NANO-COMPOSITE DENTAL RESINS: AN OVERVIEW

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Abstract
Dental composite resins, due to their superior esthetic and shade matching properties, have been widely used as the material of choice for restoring anterior teeth. However, their application in the posterior stress bearing areas has remained questionable due to the lack of adequate physical & mechanical properties.

The recent advent of nanotechnology has enabled manipulation of these conventional dental composites at a nanoscale level resulting in the newer and advanced materials called Nanocomposites. In these nanocomposites, the resin matrix is reinforced with the nanosized filler particles, resulting in significantly improved mechanical properties.

The resultant improvement in physical properties, coupled with superior esthetics, has made nanocomposites as the ideal material of choice in anterior as well as posterior class-I & II situations. This paper attempts to give an overview on the applications and properties of nanocomposites.

Key words – Dental Resin, Nanocomposites, Nanotechnology, Nanofill, Nano-hybrids

Introduction
Dental Resins, in the recent past, have perhaps been the most popular restorative materials available to dentistry leaving behind the much older and time tested silver amalgam which reigned the top slot for years. This is primarily due to their metal free tag, which allows the composite resins to mimic the shade of the natural tooth, especially in the highly esthetic anterior regions, thus fulfilling the patient’s demand for a “tooth-like” restoration. The adhesive bonded resin composites also offer the advantage of conserving and reinforcing the remaining tooth structure.1,2 To add to this, being mercury free materials, these composites pose no health concerns, in contrast to dental amalgams.

Notwithstanding the excellent esthetics, conventional composites, however, have limited applicability in the posterior stress bearing areas. Posterior composite restorations tend to undergo tooth and or restorative fractures in response to masticatory stresses and due to internal stresses generated during polymerization shrinkage.

In an attempt to improve their physical properties, the unfilled dental resins have undergone progressive evolution, from the conventional composites reinforced with strong filler particles to the relatively newer micro-filled and hybrid composites. These micro-filled and hybrid materials, still, however, have not proven to be ideal for use in the posterior regions.

The recent application of the science of Nanotechnology to the field of dentistry has resulted in development of resin materials with more favourable mechanical properties. The term “Nanotechnology” refers to the science of producing functional materials and structures in the size range of 0.1 to 100 nanometers by using various chemical & physical processes. The material’s micro-structure is modified by arranging individual atoms & molecules, leading to an enormous improvement in the electrical, chemical and physical properties.1 The nanomaterial might be a nanoatom, nanograin, nanofibre, nanocluster or a composite where the size of each particle is less than 100 nm at least in one dimension.3

The novel technique of nanotechnology has enabled incorporation of nanofiller particles in the organic resin matrix of dental composites at a nano-scale, resulting in a substantial improvement in mechanical, esthetic and optical properties as compared to those of the conventional, microfilled and hybrid resins.4

How does Nanotechnology improve the conventional dental composite resin?

The emergence of nanocomposites has made possible the use of a single restorative material universally in various areas of the oral cavity, as these composite materials possess not only favourable esthetic properties such as high initial polish & polish retention, but also excellent mechanical properties and improved handling characteristics.1

To understand how the technique of nanotechnology helps improve the conventional composite resins, an insight is required into the basic structure of a composite resin. A composite is basically a material made up of two or more constituent materials having significantly different physical & mechanical properties with the final product displaying characteristics better than the individual components. Like any other composite, there are three basic phases in the dental composite resin.

1) The first phase (Organic phase) consists of the resin matrix or body of the material. This is the chemically activated component of the composite which undergoes polymerization.

2) The second phase (Dispersed phase) is constituted by the filler material, which is embedded in the matrix. It is this phase which provides the bulk and overall strength to the composite material.

3) The third phase (Interfacial phase) is the coupling agent, which forms a bond between the matrix and the filler.5

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Apart from these phases, an activator-initiator system is also required to initiate the polymerization process. Out of the three basic phases or components, the dispersed (filler) phase is of utmost significance. The overall mechanical and physical behaviour and clinical performance of the composite resins is largely governed by the size, quantity and distribution of the filler particles incorporated in the matrix. The refractive index, radiopacity and hardness of the filler particles are also important parameters.

The amount of filler that can be incorporated in any resin matrix is dictated by the surface area of the filler particle. Greater is the surface area of the fillers for a particular weight percentage, more is the filler loading, subsequently resulting in increased bulk and strength of the composite material.

The conventional dental resin composites comprised of large filler particles of uneven size distribution. Traditionally, the most commonly used conventional filler particles have been quartz (silica/silicon dioxide), glass, barium, strontium and zirconia, with their particle size ranging from 0.06 micrometres to 100 micrometres. In the conventional composites, these large filler particles were milled down to smaller particles in a grinding mill by using the “Top-Down approach”.6

In contrast, the novel technique of nanotechnology employs the “Bottom-Up” approach, whereby individual atoms and molecules are modified at molecular and atomic level to fabricate functional structures.7 The filler particles are thus manipulated to produce “nanofillers” which are then incorporated into the resin matrix at a nanoscale dimension, resulting in the formation of such “Nanocomposites”.

Particle building and bonding is thus started at a nanoscale level and gradually the larger size is achieved. This is done through synthetic chemical processes such as flame pyrolysis, flame spray pyrolysis & sol-gel processes etc.5

Nanocomposites are generally of two types: Nanohybrid types & Nanofill types.8 Nanohybrids comprise of milled glass fillers along with nanoparticles in the size range of 40-50nm. The nanofil type of composites on the other hand, are formed by a combination of: (a) Nanomers, which are nanosized mono-dispersed, non-aggregated silica filler particles in the size range of 20-75nm and (b) Nanoclusters, which are agglomerations of combination of zirconia-silica and silica nanomeric particles.1,4,9 The typical “non-agglomerated” property in nanocomposites is achieved by utilizing a proprietary coating process during particle manufacturing process.9 This ensures even distribution of the discrete filler particles within the matrix with no clumping or sticking of particles, thus ensuring a smoother consistency & improved flow.

The smaller size of these particles enables higher filler packing (as much as 79%) and distribution in the resin matrix and also tends to increase the interfacial area between the filler and the matrix, leading to better dispersion and reduced polymerization shrinkage. The nanosized filler particles so achieved have superior strength and hardness, along with better shade characterization, finish, texture, translucency, gloss retention and lesser biodegradation.8

Properties & Applications of Nanocomposites

Nanotechnology allow the incorporation of a larger volume of the small sized filler particles in the resin matrix at a nanoscale level, thus resulting in composite materials with improved physical, chemical and biological properties.10 Nanocomposites possess a higher modulus of elasticity and greater flexural, compressive and diametrical tensile strengths, along with improved hardness, fracture toughness and wear resistance.7 Also, the decreased inter-particle distance between the nanofillers reduces the tendency for crack formation & propagation. The smooth & rounded edges of the spheroidal nanoparticles tends to distribute stress more evenly throughout the composite resin.9

The increased filler loading, decreased overall content of the soft organic matrix and strong interfacial interactions between the resin matrix and filler particles result in lesser polymerization shrinkage.5 Nanocomposites thereby respond much better to the functional stresses of mastication as compared to the conventional resins. Since nanohybrids contain the least amount of organic matrix, they demonstrate lesser polymerization shrinkage than the nanofill composites.2,12 Clinically, there tends to be lesser tendency for appearance of micro-fissures resulting in a better marginal seal and color stability.8

Nanofillers also enable an improvement in the material’s esthetic and optical properties. There is a significant increase in the material’s polish-ability, precision of shade characterization, color stability and translucency thus providing excellent finish & gloss retention to the final product. In the case of conventional composite resins, larger filler particles scatter the light passing through the composite giving it an opaque appearance if these particles are mismatched in their refractive indices.1 On the contrary, in nanocomposites, the small sized fillers are far below the wavelength of light so they are no longer measured by the refractive index. Light directly passes through the composite resin and the material resulting in higher translucency.8

The nanocomposites also demonstrate high polish retention after tooth brush abrasion. When these materials undergo toothbrush abrasion, only the nanosized particles are plucked away, leaving the surface with defects smaller than the wavelength of light.1 This is in contrast to the effect of abrasion on hybrid/microhybrid resins, where large particles are sheared off in toto leaving behind large craters of defect. The nanofiller composites also show decreased water sorption, decreased solubility and decreased mismatch in the coefficient of thermal expansion.8

Owing to all these superior properties, nanocomposites are today being successfully used as esthetic dental restorative materials in both the anterior as well as posterior class I & II cavities. They are indeed a blend of microfilled & hybrid
composites where the esthetics of the former & mechanical features of the latter are retained to the maximum.\textsuperscript{13}

Various commercially available brands of nanocomposites include Filtek Supreme XTE Universal Restorative (3M ESPE), Premise (Kerr/Sybron, Orange, CA), IPS Empress Direct & Tetric N-Ceram (both Ivoclar Vivadent) etc.

**Discussion**

The contemporary dental surgeon has to his disposal, a wide variety of materials to restore the lost form and function of decayed teeth. Conventional dental amalgam was, in the past, widely used as the restorative material of choice in stress bearing areas due to its superior strength, but lagged behind in terms of esthetics due to its distinctive metallic color. Mercury toxicity issues were also a concern with silver amalgam.

Esthetic demands, especially in the anterior regions of the oral cavity, necessitated the use of tooth coloured materials for restorative purposes. As a result, dental composites were introduced, which evolved from the initial unfilled resins to filled resins and further to micro-filled and hybrid composite resins. Even though these composites were successfully used as esthetic restorative materials in the anterior region, they could not efficiently bear the functional loading in the posterior regions. Also, the inherent polymerization shrinkage of these materials tended to produce stresses in both the composite restoration and in the surrounding tooth structure. Poor marginal adaptation and inappropriate proximal contacts further contributed to composite failures in posterior teeth.\textsuperscript{1} Conventional composite Class I & Class II restorations were thus often associated with problems such as postoperative pain, tooth fracture and opening of the restorative margins leading to micro-leakage and recurrent caries.\textsuperscript{14} Since there exists an inherent discrepancy between the particle size of the macroscopic composite restorative material (40nm-0.7nm) and the nanoscopic tooth structure (1nm-10nm) comprising of hydroxyapatite crystals, dentinal tubule & enamel rods, the adhesion between the conventional composite resin and tooth structure tends to be unsatisfactory. Amongst the conventional variants of composite resins, hybrid composites possess greater strength owing to the wider size distribution of the filler particles as compared to the unfilled and microfilled resins.

Recent advances in the material sciences and nanotechnology has however led to the development of superior nanocomposite materials. These are modified composite resins in which the basic organic matrix has been reinforced with nanofillers. The use of nanocomposite resins allows for a better nano-bonding interface between the tooth structure & the restorative material resulting in a more stable and natural interface.\textsuperscript{15} Nanocomposites possess a much larger volume of the nanomeric filler particles in the resin matrix, resulting in improved physical, chemical & biological properties.

As compared to conventional composites, nanocomposites possess a greater elastic modulus and higher flexural, tensile and impact strengths, along with improved abrasion resistance. Greater filler loading also consequently reduces the volume of the polymer matrix and toughens the composite resin by increasing hardness & fracture resistance and by reducing the viscosity.

The stress is distributed more uniformly within the resin. Also, the curing shrinkage reduces to half and so does the shrinkage stress. This is probably due to the stronger interfacial interactions of the organic resin matrix and the inorganic nanofiller particles.\textsuperscript{4} The surface is smoother, with a higher translucency and polish retention along with better shade characterization. The nanoparticle size is smaller than the wavelength of visible light hence the absorption of light does not occur and light shines through it.\textsuperscript{5} This helps in maintaining the smoothness of the surface for a longer duration of time. Greater scattering of light by small sized nanoparticles also produces excellent blending of the restoration, giving it a life like effect. Significantly smoother surfaces reduce the plaque accumulation and resultant periodontal disease.\textsuperscript{13}

**Conclusion**

The application of nanotechnology to the field of restorative dentistry has resulted in the development of dental resins with greatly improved physical, mechanical, esthetic and optical properties. These nanocomposites today serve as universal restorative materials in the anterior and posterior regions of the oral cavity. Further long term follow up studies, however, may in the future ascertain the clinical success of nanocomposite restorative resins.

**References**


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