 5 After conditioning, an RMGI (Fuji II LC) was placed into the mesial preparation of tooth No. 19 and the entire preparation of tooth No. 18. The RMGI layer thickness mimicked the original height of the dentin.

Figure 6 After light-polymerizing the RMGI, a selective etch technique with 37% phosphoric acid (Ultra-etch®, Ultradent Products Inc) was used before placing a fifth-generation dentin bonding agent. The dentin in the distal preparation of tooth No. 19 was etched because the tooth was to be restored only with resin (Gradia Direct, GC America Inc).

Figure 7 The completed closed sandwich restorations.

after polymerization, is "locked" in and around the exposed collagen. If patent dentinal tubules are present, the surface area for resin infiltration is increased.[18]

Almost all research demonstrates that the efficacy of dentin bonding is highly dependent on the degree to which monomers infiltrate collagen fibers, creating the hybrid layer (also known as the resin–dentin diffusion zone).[18,19] However, there is disagreement on which step of the process is the most critical: etching, drying, priming, or placing the adhesive. In actuality, each step is critical, and each builds on the success of the previous step.

Excessive dentin etching results in weak, denatured collagen and a collagen fibril network too thick for primer and adhesive resin to adequately penetrate. The result is a "hybridoid layer"[20] containing numerous voids and porosities. These voids allow collagenases to access the collagen network and may lead to hydrolytic breakdown of the interface. Ultimately, any errors in dentin bonding protocols result in debonding, microleakage, and/or nanoleakage, thus increasing the potential for restoration failure.[21]

Although dentin etching is necessary for stable dentin bonds, the process can set up the restoration for future failure. Dentin contains enzymes known as matrix metalloproteinases (MMPs) that become activated in the presence of acid.[22] Usually MMPs are involved in a variety of homeostatic functions—such as bone remodeling, healing, and host defense—but they are responsible for pathological processes as well.[23] This is significant, because upon activation, MMPs are capable of denaturing the collagen network that links the bonding agent to the tooth structure via the hybrid layer.[24]

Attempts to minimize technique sensitivity have caused dental manufacturers to create one-step (seventh-generation) bonding agents. The application technique used with these one-step bonding agents appears straightforward and very easy. In actuality, these types of bonding agents require strict adherence to manufacturer protocols and are less forgiving of operator error than are products of previous generations,[25] making them more technique-sensitive than the well-proven, but multistep, fourth-generation adhesives.[26]

As adhesive systems become more simplified, they become more hydrophilic[27] and exhibit high permeability after polymerization.[28] Because the dentin bonding agent acts as a permeable membrane, moisture is absorbed into the hybrid layer, causing polymer plasticization and degrading the resin–dentin interface.[9] This process begins as nanoleakage and causes a phenomenon known as water-treeing.[29] As the process progresses, collagen is degraded and resin is removed from interfibrillar spaces.[30] Although uncommon, there is the potential for failure of the dentin–adhesive joint.[11]

GLASS IONOMER

Glass ionomer seems to be the opposite of composite resin. Although lacking in cohesive tensile strength, polishability, and esthetics, glass ionomers are able to bond chemically to tooth structure without any supplemental bonding agent. They are biocompatible and anticariogenic,[31] and have the unique ability to expand and contract at the same rate as dentin. When these materials fail, it is usually cohesive failure within the material, resulting in dentin that is still sealed.[32] These properties led Davidson to refer to glass ionomer as an "intelligent" material.[33]

Glass ionomers possess tooth-friendly physical properties because of the nature of the material. All glass ionomers are created by an acid–base reaction, which occurs immediately before placement within the preparation between powdered calcium fluoroaluminosilicate glass and liquid polyacrylic acid, although variations abound in the exact chemistry between manufacturers.

When the acid contacts the glass particles, calcium, aluminum, and fluoride ions are released. The calcium and aluminum ions crosslink the acid molecules leaving unassociated fluoride ions free within the matrix. The high affinity between the acid molecules and calcium ions results in a chemical bond to tooth structure and base metals.[31] The free fluoride ions can diffuse into surrounding tooth structure, where there is a zone of interaction that is highly resistant to microleakage and hydrolytic breakdown.[34,35]

Conventional glass ionomers require mixing before use and set without any external influences (eg, light). Most dentists prefer materials that set on command and, consequently, polymerizable resin components have been added to some products, resulting in a class of materials called resin-modified glass ionomers (RMGIs). RMGIs exhibit higher flexural and diametric tensile strength than pure glass ionomers, and their mechanical properties (flexural strength, modulus of elasticity, and diametric tensile strength) are comparable to microfilled and packable composites.[36] RMGIs also exhibit higher levels of fluoride release for longer periods of time than conventional glass ionomers.[37]

Before placing glass ionomer restorations, it is recommended that the dentin and enamel be conditioned instead of etched.[38,39] Conditioning agents are weak acids (usually polyacrylic acid) that remove the smear layer but do not demineralize the inorganic matrix of the tooth.[40] The weak conditioning agent is not strong enough to remove smear plugs that form at the orifices of dentinal tubules as a result of the mechanical removal of tooth structure.[41] Tubule blockage prevents leakage of dentinal fluid onto the restorative interface and is proposed to be responsible for the remarkable ability of glass ionomer to prevent postoperative sensitivity and microleakage.[42]

Ever since the first glass ionomer restorative materials came on the market, claims have been made about their inherent caries-resistant properties. These claims have been verified numerous times with in vitro research, but with few clinical trials.[43] Although broad consensus is not likely in the future, there is significant evidence that glass ionomers provide a marginal seal that resists future decay and is far superior to that formed by any dentin bonding agent.[32,34]

Glass ionomer restorations provide superior marginal integrity because they release various ions, including fluoride.[44] Within the vicinity of the glass ionomer restorations, dentin and enamel hypermineralization is present.[34,45] Although not completely understood, it is presumed ions from the restoration are deposited in pores within the tooth structure, and thus, limit diffusion pathways for plaque acid.[45]

There is considerable disagreement regarding the amount of fluoride released from glass ionomers, and the longevity of the phenomenon. However, it appears that the fluoride release is substantial enough to resist recurrent decay,[43-46] reverse incipient lesions on adjacent interproximal surfaces,[47-49] and shift the ionic properties of saliva toward remineralization.[50]

The release of fluoride from glass ionomers is not a static process. Clinicians unfamiliar with the chemistry of the material may be under the false impression that fluoride release is high initially after restoration placement and then tapers off gradually over time until all of the fluoride has been released. In actuality, the fluoride release from glass ionomer restorations is very dynamic.[51] Initially, there is a high "burst" of fluoride release that declines rapidly over the first 3 days.[37] Then, a sustained low-level release of fluoride continues for a relatively long time.[37] Although fluoride-containing composites can release low levels of fluoride for extended periods,[52] glass ionomer has the unique capability to "recharge" with additional fluoride.[44] Any time fluoride contacts the glass ionomer (via toothpaste, rinse, varnish, etc), the fluoride diffuses into the restoration.[53] Thereafter, the process of "burst" release and sustained low-level release is repeated.[37]

A number of clinicians are of the opinion that glass ionomer is an inferior material to composite resin because it appears to fail quickly. However, research has shown that Class 3 and Class 5 glass ionomer restorations (Fuji II LC, GC America, Inc, Alsip, IL and Ketac™ Fil, 3M ESPE, St. Paul, MN) have only a 3% failure rate after 8 years in the mouth.[54] A thorough systematic review of university-centered clinical trials regarding the longevity of noncarious Class 5 restorations in vivo showed that glass ionomers have an annual failure rate of 1.9%. Compared with three-step adhesives, which had an annual failure rate of 4.8%, the glass ionomers category was the only group of adhesive restorative material to fulfill all American Dental Association requirements.[26]

Nevertheless, most dentists have witnessed glass ionomer sealants debond from occlusal surfaces and have inferred that the material was failing. However, when observed microscopically, glass ionomer material tends to remain within the depths of the fissures even after the visual bulk of sealant material has been lost.[55,56] This is because the cohesive bonds within set glass ionomer material are weaker than their bond to tooth structure. Although not visually detected, glass ionomer forms a resilient interaction zone at the glass ionomer–tooth interface. In contrast, resin sealants may exhibit retention for 5 or more years, but resin-sealed teeth develop more caries than teeth sealed with glass ionomer.[57,58]

CLINICAL APPLICATION

To successfully treat carious lesions with minimally invasive techniques, one must understand the disease process occurring within the tooth. As caries progresses through sound dentin, the apatite is replaced by whitlockite, which is a mineral comprised of very large crystals that provide little retention.[59] In a similar fashion, the collagen in caries-affected dentin is weakened by the decay,[60] providing poor bonding potential.[61] The combination of inorganic demineralization and an enzymatically disintegrated organic matrix results in two types of dentin: affected and infected.[62]

A successful restoration requires that only the infected dentin be removed. After a well-sealed restoration is placed, the tooth is able to remineralize the affected dentin.[63] Caries indicator dye, although controversial, is one of the best tools to determine if dentin is capable of remineralizing. Solvent in the dye carries the color into the dentin with less mineral content, indicating areas with limited remineralization potential.[64] Unfortunately, caries indicator dye also

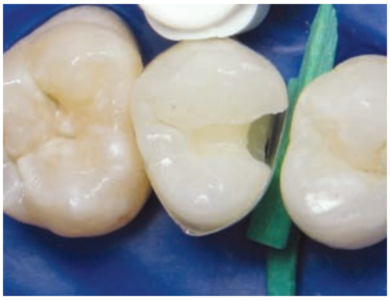

Figure 8 In vitro preparation to remove occlusal and interproximal caries in tooth No. 4, which extended below the cementoenamel junction.

Figure 9 Entire preparation conditioned with polyacrylic acid (Cavity Conditioner).

Figure 10 An RMGI (Fuji II LC) was placed in the gingival portion of the proximal box and on the pulpal floor to approximate the tooth's original dentin.

Figure 11 After the RMGI was light-polymerized, 37% phosphoric acid etch (Ultra-Etch) was placed before application of a fifth-generation bonding agent.

Figure 12 A fifth-generation bonding agent (Peak™ LC, Ultradent Products Inc) was applied to the etched enamel and RMGI (Gradia Direct).

Figure 13 Occlusal view of the completed restoration.

may stain sound circumpulpal dentin as well as protein at the dentin–enamel junction.

Resin-based dentin bonding agents have limited bonding potential to caries-affected dentin,[61] because of poor resin infiltration into the compromised collagen network that remains after etching. Applying a dentin bonding agent to affected dentin results in a thick, weak, and highly unorganized hybridoid layer.[16] The presence of poorly converted monomer within such a hybrid layer makes the layer susceptible to water degradation, leading to a breakdown of the interface.[61,65,66]

In contrast, glass ionomer can strengthen affected dentin and remineralize the surrounding structure.[67] It is able to form a nearly hermetic seal to the compromised dentin,[64] and the ion processes within and around the material assist the healing of remaining tooth structure that has been damaged.[68]

Sandwich restorations take advantage of the individual benefits of composite resin and glass ionomer.[69] When glass ionomer is used as a base and completely covered with composite resin, a "closed sandwich" restoration is created (Figure 1 through Figure 7). If the glass ionomer is exposed to the oral environment in any area, the restoration is considered an "open sandwich" restoration (Figure 8 through Figure 15). Some glass ionomer formulations (those marketed as liners) are specifically designed to be internal material only (not exposed to saliva) and care must be taken to ensure these materials are not exposed at the margin. Glass ionomer restoratives marketed as base material require less precision during placement because they are formulated to be exposed to the oral environment. Consequently, any material inadvertently placed (and unnoticed) in a marginal area does not negatively affect the success of the finished restoration.

Sandwich restorations are the ideal way to replace a failing amalgam restoration.[67] After the tooth has been conservatively prepared, glass ionomer (or RMGI) is used to replace only the missing dentin structure. After the material has set (or polymerized), a dentin bonding agent is applied, with appropriate etching of enamel. Then, the outer surface is restored with composite resin. The completed restoration mimics the structure of a natural tooth in that the glass ionomer material has intrinsic properties similar to dentin in contraction and expansion, while the composite replaces the durable, yet brittle enamel.[67]

A benefit of placing sandwich restorations is the elimination of configuration-factor stresses on the restored tooth.[69] Unlike composite resin, which rapidly shrinks upon polymerization, glass ionomer has a higher degree of elastic deformation during setting.[70] This helps to prevent postoperative sensitivity[71] because the stresses of resin polymerization are distributed to the glass ionomer rather than the tooth. Ikemi and Nemoto[72] saw a 50% reduction in contraction stresses when RMGI liners were used, and Tolidis et al[73] found significantly less shrinkage of composite when cured in contact with a RMGI liner. Of course, the ultimate test of a restoration's success is its longevity, and in vivo research has shown that open-sandwich restorations exhibit a higher percentage of gap-free interfacial adaptation than restorations comprised entirely of composite resin.[69]

Naturally, glass ionomer is not limited to liners and bases. It also can be used to completely restore a tooth. It is the material of choice to restore class V lesions,[74] root caries, or recurrent decay at the margins of fixed appliances.

Figure 14 Lingual view of the completed open sandwich restoration. Note the excellent marginal adaptation in the floor of the proximal box.

Figure 15 Radiograph demonstrating the continuity of RMGI across the pulpal floor, extending to the proximal surface, and replicating the original dentin. The dentin bonding agent is indicated by the radiolucent layer. Composite resin acts as an enamel replacement. Note the excellent adaptation of the RMGI to the dentin in the proximal box.

Retention rates of 93% and 99% after 2 years have been reported for class V RMGI restorations placed without mechanical retention.[75]

CONCLUSION

Composite resins and glass ionomers are fundamental materials in offices practicing minimally invasive dentistry. They complement each other, and clinicians should keep in mind the inherent strengths and weaknesses of each. It is not necessary to completely comprehend the physical chemistry and composition of every material, but with knowledge comes the ability to provide stronger, more biomimetic, and ultimately longer-lasting restorations.

DISCLOSURE

Dr. Nový is a consultant for GC America, Inc.

REFERENCES

1. Osborne JW, Norman RD. 13-year clinical assessment of 10 amalgam alloys. *Dent Mater.* 1990;6(3):189-194.
2. Osborne JW, Summit JB. Extension for prevention: Is it relevant today? *Am J Dent.* 1998;11(4):189-196.
3. Gary A, Berg J, Brucia J. Clinical roundtable. *Inside Dentistry.* 2007;3(10):30.
4. Summitt JB, Robbins WJ, Hilton TJ, eds. *Fundamentals of Operative Dentistry.* 3rd ed. Hanover Park, IL: Quintessence Publishing Co, Inc.; 2006:227-231.
5. Powers JM, Sakaguchi RL. *Craig's Restorative Dental Materials.* 12th ed. St. Louis, MO: Elsevier Inc; 2006:173-179.
6. Berg JH. Glass ionomer cements. *Pediatr Dent.* 2002;24(5):430-438.
7. Ottenga ME, Mjör I. Amalgam and composite posterior restorations: curriculum versus practice in operative dentistry at a US dental school. *Oper Dent.* 2007;32(5):524-528.
8. Hashimoto M, Ohno H, Kaga M, et al. In vivo degradation of resin-dentin bonds in humans over 1 to 3 years. *J Dent Res.* 2000;79(6):1385-1391.
9. Okuda M, Pereira PN, Nakajima M, et al. Long-term durability of resin dentin interface: nanoleakage vs. microtensile bond strength. *Oper Dent.* 2002;27(3):289-296.
10. Carrilho MR, Carvalho RM, Tay FR, et al. Durability of resin-dentin bonds related to water and oil storage. *Am J Dent.* 2005;18(6):315-319.
11. Tay FR, Pashley DH, Suh BI, et al. Water treeing in simplified dentin adhesives—déjà vu? *Oper Dent.* 2005;30(5):561-579.
12. Ferracane JL. Elution of leachable components from composites. *J Oral Rehabil.* 1994;21(4):441-452.
13. Goldberg M. In vitro and in vivo studies on the toxicity of dental resin components: a review. *Clin Oral Investig.* 2007; Nov 27. Epub ahead of print.
14. Leggat PA, Kedjarune U. Toxicity of methyl methacrylate in dentistry. *Int Dent J.* 2003;53(3):126-131.
15. Aalto-Korte K, Alanko K, Kuuliala O, et al. Methacrylate and acrylate allergy in dental personnel. *Contact Dermatitis.* 2007;57(5):324-330.
16. Rode KM, Kawano Y, Turhino ML. Evaluation of curing light distance on resin composite microhardness and polymerization. *Oper Dent.* 2007;32(6):571-578.
17. Anusavice KJ. *Phillips' Science of Dental Materials.* 11th ed. St. Louis, MO: Saunders; 2003:383.
18. Perdigão J, Lopes M, Geraldeli S, et al. Effect of sodium hypochlorite gel on dentin bonding. *Dent Mater.* 2000;16(5):311-323.
19. Nakabayashi N, Kojima K, Masuhara E. The promotion of adhesion by the infiltration of monomers into tooth substrates. *J Biomed Mater Res.* 1982;16(3):265-273.
20. Prati C, Chersoni S, Pashley DH. Effect of removal of surface collagen fibrils on resin-dentin bonding. *Dent Mater.* 1999;15(5):323-331.
21. Okuda M, Pereira PN, Nakajima M, et al. Long-term durability of resin dentin interface: nanoleakage vs. microtensile bond strength. *Oper Dent.* 2002;27(3):289-296.
22. Pashley DH, Tay FR,Yiu C, et al. Collagen degradation by host-derived enzymes during aging. *J Dent Res.* 2004;83(3):216-221.
23. Ra HJ, Parks WC. Control of matrix metalloproteinase catalytic activity. *Matrix Biol.* 2007;26(8):587-596.
24. Hebling J, Pashley DH, Tjäderhane L, et al. Chlorhexidine arrests subclinical degradation of dentin hybrid layers in vivo. *J Dent Res.* 2005;84(8):741-746.
25. Yuan Y, Shimada Y, Ichinose S, et al. Effects of dentin characteristics on interfacial nanoleakage. *J Dent Res.* 2007;86(10):1001-1006.
26. Peumans M, Kanumilli P, De Munck J, et al. Clinical effectiveness of contemporary adhesives: a systematic review of current clinical trials. *Dent Mater.* 2005;21(9):864-881.
27. Tay FR, Pashley DH. Dental adhesives of the future. *J Adhes Dent.* 2002;4(2):91-103.
28. Tay FR, Pashley DH, Suh BI, et al. Single-step adhesives are permeable membranes. *J Dent.* 2002;30(7-8):371-382.
29. Tay FR, Pashely DH, Yoshiyama M. Two modes of nanoleakage expression in single-step adhesives. *J Dent Res.* 2002;81(7):472-476.
30. Hashimoto M, Ohno H, Sano H, et al. In vitro degradation of resin-dentin bonds analyzed by microtensile bond test, scanning

and transmission electron microscopy. *Biomaterials.* 2003;24 (21):3795-3803.

31. Xie D, Brantley WA, Culbertson BM, et al. Mechanical properties and microstructures of glass-ionomer cements. *Dent Mater.* 2000;16(2):129-138.
32. Yip HK, Tay FR, Ngo HC, et al. Bonding of contemporary glass ionomer cements to dentin. *Dent Mater.* 2001;17(5): 456-470.
33. Davidson CL. Advances in glass-ionomer cements. *J Appl Oral Sci.* 2006;14(Spec Iss):3-9.
34. Ngo H, Mount GJ, Peters MC. A study of glass-ionomer cement and its interface with enamel and dentin using a low-temperature, high-resolution scanning electron microscopic technique. *Quintessence Int*. 1997;28(1):63-69.
35. Ngo H, Mount G, McIntyre J, et al. Chemical exchange between glass-ionomer restorations and residual carious dentine in permanent molars: an in vivo study. *J Dent.* 2006; 34(8):608-613.
36. Ilie N, Hickel R. Mechanical behavior of glass ionomer cements as a function of loading condition and mixing procedure. *Dent Mat J*. 2007;26(4):526-533.
37. Xu X, Burgess JO. Compressive strength, fluoride release and recharge of fluoride-releasing materials. *Biomaterials.* 2003; 24(14):2451-2461.
38. Inoue S, van Meerbeek B, Abe Y, et al. Effect of remaining dentin thickness and the use of conditioner on micro-tensile bond strength of a glass-ionomer adhesive. *Dent Mater.* 2001; 17(5):445-455.
39. Inoue S, Abe Y, Yoshida Y, et al. Effect of conditioner on bond strength of glass-ionomer adhesive to dentin/enamel with and without smear layer interposition. *Oper Dent.* 2004;29(6): 685-692.
40. Summitt JB, Robbins WJ, Hilton TJ, eds. *Fundamentals of Operative Dentistry.* 3rd ed. Hanover Park, IL: Quintessence Publishing Co, Inc.; 2006:227.
41. Mount GJ. *An Atlas of Glass-Ionomer Cements: A Clinician's Guide.* 3rd ed. London, UK: Informa Healthcare; 2002.
42. Yilmaz Y, Gurbuz T, Kocogullari ME. The influence of various conditioner agents on the interdiffusion zone and microleakage of a glass ionomer cement with a high viscosity in primary teeth. *Oper Dent.* 2005;30(1):105-112.
43. Swift EJ Jr. Effects of glass ionomers on recurrent caries. *Oper Dent.* 1989;14(1):40-43.
44. Billington RW, Williams JA, Pearson GJ. Ion processes in glass ionomer cements. *J Dent.* 2006;34(8):544-555.
45. ten Cate JM, van Duinen RN. Hypermineralization of dentinal lesions adjacent to glass-ionomer cement restorations. *J Dent Res.* 1995;74(6):1266-1271.
46. Tyas MJ. Cariostatic effect of glass ionomer cement: a five-year clinical study. *Aust Dent J.* 1991;36(3):236-239.
47. Donly KJ, Sequra A, Wefel JS, et al. Evaluating the effects of fluoride-releasing dental materials on adjacent interproximal caries. *J Am Dent Assoc.* 1999;130(6):817-825.
48. Qvist V, Laurberg L, Poulsen A, et al. Longevity and cariostatic effects of everyday conventional glass ionomer and amalgam restorations in primary teeth: three-year results. *J Dent Res.* 1997;76(7):1387-1396.
49. Knight GM, McIntyre JM, Craig GG, et al. An in vitro investigation of marginal dentine caries abutting composite resin and glass ionomer cement restorations. *Aust Dent J.* 2007; 52(3):187-192.
50. Nicholson JW, Aggarwal A, Czarnecka B, et al. The rate of change of pH of lactic acid exposed to glass-ionomer dental cements. *Biomaterials.* 2000;21(19):1989-1993.
51. Can-Karabulut DC, Batmaz I, Solak H, et al. Linear regression modeling to compare fluoride release profiles of various restorative materials. *Dent Mater.* 2007;23(9):1057-1065.
52. Xu X, Burgess JO. Compressive strength, fluoride release and recharge of fluoride-releasing materials. *Biomaterials.* 2003; 24(14):2451-2461.
53. Wiegand A, Buchalla W, Attin T. Review on fluoride-releasing restorative materials—fluoride release and uptake characteristic, antibacterial activity and influence on caries formation. *Dent Mater.* 2007;23(3):343-362.
54. Mount GJ. Longevity of glass ionomer cements. *J Prosthet Dent.* 1986;55(6):682-685.
55. van Duinen RN, Davidson CL, De Gee AJ, et al. In situ transformation of glass-ionomer into an enamel-like material. *Am J Dent.* 2004;17(4):223-227.
56. Berg JH. Glass ionomer cements. *Pediatr Dent*. 2002;24(5): 430-438.
57. Karlzén-Reuterving G, van Dijken JW. A three-year follow-up of glass ionomer cement and resin fissure sealants. *ASDC J Dent Child.* 1995;62(2):108-110.
58. Mejàre I, Mjör IA. Glass ionomer and resin-based fissure sealants: a clinical study. *Scand J Dent Res*. 1990;98(4):345-350.
59. Ogawa K, Yamashita Y, Ichijo T, et al. The ultrastructure and hardness of the transparent layer of human carious dentin. *J Dent Res.* 1983;62(1):7-10.

60. Ohgushi K, Fusayama T. Electron microscopic structure of the two layers of carious dentin. *J Dent Res.* 1975;54(5):1019-1026.
61. Erhardt MC, Toledano M, Osorio R, et al. Histomorphologic characterization and bond strength evaluation of caries-affected dentin/resin interfaces: effects of long-term water exposure. *Dent Mater.* 2007; Nov 14. Epub ahead of print.
62. Yoshiyama M, Tay FR, Torii Y, et al. Resin adhesion to carious dentin. *Am J Dent.* 2003;16(1):47-52.
63. Kidd EA. How 'clean' must a cavity be before restoration? *Caries Res.* 2004;38(3):305-313.
64. Gao W, Smales RJ, Yip HK. Demineralisation and remineralisation of dentine caries, and the role of glass-ionomer cements. *Int Dent J.* 2000;50(1):51-56.
65. Wang Y, Spencer P, Walker MP. Chemical profile of adhesive/caries-affected dentin interfaces using Raman microspectroscopy. *J Biomed Mater Res A.* 2007;81(2):279-286.
66. Yoshiyama M, Urayama A, Kimochi T, et al. Comparison of conventional vs self-etching adhesive bonds to caries-affected dentin. *Oper Dent.* 2000;25(3):163-169.
67. Mount GJ. Clinical performance of glass-ionomers. *Biomaterials.* 1998;19(6):573-579.
68. Hewlett ER, Mount GJ. Glass ionomers in contemporary restorative dentistry—a clinical update. *J Calif Dent Assoc.* 2003;31(6):483-492.
69. van Dijken JWV, Kieri C, Carlén M. Longevity of extensive class II open-sandwich restorations with a resin-modified glass-ionomer cement. *J Dent Res.* 1999;78(7):1319-1325.
70. Andersson-Wenckert IE, van Dijken JWV, Hörstedt P. Modified class II open sandwich restorations: evaluation of interfacial adaptation and influence of different restorative techniques. *Eur J Oral Sci.* 2002;110(3):270-275.
71. Christensen GJ. Preventing postoperative tooth sensitivity in Class I, II and V restorations. *J Am Dent Assoc.* 2002;133(2):229-231.
72. Ikemi T, Nemoto K. Effects of lining materials on the composite resins shrinkage stresses. *Dent Mater J.* 1994;13(1):1-8.
73. Tolidis K, Nobecourt A, Randall RC. Effect of resin-modified glass ionomer liner on volumetric polymerization shrinkage of various composites. *Dent Mater.* 1998;14(6):417-423.
74. Wilder AD Jr, Swift EJ Jr, May KN Jr, et al. Effect of finishing technique on the microleakage and surface texture of resin-modified glass ionomer restorative materials. *J Dent.* 2000;28(5):367-373.
75. Abdalla AI, Alhadainy HA. Clinical evaluation of hybrid ionomer restoratives in Class V abrasion lesions: two-year results. *Quintessence Int.* 1997;28(4):255-258.

1. Because the free radical addition polymerization reaction is never complete, the remaining free monomers are known to:
   a. arrest the development of secondary caries.
   b. upgrade the complexity of the polymers.
   c. encourage the growth of cariogenic bacteria.
   d. promote cell health.

2. Almost all research demonstrates that the efficacy of dentin bonding is highly dependent on the degree to which monomers:
   a. infiltrate collagen fibers and create a hybrid layer.
   b. avoid the microscopic porosities.
   c. decrease the surface energy of the tooth.
   d. break down the collagen network.

3. Any errors in dentin bonding protocols result in:
   a. debonding.
   b. microleakage.
   c. nanoleakage.
   d. all of the above

4. Glass ionomers have the unique ability to:
   a. be highly polished.
   b. expand and contract at the same rate as dentin.
   c. provide high compressive strength to the restoration.
   d. all of the above

5. What results in glass ionomers' chemical bond to tooth structure and base metals?
   a. high affinity between the acid molecules and calcium ions
   b. creation of covalent bonds between glass particles and coupling agents
   c. free radical polymerization
   d. photoactivation of amines within the organic matrix

6. Before placing glass ionomer restorations, it is recommended that the dentin and enamel be conditioned instead of etched because conditioning agents:
   a. create porosities and allow for resin tags to form.
   b. remove the smear layer but do not demineralize the inorganic matrix of the tooth.
   c. decrease the surface energy of the tooth.
   d. demineralize the surface of the interface, exposing a collagen network.

7. It appears that the fluoride release in glass ionomer restorations is substantial enough to:
   a. resist recurrent decay.
   b. reverse incipient lesions on adjacent interproximal surfaces.
   c. shift the ionic properties of saliva toward remineralization.
   d. all of the above

8. According to a thorough systematic review of university-centered clinical trials regarding the longevity of non-carious Class 5 restorations in vivo, what is the annual failure rate of glass ionomers?
   a. 9.1%
   b. 8.4%
   c. 4.8%
   d. 1.9%

9. In a sandwich restoration, glass ionomer is used to:
   a. replace only the missing dentin structure.
   b. replace only the missing enamel structure.
   c. change the contraction and expansion properties of the missing dentin structure.
   d. mimic configuration-factor stresses on the restored tooth.

10. A benefit of placing sandwich restorations is:
    a. that the glass ionomer has a low degree of elastic deformation during setting.
    b. that the composite resin will not shrink rapidly upon polymerization.
    c. the elimination of configuration-factor stresses on the restored tooth.
    d. all of the above

Please see tester form on page xxx.

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