Direct Applications of a Nanocomposite Resin System: Part 1 — The Evolution of Contemporary Composite Materials

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The delivery of functional, aesthetic restorations has been simplified by the introduction of contemporary composite materials. The most recent innovation in composite resin technology is the revolutionary application of nanocomposite theories in restorative materials. Contemporary nanocomposite materials deliver increased aesthetics, strength, and durability, combining scientific principles for increased longevity. This article discusses the application of nanocomposite resin systems and demonstrates the historical perspective of composite resin technologies in restorative treatment. The second installment to this series will address the clinical applications of such a system in the anterior region.

Learning Objectives:

This article addresses material selection considerations that must be addressed when selecting an appropriate direct restorative material. Upon reading this article, the reader should:

- Understand the historical background and application of nanocomposite materials.
- Be aware of the clinical implications of a nanocomposite resin system.

Key Words: nanocomposite, resin, anterior, posterior, aesthetic, minimally invasive

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Aesthetic dentistry continues to evolve through innovations in bonding systems, restorative materials, function-based treatment, and minimally-invasive preparation designs. Such advances have increased the myriad of opportunities available to discriminating patients and have provided solutions to many of the restorative and aesthetic challenges faced by clinicians. Increased utilization of composite materials to restore the anterior and posterior dentition has drawn increased attention to contemporary technological advances.

Historical Perspective

Composite resin technology has continuously evolved since its inception by Bowen as a reinforced "Bis-GMA" system. Since this time, numerous improvements have been made in the design of composite resin materials. A major breakthrough in composite technology surfaced with the development of photo-curable composite resins. These light-initiated composite resins were more color-stable than the earlier self-cured composites and had smaller filler particles that improved the material's wear resistance.[1,2] Later, microfill resins were introduced with a submicron average particle size that resulted in high polishability and wear. A continued metamorphosis resulted in the development of reduced particle size and increased filler loading that significantly improved the universal applicability of light-cured composite resins.[2]

Figure 1. A 15-year-old female patient presented with diastemata that required restorative treatment following orthodontic therapy.

Figure 2. Custom-fabricated shade tabs were developed from the composite material and compared to the existing tooth structure.

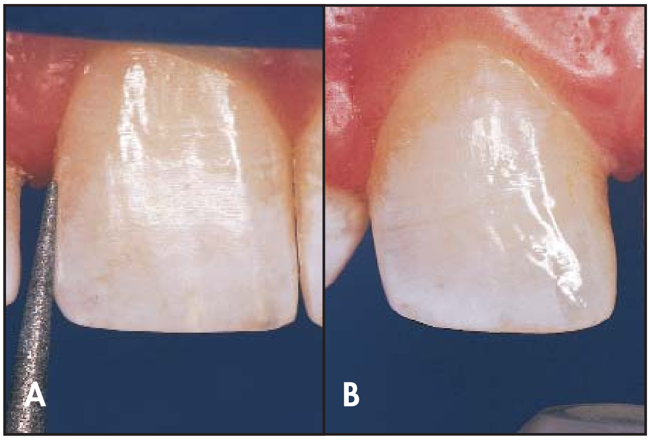

Figure 3A. The distal surface of the right central incisor was conservatively prepared in the enamel with a long, tapered diamond. 3B. The prepared tooth surface was adhesively conditioned.

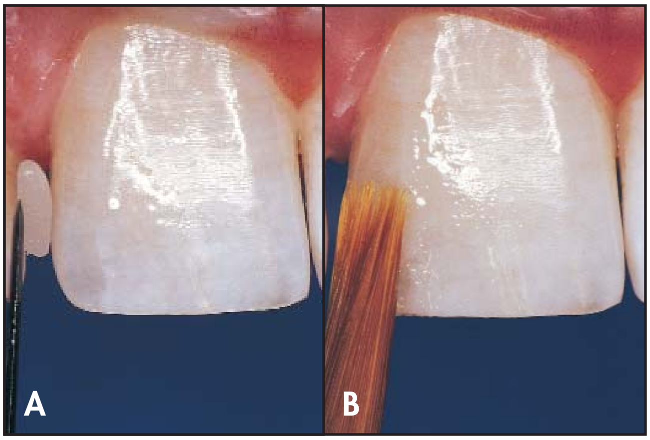

Figure 4A. An increment of A1-shaded nanocomposite resin was placed on the distal aspect. 4B. An artist's sable brush was used to contour the resin to place.

Figure 5. A small increment of translucent-shaded nanoparticle hybrid resin (Premise, Kerr/Sybron, Orange, CA) was placed over the previous layer.

Figure 6. The translucent layer of resin was then sculpted, adapted, and smoothed cervicoincisally and mesiodistally to obtain an anatomically correct profile.

Manufacturers, researchers, scientists, and clinicians continue their search for an ideal restorative material that is similar to tooth structure. This biomaterial should be resistant to masticatory forces and possess an appearance akin to natural dentin and enamel. In addition, its physical and mechanical properties should be similar to that of the natural tooth, because, as the mechanical properties of a restorative material approximate that of enamel and dentin, the restoration's longevity increases.[3] This article reviews the composition of contemporary composites and describes the mechanical and physical significance of the resin properties.

Nanotechnology With Composite Resin

In composite resin technology, particle size and quantity are crucial when determining how to best utilize the restorative materials. Alteration of the filler component remains the most significant development in the evolution of composite resins,[4] because the filler particle size, distribution, and the quantity incorporated dramatically influence the mechanical properties and clinical success of composite resins.[5] In general, the mechanical and physical properties of composites improve in relation to the amount of filler added. Many of the mechanical properties depend on this filler phase, including compression strength and/or hardness, flexural strength, elastic modulus, coefficient of thermal expansion, water absorption, and wear resistance.

Figure 7. The lateral incisors were developed using the same restorative protocol, which allows optimal adaptation of the composite to the adjacent tooth.

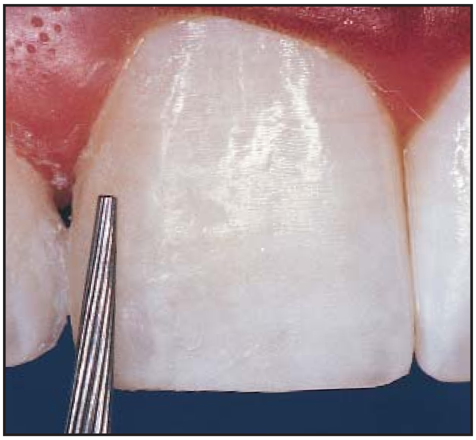

Figure 8. To reproduce natural form and texture, the initial contouring was performed with a 30-fluted needle-shaped finishing bur.

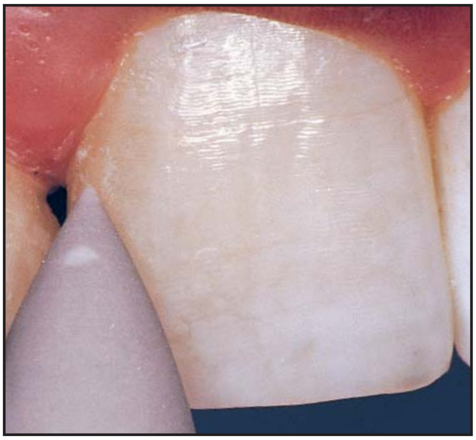

Figure 9. After preliminary contouring and use of finishing strips interproximally, silicone rubber points were used to establish natural indentations, lobes, and ridges.

Figure 10. Once the initial diastema was restored, the identical direct buildup of nanocomposite hybrid resin was performed for the adjacent central incisor.

Nanotechnology or molecular manufacturing may provide composite resin with filler particles that are dramatically smaller, can be dissolved in higher concentrations, and are polymerized into the resin system with molecules designed to be compatible when coupled with a polymer, and provide unique characteristics (physical, mechanical, and optical).[5] In addition, optimizing the adhesion of restorative biomaterials to the mineralized hard tissues of the tooth is a decisive factor for enhancing the mechanical strength, marginal adaptation, and seal, while improving the reliability and longevity of the adhesive restoration. The particle size of conventional composites are so dissimilar to the structural sizes of the hydroxyapatite crystal, dentinal tubule, and enamel rod, that there is a potential for compromises in adhesion between the macroscopic (40 nm to 0.7 nm) restorative material and the nanoscopic (1nm to 10 nm in size) tooth structure.[6] Nanocomposite systems have the potential to improve this continuity between the tooth structure and the nanosized filler particle and provide a more stable and natural interface between the mineralized hard tissues of the tooth and these advanced restorative biomaterials.

Infrastructure of the Composite System

To understand the rationale for the use of a specific composite resin system requires a discussion of the system's infrastructure. Three phases comprise the infrastructure of composite resins — the organic phase (matrix), the dispersed phase (filler) and the interfacial phase (coupling agent).[7] The organic phase or matrix of this composite resin system consists of a mixture of base monomers that include ethoxylated bis-phenol-A-dimethacrylate and triethylene glycol dimethacrylate (TEGDMA) that provides a solidifying liquid for composite resin. Other matrix components include an initiator (eg, benzoyl peroxide for chemical activation or camphoroquinone for visible light activation), co-initiators, polymerization inhibitors (to extend working time and storage stability), and various pigments.[4,8-10]

The mineral component of the composite, which is a filler, is termed "the dispersed phase" and has been noticeably improved with the addition of small particles or fillers.[11] In dental composites, fillers provide strength and reinforcement to the matrix.[12-18] One such nanocomposite system (Premise, Kerr/Sybron, Orange, CA) is composed of three different types of filler components: nonagglomerated "discrete" silica nanoparticles, barium glass, and prepolymerized filler. The nanoparticles are monodispersed discrete non-aggregated and nonagglomerated nanosized silica particles that are spheroidal in shape and 20 nm in diameter. The barium glass in the nanocomposite is from the same technology as the microhybrid resin Point 4 (Kerr/Sybron, Orange, CA), which has an average particle size of 0.4 μm. The same technology is used within the PPF filler of Premise

Figure 11. An increment of translucent-shaded Premise (Kerr/Sybron, Orange, CA) was added to the incisal third of the tooth.

Figure 12. Postoperative appearance demonstrates aesthetic form and color developed using a nanocomposite system for optimal results.

(the result is particles 30 μm to 40 μm in size). This nanocomposite system uses a "trimodal" approach to provide an optimal combination of these nano-fillers with barium glass and prepolymerized filler in a new low-shrinkage resin matrix. The introduction of these nanosized particles with the other two inorganic fillers allows for an increased filler loading that should provide improved clinical performance through increased polishability, increased wear resistance, reduced polymerization shrinkage, and increased fracture resistance. Since particle concentration depends on the viscosity, the filler loading that can be attained is 69% by volume and 84% by weight, which results in reduced polymerization shrinkage and shrinkage stress. The polymerization shrinkage is reported to be 1.4% to 1.6%. As the interparticle dimension decreases, the load-bearing stress on the resin is reduced, inhibiting crack formation and propogation.[19] The spheroidal shape provides smooth and rounded edges, distributing stress more uniformly throughout the composite resin. This phenomenon has been termed the "roller bearing" effect, and is said to improve the sculptability and handling characteristics (Figures 1 through 7). It is suggested that the long-term polishing retention arises from the exposed nanoparticle fillers in the resin matrix during wear, tooth brushing, or polishing. These fillers may act as a nano-polishing medium on the surface of the composite (Figures 8 through 12).

The interfacial phase or coupling agent, the third basic component of composite resins, includes a bifunctional coupling that can connect the resin matrix and the inorganic filler.[5,7] Since there is no chemical bond between the filler particles and the matrix of conventional composites, the coupling agents act as the adhesive and ionically bond to the inorganic filler while simultaneously bonding to the organic matrix, thus reducing the gradual loss of filler particles from the composite. The most commonly used coupling agents are vinyl, epoxy, and methyl silane.

The suggested clinical indications for use with this nanocomposite system include all anterior and posterior restorative applications (C. Angelatakis, oral communication, April 2004). Additional parts of this article will describe the utilization of this nanocomposite in the restoration of anterior and posterior regions. Part 1 has familiarized the clinician with the evolution of resin technology and described the infrastructure for this specific nanoparticle-hybrid composite resin system (Premise, Kerr/Sybron, Orange, CA) so that the reader can better understand the rationale for these applications.

Conclusion

Although the nano scale is small in size, its potential is vast. Recent advances by scientists and engineers in manipulating matter at this small magnitude indicate potential contributions for applications of this nanoscience through developments of advanced restorative biomaterials. The continual development of this technology will improve the ability of scientists, manufacturers, and clinicians to create a more ideal composite. The recent introduction of these advanced nanoparticle biomaterials represents the profession's continual research and development for the ideal composite material. These newer formulations of nanosized particle hybrid composite resin systems have improved physical, mechanical, and optical characteristics that are directly related to the filler particle size, distribution, orientation and the quantity incorporated. Prior to the introduction of such nanoparticle composite resins, it was often necessary to combine hybrid and microfilled composites to achieve proper aesthetics (ie, luster, color) and mechanical stability (ie, strength, wear resistance, fracture resistance) in adhesive restorations.

Since the development of nanosized-particle composite resins, it appears that these properties have been incorporated into a single restorative material. Although polychromatic stratification techniques are still necessary with this revised composite resin formulation, they are used only to attain natural aesthetics and color rather than physical attributes. Although the long-term benefits of this material (Premise, Kerr/Sybron, Orange, CA) remain to be determined, the utilization of this nanoparticle hybrid composite in the author's practice has demonstrated enhanced sculptability, the polishability of a microfill, the strength of a hybrid, and the ability to simulate the optical properties of the natural tooth. While this article primarily focuses on the infrastructure of this nanoparticle hybrid composite resin system to allow the clinician a better understanding for its application, subsequent parts of this discussion will provide the clinician with the preoperative considerations for developing directly placed composite resin restorations. An incremental layering technique that uses restorative adhesive concepts with this system to develop anatomically correct morphology will be described, and methods of managing and combating polymerization shrinkage will be addressed while illustrating a special technique for developing the interproximal zone with anterior and posterior composite resin restorations.

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References

1. Leinfelder KF, Sluder TB, Sockwell CL, et al. Clinical evaluation of composite resins as anterior and posterior restorative materials. J Prosthet Dent 1975;33:407-416.
2. Jackson RD, Morgan M. The new posterior resins and a simplified placement technique. J Am Dent Assoc 2000;131: 375-383.
3. Summitt JB, Robbins JW, Schwartz RS. Fundamental of Operative Dentistry: A contemporary approach. Carol Stream, IL: Quintessence Publishing, 2001.
4. Roulet JF. Degradation of Dental Polymers. 1st ed. Basel, Switzerland: S. Karger AG, 1987.
5. Leinfelder KF. Composite resins: properties and clinical performance. In: O'Brien WJ, Powers JM, eds. Dental Materials: Properties and Selection. Quintessence Publishing; Chicago, IL:1989:139-157.
6. Muselmann M. Composites make large difference in "small" medical, dental applications. Comp Tech 2003:24-27.
7. Talib R. Dental composites: A review. J Nihon Univ Sch Dent 1993;35(3).
8. Ruyter IE. Composites — Characterization of composite filling materials: Reactor response. Adv Dent Res 1988;2(1): 122-129.
9. Ferracane JL. Current trends in dental composites. Critical Reviews in Oral Biology Medicine 1995;6(4):302-318.
10. Chung KH, Greener EH. Correlation between degree of conversion, filler concentration and mechanical properties of posterior composite resins. J Oral Rehabil 1990;17:487-494.
11. Iga M, Takeshige F, Ui T, Torii M. The relationship between polymerization shrinkage measured by a modified dilatometer and the inorganic filler content of light-cured composites. Dent Mater J 1991;10(1):38-45.
12. Munksgaard EC, Hansen EK, Kato H. Wall-to-wall polymerization contraction of composite resins versus filler content. Scand J Dent Res 1987;95(6):526-531.
13. Soderholm K-JM. Influence of silane treatment and filler fraction on thermal expansion of composite resins. J Dent Res 1984;63(11):1321-1326.
14. Bowen RL. Synthesis of silica-resin direct filling material: Progress report. J Dent Res 1958;37:90. Abstract M13.
15. Ehrnford L. Dental composites reinforced with microporous sintered glassfiber networks. Swed Dent J 1983;7(Suppl 18): 1-34.
16. Hosada H, Yamada T, Inokoshi S. SEM and elemental analysis of composite resins. J Prosthet Dent 1990;64(6):669-676.
17. Van Dijken JWV, Wing KR, Ruyter IE. An evaluation of the radiopacity of composite restorative materials used in Class I and Class II cavities. Acta Odontologica Scandinavica 1989;47(1):401-407.
18. Lutz F, Setcos JC, Phillips RW, Roulet JF. Dental restorative resins: Types and characteristics. Dent Clin North Am 1983;27(4): 699-712.
19. Albers H. Tooth-Colored Restoratives: Principles and Techniques. 9th ed. BC Decker Publishing, 2002.