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Nanocomposites for dental application - A review

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ABSTRACT

Nanotechnology was first described by physicist Richard P Feynman, who viewed it as an unavoidable development in the progress of science, and has since been part of mainstream scientific theory with potential medical and dental applications since the early 1990s. Nanoparticles, nanospheres, nanorods, nanotubes, nanofibers, dendrimers and other nanostructures have been studied for various applications in different biological spheres. Nanotechnology's most tangible contribution to dentistry to date has been the restoration of tooth structure with nano composites. Nanocomposites are characterized by filler-particle sizes of < 100 nm, which offer these materials' aesthetic and strength advantages over conventional micro filled and hybrid resin-based composite (RBC) systems. They offer advantages primarily in terms of the smoothness, polishability and precision of shade characterization, not withstanding the flexural strength and micro hardness they offer similar to those of the better-performing posterior RBCs. The strength and aesthetic properties of the resin based nanocomposite make it possible for it to be used for both anterior and posterior restorations. This article aims at to address the current major uses of practical nanotechnology in dentistry, mainly the restoration of tooth structure with RBCs that make use of nanoparticles.

Key Words : Dentistry, nanocomposite**,** nanoparticles**,** tooth structure

INTRODUCTION

Nanotechnology in medicine has been recently reviewed from various perspectives relative to the human molecule-tissue interface (Borlongan *et al*. 2007; Catledge and Vohra, 2002; Dalby, 2007; Dalby and Gadegaard, 2007). A common trend in this ongoing discussion is the capability to operate on a scale small enough to interact with intracellular components including DNA (Abeil and Leinfelder, 1983; Abu-Bakr, 2001 and Adabo, 2001). Over the last 40 years, the routine use of dental amalgam is gradually decreasing due to poor aesthetics of amalgam especially for anterior restoration, mercury toxicity, and environmental consideration arising from mercury disposal, potential dental fracture, secondary carries, and marginal leakage. Dental composites are among the synthetic resins used as adhesives or restorative material in dentistry and now represent general alternation to dental amalgam. However, composites have limited uses because of low durability and strength (Antonson *et al.,* 2001; Anusavice, 2003; Asmussen and Peutzfeldt, 1998). Nanocomposites are the premises of new materials that can be applied in many fields due to their improved mechanical properties (determined by the

reinforcement of nanoparticles in the organic part), to their light weight, and to their light conducting properties.

TYPES OF NANOCOMPOSITES

When inorganic phases in an organic/ inorganic composite become nano-sized, they are called nanocomposites. Nanocomposites may be metal, ceramic and polymer depending on the type of matrix where dispersed phase is nano size. Nanocomposites are available as nanohybrid types containing milled glass fillers and discrete nanoparticles (40 – 50 nm) and as nanofill types, containing nano-sized filler particles, called nanomers and agglomerations of these particles described as nanoclusters (Abeil and Leinfelder,1983). Increasing the filler fraction in a nanocomposite is a good strategy for manufacturers in aiming for improved mechanical performance. A higher filler fraction helps in increasing the fracture toughness because fillers decrease the volume of the weak polymer matrix and act as toughening sources, besides increasing the elastic modulus. Filler packing is also influenced by the size, arrangement, distribution and shape of the particles. Another commercially available nanocomposite is an ormocer-based, nano-ceramic composite. It contains glass fillers (1.1 - 1.5 μm), but differs from the conventional hybrid composites in two main features. Inorganic-organic composites are used as dental cements, implant super structures and fillings. The long term prognosis of dental implants and fillings shall be improved by optimizing the degradation stability and the mechanical properties of the composites by the development of innovative nanoscale fillers and tailored polymeric binders.

NECESSITY OF NANO MATERIALS FOR DENTAL APPLICATION

Due to the improvement in physical properties of nano composite material, no such material has been found to be ideal for any dental application (Mitra and Wu, 2003). For example, silver amalgam has been used for dental restoration for more than a century; however, there has been a major concern about mercury toxicity from the amalgam restorations for many years (Eley, 1997 and Jones, 1998). Another major issue is the color of amalgam for aesthetic considerations and alternative materials are being sought to replace (Eley, 1997, Mclean, 1984 and Yardley, 1984).The composite restorative materials have promising aesthetics; however these materials are very technique sensitive and mechanical properties are not as good as of amalgams (Saunders, 2009). Nature has arranged complex biominerals in the best way from the micro to the nano-scale and no one can yet combine biological and physical properties to get ideal structures. In addition, no synthetic material can be intelligent enough to respond to external stimuli and react like nature made tissues (Kanaparthy 2011 and Kanaparthy, 2011). There are number of possible options to make smart materials for the construction and mimicking of nature (Table 1).

Table 1. Options for the production of smart materials for dental applications

Option	Description
Material synthesis	Producing synthetic materials matching morphology and properties similar to natural dental tissues.
Biomimetic approaches	To replace lost dental tissues follow the nature's principles producing biomaterials resembling their properties very closely to the replacing tissues.
Tissue engineering	Use of regenerative medicine and tissue engineering approaches for replacing the lost dental tissues by regenerations.

PROPERTIES OF NANO COMPOSITES FOR DENTAL APPLICATIONS

The most unique nature of the filler particles of nanocomposites provides it with the mechanical strength and wear resistance similar to hybrid composites, and superior polish and gloss retention similar to microfill composites. The following are the properties of nano composites described here.

Polymerization shrinkage

The polymerization shrinkage especially in composite resin is reported to be 1.4% to 1.6%. The low shrinkage value of nanocomposites is due to the low shrinkage epoxy resin and strong interfacial interactions between resin and nanoparticles (Fortin and vargas, 2000; Chen *et al.,* 2006; Boaro and Goncalves, 2010).The volumetric shrinkage also depend on the total content of organic matrix of composites. Nanohybrid composites (Grandio) showed least amount of organic matrix (13.0 wt-%) and least shrinkage when compared to nanofill composites (Filtek Supreme Translucent), which had 30.0 wt % organic matrix. Polymerization shrinkage depends on the chemistry of the organic matrix (Moszner and Klapdohr, 2004; Mitra, 2003; Dresch, 2006 and Goncalves, 2009)

Water Sorption

Polymeric phase of composites in water causes generally two opposing processes. The solvent will extract unreacted components, mainly monomer, resulting in shrinkage, reduction in mechanical properties and loss of weight. Conversely, solvent uptake leads to swelling of the composite and increase in weight. This solvent diffuses into the polymer network and separates the chains creating expansion (Asmussen, 1998). However, since the polymer network contains micro voids created during the period of polymerization and free volume between chains, a part of the solvent is accommodated without creating a change in volume. Thus, the dimensional change of a polymer composite in a solvent is complex and difficult to predict that depends on the chemical structure of the polymer matrix. In general, nanohybrid composites show less water sorption than nanofill composite.

Wear and gloss retention

The primary particles having nano-sized in the nanoclusters wear by breaking off individual primary particles rather than plucking out the larger secondary particles from the resin which may result wear surfaces having smaller defects.

Flexural strength

The flexural strength depends on both filler content and filler chemistry. The flexural strength of nanocomposites was found to be statistically equivalent or higher than that of the hybrid or micro hybrid composites. It is significantly higher than those of the micro fill composites.

Nano fill composites have higher filler loading, also show greater flexural strength than nanohybrid composites and also have lesser filler loading (Fortin, 2000).

APPLICATION OF NANOTECHNOLOGY IN DENTISTRY WITH AVAILABLE PRODUCTS

In recent years, remarkable research has been obtained on nanocomposite materials which have transformed it from theoretical foundation to clinical practice. Currently, there is a wide range of nanomaterial's applications (Table 2) in different subspecialties of dentistry (Mitra, 2003; Kanaparthy, 2011; Chandki, 2012; Gaiser, 2012 and Mikkilineni, 2013). As a result of active and continued research to develop new nano-products, the variety of available products for various dental applications are expected to increase remarkably in the near future.

The properties of nanocomposites (good translucency, contouring and surface finish) are excellent and can restore lost or damaged dental tissues (Fig. 1). Current research is focused on reducing the polymerization shrinking. The addition of using monovinyl methacrylate monomers into dental resin was introduced by Decker, and reported enhanced polymerization kinetics and improved mechanical properties. They were made of secondary and tertiary functionalities including urethanes, carbonates or cyclic carbonates. They were also referred as ultra-rapid monomethacrylates. Recently researchers are investigating options of adding acidic functional groups in monomers (Cramer, 2011).

Table 2. Application of nanotechnology in dentistry with available products

Discipline	Available Materials
Restorative dentistry	Ketac™ (3M ESPE, St. Paul, MN, USA), Ketac N100; Nano-ionomers (3M ESPE), Filtek Supreme XT (3M ESPE), Fuji IX GP (GC, Leuven, Belgium), Nano-primer, Premise™ (Kerr/Sybron, Orange, CA, USA), Adper™ Single bond plus Adhesive (3M ESPE), Ceram X™ (DENTSPLY International, Milford, CT, USA).
Regenerative dentistry and tissue engineering	Ostim® (Osartis GmbH, Elsenfeld, Germany), VITOSSO™ (Orthovita-Inc, Malvern, PA, USA), Nano-Bone® (ARTOSS, Rostock, Germany).
Periodontics	Arestin® (Valeant, Bridgewater, MA, USA), Nanogen® (Orthogen, Springfield, IL, USA).
Preventive dentistry	NanoCare® Gold (Nano-Care, Saarwellingen, Germany).
Orthodontics	Ketac™ N100 Light Curing Nano-Ionomers (3M ESPE), Filtek Supreme Plus Universal (3M ESPE).
Prosthodontics	Nanotech elite H-D plus (Zhermack, Badia Polesine, Italy), GC OPTIGLAZE color® (GC).
Oral implantology	Nanotite™ Nano-coated implant (BIOMET 3i, Palm Beach Gardens, FL, USA).

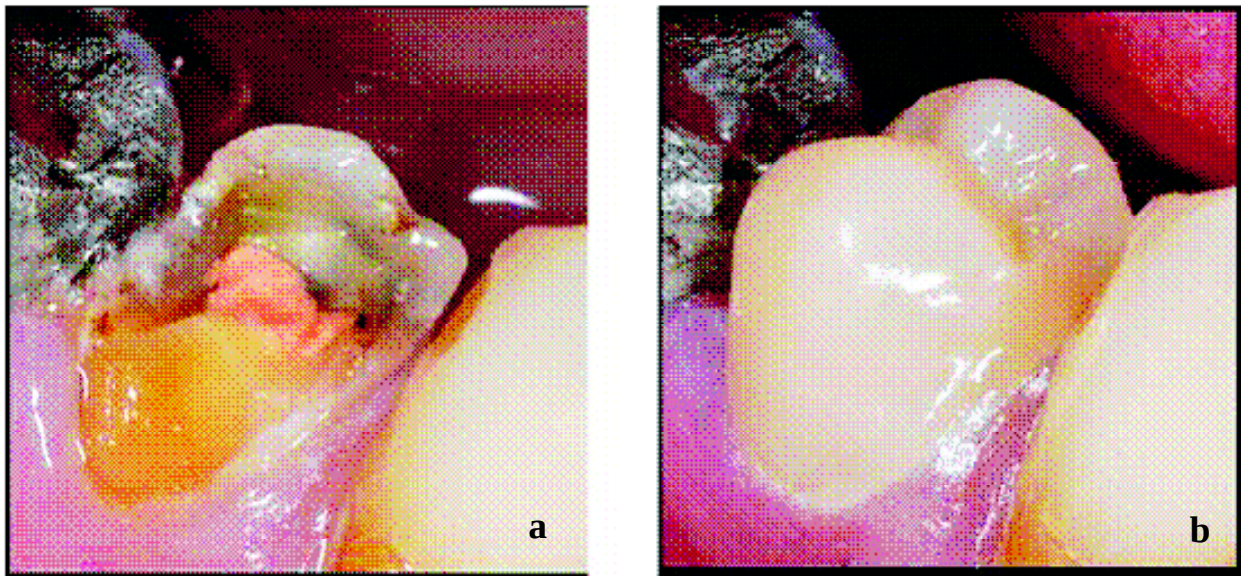

Fig. 1. Clinical applications of tooth colored nanocomposite restorative materials (**a**) Root treated and unrestored premolar tooth; (**b**) Crown build up with a post and core using a modern nanocomposite restorative material

In the process of evolution of dental composites, the alteration of filler size, shape, morphology and loading efficiency still remains a landmark. Various methods adapted to synthesize nanofillers are, flame pyrolysis, flame spray pyrolysis or sol-gel processes. Since the dimensions of these filler particles are below that of visible light, it is impossible for them to either scatter or absorb visible light. This phenomenon plays a key role in getting excellent aesthetic properties and can be used for anterior teeth restorations (Fig. 2 a,b,c).

Fig. 2. Aesthetic applications of resin nanocomposite restorative materials (**a**) Preoperative labial aspect of defective maxillary anterior segment with recurrent decay and discoloration; (**b**) Composite layering technique adapted to restore decayed tooth structure and midline; (**c**) Postoperative appearance of midline correction using a nanocomposite dental restorative material

CONCLUSION

Nanocomposite materials maintain its physical properties as well as wear resistance equivalent to different types of hybrid composites. It is used for dental restorative composites and it offers high translucency, polish retention and high polish. It is very much useful for on posterior andanterior restorative applications. The nanocomposite material for dental application has been performing a remarkable job for the past four decades. In recent times, a tremendous progress has been made in terms of mechanical performance with increase in flexural strength and fracture toughness for dental applications.

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