Advances in Tooth-Colored Restoratives

A Peer-Reviewed Publication
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Educational Objectives
The overall goal of this article is to provide dental professionals with information on tooth-colored restorations. Upon completion of this course, the clinician will be able to do the following:
1. Describe the early tooth-colored direct restorative materials
2. List and compare the attributes of composite resins and glass ionomer cements
3. Describe the composition of a compomer, and compare it to composite resins and conventional glass ionomers
4. Describe the restoratives containing nanotechnology and the effect of nanotechnology in nano-ionomer restorations

Abstract
Researchers have developed multiple tooth-colored restoratives in the search for a material that has optimal strength, esthetics, handling properties and a preventive function. Materials currently available include glass ionomer-based materials, composite-based materials, compomers, giomers, and the use of nanotechnology for composites and nano-ionomers. Each offers benefits for the individual patient case.

Introduction
The quest for suitable tooth-colored restoratives began with the introduction of acrylics and silicates. While weak and offering relatively poor esthetics, as well as being difficult to accurately mix and handle, they represented the first efforts at providing the clinician and patient with both esthetics and functionality in a restoration. As researchers investigated various chemistries, two main categories of direct tooth-colored restorations evolved – composite resins and glass ionomer cements. These represented a significant improvement over the pre-existing options, which rapidly fell out of favor.

Figure 1. Development of early tooth-colored restoratives

Glass Ionomer Cements
Glass ionomer cements consist of two components that initially were available only as a powder and liquid. Fundamentally, these consist of fluoroaluminosilicate glass particles and an aqueous solution of polyalkenoic (or polyacrylic) acid. A major difference between glass ionomer restoratives and composite-based restoratives is the inclusion of water in the glass ionomer formulations and their hydrophilicity, which results in wet contact with the tooth surface and a strong bond over time. The setting reaction for glass ionomers is acid-based, rather than setting through polymerization; therefore, no polymerization shrinkage can exist. Using infrared spectroscopy and band-narrowing treatments to assess materials, Arrondo et al. confirmed that glass ionomers set through an acid-based reaction as well as cross-linking of the polyacrylic acid in the glass ionomer. Glass ionomer cements tolerate moist environments and are applied to moist tooth surfaces. In addition, they adhere directly to the tooth structure and provide a solid marginal seal. In combination, these attributes can provide for an easier and quicker chairside experience for patient and clinician alike compared to using composite resins. In general, however, glass ionomer cements have lower strength than composites. One of the main benefits of glass ionomers is their ability to release fluoride. Based on studies of up to three years duration, fluoride release is ongoing; the amount released exceeds the initial fluoride content of the fluoroaluminosilicate glass particles—demonstrating the uptake of fluoride from external sources—and has been found to be regulated by the phospho-
Fluoride release is highly desirable. The fluoride release from glass ionomers has been shown to help prevent the formation of secondary caries, by creating a zone of inhibition, and in addition has been found to have a preventive effect on adjacent teeth. Since the main reason for replacement of direct restorations is secondary caries, caries inhibition through fluoride release is highly desirable.

**Bridging the Gap**

As a result of their respective attributes, resin-based composites became the material of choice where strength and esthetics were of greatest importance. Glass ionomers have been favored in situations where caries control, the intraoral environment and ease of placement were more important considerations than strength and esthetics. Improving the strength and esthetic properties of both composites and glass ionomers became a strong focus, as well as improving specific attributes (such as reducing polymerization shrinkage in resin-based composites). Researchers investigated and continue to investigate potential solutions that might offer all the benefits of composites and glass ionomers but without any of the drawbacks associated with either category. In the quest for a single material that might meet all requirements for the ideal restorative, composites and glass ionomers have both evolved. Chemistry from each category has been incorporated into the alternative restorative material, with differentiation of fillers, unique chemistries, delivery systems, curing mechanisms, and single-layer versus multi-layer techniques.

**Resin-modified Glass Ionomers**

The strength of glass ionomers was improved through the addition of methacrylate monomer in the aqueous polyalkenoic acid solution as well as the addition of monomer containing free radical double bonds in the fluoroaluminosilicate-containing component. This created a new subset within the category that was named resin-modified glass ionomer cement. The monomer sets through polymerization when light-activated and cross-links, but does not interfere with the acid-based setting reaction due to the limited amount added to the glass ionomer. Light-curing of these glass ionomers offers control whereby the initial self-setting is accelerated. After exposure to polyalkenoic acid conditioner, resin-modified glass ionomer forms a hybrid layer at the dentin surface of bur-cut dentin and a typical submicron gel phase can be observed with transmission electron microscopy. Assessments in laboratory testing found that the direct bonding to the tooth structure was attributable to bonding of the gel phase around the hydroxyapatite as well as to the hybrid layer (depending on the product), which resulted in micro-mechanical bonding through an interlocking mechanism. Interestingly, and as a note of caution, no hybrid layer or gel phase is found using the same protocol on Er:YAG laser-irradiated dentin, nor any dentin demineralization or collagen melting. A separate study comparing the adhesion mechanism of bur-cut and laser-irradiated dentin supports these results; although partial demineralization was observed, there was still no hybrid layer formation. It was also determined that the use of glass ionomer conditioner was important for microtensile bond strength in bur-cut dentin. The fracture resistance of resin-modified glass ionomers has been found to be significantly greater than that of conventional glass ionomers. In addition, a reduction in particle size (of up to 10 microns) of the fluoroaluminosilicate-based component has been found to increase fracture resistance as well as result in a smooth surface. Resin-modified glass ionomers are still not a material of choice for posterior stress-bearing areas, due to their relatively low surface hardness and fatigue resistance. Light-activated glass ionomers enable immediate finishing and reduced incidence of subsequent microleakage.

**Metal-reinforced Glass Ionomers**

Metal-reinforced glass ionomers include metal ions in the mix – typically silver-based alloys such as the silver-tin alloy found in amalgam. These are used primarily for core buildups and are also used to restore primary molars. A subset of this category, the cermet, results from fusing the metal ions to the fluoroaluminosilicate glass particles; however, cermets release less fluoride than other glass ionomers.

**Compomers**

Compomers, also known as polyacid-modified resin composites, were developed from composites. They contain filler similar to the glass particles contained in glass ionomers, dimethacrylate monomer and polyacid, but they do not contain water. Setting occurs through polymerization and, as with conventional composites, adhesion is achieved through the mandatory use of bonding agents rather than direct bonding to the tooth structure. Based on the absence of a COO bond, it was determined that no acid-based reaction occurs. Finally, it was also concluded that the release of metal ions that chelate with the methacrylate-based polymer molecules was due to dilution of filler particles through the presence of water. Compomers have lower compressive strength and flexural strength, a lower Young’s modulus (modulus of elasticity), and reduced resis-
tance to fracture and wear compared to composites, and should not be used in stress-bearing areas.18,19,20 A study comparing tooth-colored restorative materials found that the surface finish of glass ionomers and compomers were both significantly poorer than that of conventional composites.21 Biofilm development is significant on both compomer and composite materials. The glass particles in compomers are responsible for the fluoride release from the set compomer which, while lower than with glass ionomers, is still ongoing.22,23,24,25,26 There have been concerns about the release of HEMA from compomers,26 due to the risks of adverse pulpal responses in patients and of allergy in patients and dental personnel. The amount of HEMA released is influenced by the individual material, depth of cure and degree of curing.27,28 Although compomers do not meet esthetic requirements where these demands are primary, some offer greater polishability than glass ionomers and resin-modified glass ionomers.18 Compomers may be suitable for restorations where neither strength nor esthetics are primary considerations, such as in pediatric restorations, and have also been used as orthodontic bonding agents.

**Giomers**

Another approach has been the use of milled, silanized glass ionomer fillers that have already undergone the acid-base reaction between fluoroaluminosilicate glass and polyalkenoic acid prior to milling. These fillers are then used in a composite resin base to provide fluoride release from the fillers together with the strength and esthetics of composites and have been found to be successful in these regards.29

**Nanotechnology**

The introduction of nanotechnology, initially in composites, heralded improved esthetics without compromising strength or wear resistance. Strength and wear resistance were also improved, depending on the material.

**Nanofilled Composite Resins**

Nanofilled composite resins were designed to combine the polishability and esthetics of microfilled composites with the strength and wear resistance of microhybrid composites. They contain nanofillers that are heavily loaded into the composite, these improve the translucency and opalescence of the composite, making it more natural looking and better able to blend in with the surrounding area.4 The addition of nanosized particles to composite resins increases their polishability. Azevedo et al referred to the recent studies suggesting that these particles should ideally be evenly dispersed together with microfillers.30 Nanofilled composites offer improved strength compared to microfilled composites and equal to or better than other composites.31 The addition of pre-polymerized nanofillers forming nanoclusters has been found to reduce polymerization shrinkage, further increase strength and esthetics, and offer a smoother surface that is less subject to wear and that wears more evenly.4

**Nano-ionomers**

Nano-ionomers were developed with the desire to combine the proven benefits of glass ionomers, in particular fluoride release, with the proven benefits of nanotechnology available in resin-based composites discussed above – notably improved esthetics, surface smoothness, strength and wear resistance. The nano-ionomer consists of one paste containing water, polycarboxylic acid, nanofillers and reactive resins. With the exception of the nanofillers, these components are contained in resin-modified glass ionomers and compomers. The other paste contains a combination of nanofillers (based on silica and zirconia) and nano-clusters of these fillers, together with reactive resins and 27% fluoroaluminosilicate glass particles.

Nano-ionomers were placed and light-cured after use of its corresponding primer. It is essential that the primer be used to optimize tensile shear bond strength. In assessing the interface and the material, nano-clusters with a high filler load and good distribution of the filler through the nano-ionomer (Ketac<sup>TM</sup> Nano, 3M ESPE) have been observed, together with bonding through micromechanical locking.32 Korkmaz et al. studied the shear bond strength of nano-ionomer to enamel and dentin after use of primer with or without the addition of 37% phosphoric acid etching, with some specimens receiving laser etching first. It was found that the use of only primer resulted in the greatest shear bond strength in dentin; in enamel, use of phosphoric acid provided the greatest bond strength. Interestingly, as with the resin-modified glass ionomers discussed earlier, laser treating the tooth structure prior to use of the primer and nano-ionomer results in poor shear bond strengths.33

The setting reaction of the nano-ionomer involves the rapid free radical polymerization of the monomers when exposed to light-curing, followed for a much longer time by a slower acid-base reaction involving the fluoroaluminosilicate glass filler and aqueous acid solution. The nano-ionomer has been found to have compressive strength at least equal to conventional glass ionomers and resin-modified glass ionomers, to have good flexural strength and diametral tensile strength, and to be less brittle than resin-modified composites.
Experimental Approaches

Experimental fillers such as trimethyletoxysilane and the use of N-vinylpyrrolidone have been investigated as additives to composites and glass ionomer cements, and the inclusion of a methacryloyl derivative of L-proline in glass ionomers was found to result in greater diametral tensile strength, higher compressive strength and higher biaxial flexural strength.\textsuperscript{30,34,35} Nanosized particles of nanohydroxyapatite and fluorapatite were created and incorporated into glass ionomer cement in another study, resulting in increased bond strength, compressive strength, diametral tensile strength and flexural strength.\textsuperscript{36} One investigation involved creating novel fillers for a resin-based composite by combining ground cured glass ionomer with ceramic whiskers composed of silica fused onto silicon nitride that were then silanized. The resulting material was found to have superior flexural strength and moderate fluoride release, the degree of release influenced by the proportions of ground glass ionomer and ceramic whiskers.\textsuperscript{37} Experimental light-cured HEMA-free glass ionomer cements have been studied and found to offer promise.\textsuperscript{38} Self-etch adhesives to further strengthen adhesion to tooth structure have also been researched for both composites and resin-modified glass ionomers.\textsuperscript{39}

Handling and Placement

As with restorative materials themselves, substantial developments have occurred with the mixing and application of tooth-colored restorative materials. Initially, glass ionomers consisted of powder and a water and polyacrylic acid-based liquid, and were always hand-mixed. Similarly, early composites consisted of two pastes and they, too, were hand-mixed. There was no possibility of a one-component delivery system, nor did mixing tips/double-barrel applicators exist. Currently, a number of options are available for the handling and application of composites and glass ionomers as well as their derivative products. For composites, one option is a multi-dose syringe from which the material is extruded onto a mixing pad before being applied to the tooth; another is direct application from a unit-dose capsule or, for flowable composites, directly into the preparation from a disposable single-use applicator tip on a multi-dose syringe. Focus has also been placed on the shapes of the syringes, the amount of pressure required for extrusion of the material, the hand grip and thumb comfort during extrusion, methods for measuring the amount extruded (such as clicks or lines representing an average extruded dose), and the overall ease of use. Although still available, hand-mixed dual-paste composites are difficult to mix accurately and without the inclusion of voids. For glass ionomers and resin-modified glass ionomers, several options exist. These include the use of a powder and liquid, or paste-paste (using the same hand-mixing method used for early glass ionomers) and the use of a unit dose that is activated by pressing on, or twisting, the unit dose and then triturated for 10 to 15 seconds (product dependent) before being applied directly to the preparation with or without the use of an applicator. A third option is the use of a Paste Pak that is placed in an applicator, after which a disposable mixing tip is added to mix premeasured amounts of each component and to dispense the material onto a pad or directly to the site of use.
Clinical Application
The two cases below illustrate the use of nano-ionomer for anterior restorations.

Case 1.
The patient presented with a large distal and buccal carious cavity on tooth #27 which served as the support for a partial denture clasp. An esthetic, wear-resistant restoration was required, and it was decided to create a closed-sandwich restoration using nano-ionomer and composite. After applying primer (Ketac Nano), a stand-alone air syringe was used (rather than a three-in-one air-water syringe) to maximally air-dry the primer and avoid any possible contamination of the site with water prior to light-curing. Nano-ionomer (Ketac Nano) was then placed in the site for the internal sandwich layer and light-cured, with the light-curing tip held close to the material to ensure maximum cure. Once cured, a soft composite finishing bur was used to prepare the surface of the nano-ionomer, after which a total-etch technique was used for bonding (XP Bond®, Dentsply Caulk) of the composite to the enamel. The composite (Filtek™ Supreme A3, 3M ESPE) was then placed and the composite light-cured and finished. The end result was a durable, esthetic restoration.
Case 2.
The patient in this case was an 89-year-old woman with xerostomia. She presented with extensive carious cervical lesions under a fixed anterior prosthesis, indicative of high caries activity, and the selected clinical solution was use of nano-ionomer. Primer (Ketac Nano) was applied, dried using an air syringe and light-cured. For the restorations, nano-ionomer (Ketac Nano) was applied and shaped using a plastic instrument prior to light-curing. The final restorations were finished using a finishing bur. To help prevent recurring caries and to recharge the nano-ionomer with fluoride, the patient was then placed on a preventive protocol that involved the use of Clinpro™ 5000 with TCP (3M ESPE) in the morning and Crest PRO-HEALTH™ (Procter and Gamble) toothpaste in the evening, followed by MI Paste™ (GC America) in a custom-made soft tray overnight.
Summary

Tooth-colored restorations have changed greatly since their initial introduction. Over time, these have developed to include several types of packable composites, flowable composites, glass ionomers and compomers and the use of nanotechnology. When selecting a material, the requirements for the patient and individual restorations are factors of paramount importance.

References

1. As researchers investigated various materials, two main categories of direct tooth-colored restorations evolved; these were _____.
   a. composite resins and silicates
   b. silicates and glass-ionomer cements
   c. composite resins and glass-ionomer cements
   d. acrylics and silicates

2. The monomer-based content in composite resins is typically _____.
   a. bis-GMA
   b. TEGDMA
   c. DMA
   d. any of the above

3. Setting of composite resins _____.
   a. occurs through polymerization of the monomers
   b. results in the fillers being dispersed in the set matrix
   c. occurs through an acid-based reaction
   d. a and b

4. Early composite resins exhibited _____.
   a. low strength
   b. a high degree of polymerization shrinkage
   c. a high level of shrinkage stress
   d. all of the above

5. The current range of composite resin restoratives offers the _____.
   a. greatest strength and wear resistance
   b. lowest strength and wear resistance
   c. greatest strength and poorest esthetics
   d. none of the above

6. Composites typically _____.
   a. contain iodide
   b. contain fluoride
   c. do not contain fluoride
   d. a and b

7. Microfilled composites offer _____.
   a. the ability to polish the composite to a high gloss
   b. the ability to retain a high gloss
   c. superior esthetics
   d. all of the above

8. _____.
   a. Fluoroaluminosilicate glass
   b. Polyalkenoic (or polyacrylic) acid
   c. Resin
   d. a and b

9. The inclusion of water in glass ionomers and their hydrophilicity results in _____.
   a. wet contact with the tooth surface
   b. a weak bond over time
   c. a strong bond over time
   d. a and c

10. The setting reaction for glass ionomers is _____.
    a. acid-based
    b. alkali-based
    c. polymerization-based
    d. none of the above

11. Glass ionomer cements _____.
    a. tolerate moist environments
    b. adhere directly to the tooth structure
    c. are applied to moist tooth surfaces
    d. all of the above

12. In the quest for a single material that might meet all requirements for the ideal restorative, _____ have evolved.
    a. composites
    b. acrylics
    c. glass-ionomer cements
    d. a and c

13. The strength of glass ionomers was improved through the addition of _____.
    a. methacrylate monomer
    b. polymer containing free radical double bonds
    c. compomer particles
    d. none of the above

14. The monomer in resin-modified glass ionomers _____.
    a. cross-links
    b. sets through polymerization when light-activated
    c. does not interfere with the acid-based setting reaction
    d. all of the above

15. The direct bonding to the tooth structure observed with glass ionomers was found in one study to be attributable to _____.
    a. bonding of the gel phase around the hydroxyapatite
    b. the hybrid layer
    c. monomer
    d. a and b

16. Following Er:YAG laser-irradiation of dentin, _____ has been observed with the use of glass ionomers.
    a. a deeper hybrid layer
    b. no hybrid layer
    c. no setting reaction
    d. a and c

17. The use of glass ionomer conditioner is important for _____.
    a. microtensile bond strength
    b. shrinkage
    c. stress reduction
    d. all of the above
## Questions

18. Metal-reinforced glass ionomers
   a. typically include silver-based alloys in the mix
   b. are used primarily for core buildups
   c. can be used to restore primary molars
   d. all of the above

19. The cermet contains________.
   a. results from fusing metal ions to fluoroaluminosilicate glass particles
   b. is a subset of metal-reinforced glass ionomers
   c. releases less fluoride than other glass ionomers
   d. all of the above

20. Compomers are also known as________.
   a. polyacid-modified glass ionomers
   b. polyacid-modified acrylics
   c. polyacid-modified composites
   d. none of the above

21. Compomers contain________.
   a. fillers similar to the glass particles contained in glass ionomers
   b. dimethacrylate monomer and polyacid
   c. no water
   d. all of the above

22. Setting of compomers occurs through________.
   a. polymerization only
   b. an acid-based reaction only
   c. both polymerization and an acid-based reaction
   d. none of the above

23. It has been found that________ with the methacrylate-based polymer molecules is due to dilution of filler particles through the presence of water.
   a. the release of metal ions that hydrate
   b. the release of metal ions that chelate
   c. the release of carbonyl groups that chelate
   d. all of the above

24. Compomers have________ compared to composites.
   a. lower compressive and flexural strength
   b. a lower modulus of elasticity
   c. less resistance to fracture and wear
   d. all of the above

25. There have been concerns about the release of________ from compomers.
   a. fluoride
   b. EDTA
   c. HEMA
   d. b and c

26. Biofilm formation is significant on________.
   a. compomers
   b. amalgam
   c. composites
   d. a and c

27. A gionomer contains________.
   a. milled, silanized glass ionomer fillers
   b. a composite resin base
   c. a silicate base
   d. a and b

28. Gionomers have________.
   a. the strength of composites
   b. the esthetics of composites
   c. been shown to release fluoride
   d. all of the above

29. The introduction of nanotechnology________.
   a. occurred initially in composites
   b. heralded improved esthetics
   c. did not compromise strength
   d. all of the above

30. Nanofilled composite resins were designed to combine the________.
   a. polishesability and esthetics of microfilled composites
   b. strength and wear resistance of hybrid composites
   c. strength and wear resistance of compomers
d. a and b

31. Nanofillers in composites________.
   a. improve the translucency of composites
   b. improve the opalescence of composites
   c. make composites more natural looking
d. all of the above

32. Nanofilled composites offer________ microfilled composites.
   a. improved strength compared to
   b. reduced strength compared to
   c. the same strength as
d. none of the above

33. The addition of pre-polymerized nanofillers forming nanoclusters has been found to________ in composites.
   a. reduce polymerization shrinkage
   b. increase shrinkage stress
   c. increase strength
d. a and c

34.________ are contained in nano-ionomers.
   a. Water and polyacrylic acid
   b. Nanofillers
   c. Reactive resins
d. all of the above

35. The nanofillers in nano-ionomer are based on________.
   a. silica and phosphate
   b. zirconia and phosphate
   c. fluoride and zirconia
   d. zirconia and silica

   a. 17%
   b. 27%
   c. 37%
d. none of the above

37. Primer must be used prior to placement of nano-ionomers to optimize________.
   a. compressive strength
   b. tensile shear bond strength
   c. flexural strength
   d. all of the above

38.________ studied the shear bond strength of nano-ionomer to enamel and dentin.
   a. Korovski et al
   b. Korkmaz et al
   c. Korobovska et al
d. none of the above

39. The use of only primer has been found to result in the greatest shear bond strength to________.
   a. enamel
   b. dentin
   c. cementum
d. a and b

40. The use of phosphoric acid has been found to provide the greatest bond strength to________.
   a. enamel
   b. dentin
c. cementum
d. a and c

41. Nano-ionomer has been found to________.
   a. have compressive strength at least equal to glass ionomers
   b. have good flexural and diametral tensile strength
   c. be less brittle than resin-modified glass ionomers
d. all of the above

42. Experimentally, the inclusion of a methacryloyl derivative of 1-proline in glass ionomers was found to result in________.
   a. greater strength
   b. greater polishability
c. lower reflectance
d. all of the above

43. Self-etch adhesives to further strengthen adhesion to tooth structure have been researched for________.
   a. composites
   b. gold inlays
c. resin-modified glass ionomers
d. a and c

44. Early composites________.
   a. were weak
   b. consisted of two pastes
   c. were hand-mixed
d. all of the above

45.________ is an option for the handling and application of composite.
   a. A multi-dose syringe with a mixing pad
   b. Direct application from a unit-dose capsule
c. Use of a disposable tip and multi-dose syringe for flowables
d. all of the above

46. The use of________ is an option for mixing glass ionomers.
   a. a powder and liquid
   b. a capsule
c. a Paste Pak
d. all of the above

47. Measuring and mixing errors can result in incorrect ratios of two-component materials and can lead to________.
   a. reduced strength
   b. reduced surface hardness
c. reduced fracture resistance
d. all of the above

48. Using premeasured unit dosing with mixing occurring as the material is extruded can________.
   a. save time
   b. provide ease of use
c. increase waste
d. a and b

49. Researchers in one investigation on the mixing of glass ionomers advocated the use of________.
   a. powder and liquid
   b. precapsulated unit doses
c. a dual paste system
d. none of the above

50. The________ is a factor when selecting a tooth-colored restorative.
   a. requirements for the patient
   b. gender of the patient
c. individual restoration
d. a and c
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Educational Objectives
1. Describe the early tooth-colored direct restorative materials
2. List and compare the attributes of composite resins and glass ionomer cements
3. Describe the composition of a composite, and compare it to composite resins and conventional glass ionomers
4. Describe the restoratives containing nanotechnology and the effect of nanotechnology in ionomer restorations

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1. Were the individual course objectives met?
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   5 4 3 2 1 0

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   5 4 3 2 1 0

4. How would you rate the objectives and educational methods?
   5 4 3 2 1 0

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   5 4 3 2 1 0

6. Please rate the instructor’s effectiveness.
   5 4 3 2 1 0

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