Nanomaterials for Preventive & Restorative Dentistry in Children

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Introduction:

Nano-dentistry is defined as" the science and technology of diagnosing, treating and preventing oral and dental diseases, relieving pain, preserving and improving dental health using nanostructured material."[1]There has been considerable research on nanomaterials in the past three decades, leading to a paradigm shift in the use of nanotechnology in different applications in the field of dentistry. While newer materials are being developed using nanotechnology, the basic requirements of a dental restorative material should not be forgotten. The newer nanomaterials should have physical properties that correspond to the dental hard tissues and optical properties like dental tissues while being easily distinguishable from them radiographically. Newer nanomaterials should be able to bond with dental tissues and be easy to manipulate. Most importantly these materials should be biocompatible.[2]

This review article is confined only to the materials that are being developed and used in the field of restorative dentistry.

Currently a wide range of restorative materials are being manufactured using nanotechnology:[1,3-15]

1. Nano-composites,
2. Nano glass-ionomers,
3. Nano structured ceramics,
4. Nano-adhesives,
5. Endodontic sealers and,
6. Tooth remineralization materials.

Nano-composites:

Development of resin based composite has been a great innovation in the field of restorative dentistry. Composite resins were introduced in dentistry to overcome the drawbacks of the acrylic resins which were used as tooth coloured restorative materials.[16]

The physical, mechanical and aesthetic properties of composites and their clinical behavior depend on their structure. Dental composites are composed of three different materials namely the organic matrix, the in organic matrix consisting of the filler or disperse phase and an organo-silane, which is a coupling agent that bonds the filler to the organic resin.[16]When inorganic phases in the composite become nano-sized or atleast one of the phase shows dimensions in nanometer range they are called nanocomposites.[17] Nanocomposites consist of two types of filler particles i.eNanomeric (NM) and Nanoclusters (NCs). NM particles are mono-dispersed, non-aggregated and non-agglomerated silica nanoparticles with average particle size of 5-75 nm.[18] There are 2 types of nanocluster fillers. The first type consists of zirconia-silica particles synthesized from a colloidal solution of a zirconyl salt and silica. The primary particle size of this NC filler ranges from 2-20 nm while the spheroidal agglomerated particles have a broad sized distribution with an average particle size of 0.6 µm. The second type of nanocluster filler which is synthesized from 75 nm primary particles of silica has a broad secondary particle size distribution with a 0.6 µm average.[19]

Extremely small filler particles have dimensions below the wavelength of visible light (0.4 - 0.8 µm) hence are unable to scatter or absorb visible light. [19] Thus, nanofillers are usually invisible and render the advantage of optical property.[19]The colour of the material appears more physiologic as they cease to reflect light. Due to the small particle sizes of nanofillers an overall increased filler level is seen since more filler can be accommodated for particle packing.[20] Theoretically, with the use of nanofillers, filler levels could be as much as 90 - 95% by weight.[20] However, the increase in nanofillers also increases the surface area of the filler particles which in turn limits the total amount of filler content. This could be attributed to the wettability of the fillers. Since polymerization shrinkage is mainly because of the resin matrix, the increase in filler level results in a lower amount of resin in nano-composites. This significantly reduces polymerization shrinkage and dramatically improves its physical properties. Thus, increasing the filler fraction in a Nano-composite is a good strategy for improved mechanical performance. A higher filler fraction helps in increasing the fracture toughness because they decrease the volume of the weak polymer matrix and act as toughening sources besides increasing the elastic modulus.

Nanohybrid composites are composed of 3 different types of filler components namely non-agglomerated discrete silica nanoparticles, pre-polymerized fillers (PPF) and barium glass fillers.[21]The non-agglomerated "discrete" silica nanoparticles are spheroidal and measure about 20 nm in size. The pre-polymerized fillers are about 30-50 µm in size, while the barium glass filler comes with an average particle size of 0.4 µm. This combination of three fillers allows for increased filler loading of 84% by weight and 69% by volume.[21]Thes pheroidal shape of the nanoparticles provides for its smooth and rounded edges there by distributing stress more uniformly throughout the composite resin.[22]

Another commercially available nano composite is a ceramic based nano-composite. It contains glass fillers (1.1 - 1.5 µm) but, differs from the conventional hybrid omposites in two main features. A methacrylate-modifiedsilicon-dioxide-containing nanofiller (10 nm) with a filler concentration of 76% by weight and 57% by volume substitutes for the micro-filler that are typically used in hybridcomposites (agglomerates of silicon dioxide particles). Most of the conventional resin matrix is also replaced by a matrix that is full of highly dispersed methacrylate-modified polysiloxane particles (2 - 3 nm). These nanoceramic particles are organic–inorganic hybrid particles. Both the nanoceramic particles and nano fillers have methacrylate groups available for polymerization.[21]

Nano Glass-Ionomer Cement (GIC):

The invention of the original glass-ionomer cement by Wilson and Kent in 1969 and its subsequent development by McLean and Wilson in the 1970s resulted in a translucent material that has long term adhesion to tooth structure and cariostatic properties.[23,24]Due to these properties glass-ionomer cements could be used in a wide range of clinical applications.[25] Despite favourable properties, their use as a restorative material in stress bearing areas is limited by their poor mechanical properties.[26,27] The incorporation of nanoparticles as fillers into the powder of glass-ionomers improved the mechanical properties by reinforcing its matrix.[28] Incorporation of nanofillers in resin-modified glass-ionomer resulted in improved resistance to bio mechanical degradation.[29] Addition of nano-fluorapatite to resin modified glass-ionomer cement resulted in improved fluoride release while maintaining clinically sufficient bond strengths.[30]Nano-hydro-xyapatite addition to conventional glass-ionomer resulted in improved mechanical properties, reduced microleakage and deposition of new hydroxyapatite crystals at tooth-restoration interface.[31]This could possibly result in better seal between the tooth and the restoration. Nano-hydroxyapatite added glass ionomer cement exhibited increased resistance to demineralization compared to micro-hydroxy apatite added glass ionomer cement.[32] Although glass-ionomer is cariostatic due to fluoride release, addition of silver nano-particles to resin modified glass ionomer enhanced its bactericidal activity.[33]The use of nano-technology to modify glass-ionomers can enhance its properties, resulting in a highly desirable material for clinical use.

Nano-structured Ceramics:

The need for tough, strong and stable bioinert ceramics should be met by either Nano-structured, alumina and zirconia based ceramics and composites or by non-oxide ceramics. Nano-structured calcium phosphate ceramics and porous bioactive glasses, possibly combined with an organic phase should present the desired properties for bone substitution and tissue engineering.[33]

The organically modified ceramic nano-particles comprise a polysiloxane backbone. These Nano-Ceramic particles can be best described as inorganic-organic hybrid particles where the inorganic part consists of siloxane and the methacrylic organic part blends all the particles with resin matrix. The good resistance to microcrack propagation might be related to the strengthening effect of the nano-ceramic particles. Propagating cracks are either more often reflected or absorbed by the nanoceramic particles.[14]

Nano Bond (Bonding agents):

The new bonding agents are prepared from nano solutions which contain homogenous nanoparticles dispersed in the solution. Silica nano fillers are stable and do not cluster in the solution so provide the superior bond strength values. Nano interaction zone (NIZ - <300 nm) with minimal decalcification and almost no exposure to collagen fibers produce an insoluble calcium compound for a better bond less likely to deteriorate from enzymes contained in the mouth.[15]

Nano Solutions:

These solutions have homogenously dispersed nanoparticles that extend their use in bonding agents. The new generation of bonding agents are one-step application. The homo-geneously dispersed nanofillers provide the maximum bond strength and prevent particle settling.[12]

Coating Agents:

These agents contain light activated nanosized fillers which can be used as coating over the composite, glass inomer cements ,jacket crowns and veneers. Incorporation of nanofillers provide superb polish on the restorations which prevents staining, increases abrasion and wear resistance.[19]

Toxicity of Nanomaterials in Dentistry:

Nanomaterials and their biological effects may lie in the interaction mechanisms between living things and the environment, as they are similar in size to DNA molecules, proteins, viruses, and biological molecules.[29] These particles show interactions in the cellular, subcellular, and protein levels by mechanisms of oxidative stress and inflammation. On exposure nanomaterials are known to readily travel throughout the body. The particles deposit in target organs, penetrate cell membranes, lodge in the mitochondria, and trigger injurious responses. Many studies in recent years have demonstrated that nanomaterials can accumulate in various organs in our body. Though the brain is an exception as the blood–brain barrier (BBB) can prevent the majority of substances from entering the brain, few studies have shown cerebral damage due to nanoparticle toxicity. Assessment of nanoparticle induced toxicity requires novel techniques, tools, assays and approaches for their assessment.[30,31,32] In restorative dentistry, most of the nanomaterials were directly applied in the oral cavity allowing easy entry into the bloodstream (or lymph fluid) via absorption through oral mucosa or through the digestive tract on swallowing. Further research needs to be carried out to study the potential neurotoxicity these materials could induce.

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