

NANOTECHNOLOGY IN RESTORATIVE DENTISTRY- CONCEPTS AND EMERGING TRENDS

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ABSTRACT

Nanodentistry is a novel multidisciplinary science with the potential to transform dental practice and advances all aspects of dental therapeutics and cosmetic beyond traditional oral care procedures. Here an outlook on current applications of nanotechnology alongside proposed applications in the future is presented. Continual refinement of traditional methods, development of advanced restorative materials will continue to improve dental care. Increasingly preventive approaches using Nanomaterials will reduce the need for curative or restorative interventions. This article aims to provide a glimpse of nanodental applications alongside proposed applications in the future.

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INTRODUCTION

Tooth structure is lost due to dental caries, mechanical wear and tear or due to the effect of various chemicals consumed in daily life.

With an increase in the average life span of a human being, there is an ever-increasing demand for materials that can replace the lost tooth structure in a manner which can mimic

the dental hard tissues. Dental tissues consist of enamel, dentin and cementum. These tissues are composed of microscale structural units and their mechanical properties such as hardness and elastic modulus vary from each other. Nature has arranged complex biomaterials in the best possible manner and it is still a challenge to replicate the biological and physical properties to get ideal replacement structures. Replacement of lost tooth structure is required primarily to restore the functions like chewing, phonetics and esthetics in most of the cases. Hence, synthetic biomaterials of a similar nature are required to closely match the properties of natural dental tissues for an effective replacement of the lost dental structure. There are four main types of materials i.e. metals, polymers, ceramics and composites for practical applications in the field of health^[1]. But no material can be intelligent enough to respond to external stimuli and react like nature made tissues.^[2]

With the advancement of Nanomedicine, dentistry also started evolving in the field of Nanotechnology from year 2000, producing nanomaterials resembling near perfect tooth structure. Dental materials such as cement, composites, ceramics, denture base resins, and other materials are used in restorative and rehabilitative dental procedures. Nanotechnologies have been applied for the

manufacturing of different types of restorative materials like dental composites (nanocomposites), glass-ionomer cement (nano-ionomers), endodontic sealers and tooth regeneration materials. The properties of nanostructured materials are completely controlled by their synthesis method of processing and their chemistry.

MATERIALS & METHODOLOGY:

To explore the various approaches and materials used involving the concept of nanotechnology, the following strategy was adopted:

Research question: “What are the approaches and/or materials involving Nanotechnology used as Restorative materials in Dentistry?”

Search strategy: The PubMed/Medline were searched to identify relevant studies published from 1981 to November 2018. The search strategy employed the following keywords related to use of Nanostructured materials: “Nanodentistry” or “Nanotechnology” or “Nanocomposites” or “Nano-ionomers” or “Nanodrugs” or “Nanomaterials”.

Inclusion and exclusion criteria: The selection was limited to clinical trials and in vitro studies published in English. Studies that explored the use of Nanotechnology as Restorative materials were included. Review

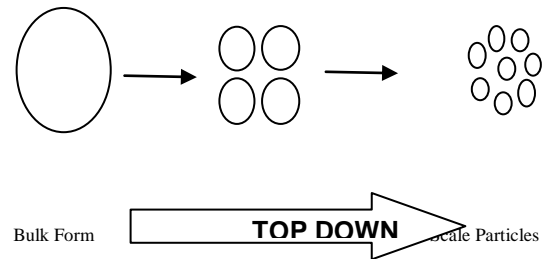
articles and case reports were excluded. Studies which only explored the use of Nanomaterials without evidence were also excluded.

Data Extraction: Two independent reviewers identified studies using a two-stage screening process. In the first stage, titles and abstracts were screened to select relevant articles that met the inclusion/exclusion criteria. In the second stage, the reviewers independently verified study eligibility after reading full texts. Data extraction and quality assessment were performed for included studies. Disagreements about the inclusion or exclusion of a study were resolved by consensus.

Analysis of these studies addressed: (1) Nanomaterials used for Restorations (2) Efficacy and clinical safety issues associated with different Nanomaterials (3) Study designs.

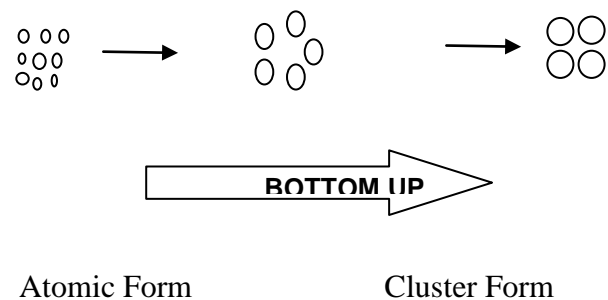
Approaches in Nanodentistry: There are two key approaches in nanotechnology i.e top down and bottom up. It has been used for creating smaller or better materials and use of smaller constituent into more complex assembling. The top-down approach is based on solid-state processing of materials. Milling, machining and lithography are typical examples of the top-down approach which is

used to create micro, nano-scale functional structures to be used in the field of health care.



In the field of dentistry nanocomposites, nano Glass Ionomer cement, nano impression material, nanoparticle coated dental implants, nano-based bone replacement cement, nanoencapsulation, nanoneedles etc are some of the examples of the application of top-down approach of nanotechnology.

The bottom-up approach is based on manufacturing nanostructures by building them up from atomic, molecular components. This begins by designing and synthesizing custom-made molecules that have the ability to self-assemble or self-organize into higher order structures.



In dentistry, this approach of nanotechnology has been adopted in the production of local anesthetics, toothpaste for hypersensitivity, tooth regeneration, nanodiagnosis, endodontic regeneration, etc.

Restorative Materials in Dentistry:

Depending upon the way the materials are placed on the tooth restorative materials can be classified as direct restorative materials and indirect restorative materials. With the evolution of material science and technology, dental materials have continuously been evolved to serve better functionally, esthetically for a longer duration than before. The materials in which Nanotechnology have been used is discussed below.

I. Glass Ionomer Cement (GIC):

GIC is a tooth-coloured restorative material that bonds chemically to the dental hard tissues. It is derived from aqueous polyalkenoic acid such as polyacrylic acid and a glass component like fluoroaluminosilicate. It is usually supplied in powder and liquid form present in two separate bottles. When the powder and liquid are mixed together, an acid-base reaction occurs resulting in a polyalkenoate salt which begins to precipitate followed by gelation and proceeds until the cement sets hard.^[3,4] Glass ionomers are used

widely in dentistry in many clinical situations due to its excellent properties like chemical bonding to the tooth structure, biocompatibility and cariostatic properties like fluoride release. At the same time, it has got limited aesthetics and weaker bond strength. Nanotechnology has been applied for improving the physical, chemical and mechanical properties of GIC. The addition of nanoparticles resulted in the aesthetic improvement of the final restoration without compromising the cariostatic properties of the material. Modification of conventional GICs with nano-glass particles decrease the setting time, enhance the compression strength and elastic modulus^[5]. The reduced setting time of GIC enhances the ease of handling and manipulation of the material during the clinical procedure. Different types of nanoparticles e.g Hydroxy Apatite, Fluoro Hydroxy Apatite, FluoroAlumino Silicate, Titanium oxide, Zirconium Oxide have been incorporated to the glass powder component. Hydroxyapatite and fluoro hydroxyapatite crystals have a similar composition to bone and enamel. It has been observed that addition of nano-hydroxyapatite or nano fluoro apatite crystals increases the compressive and tensile strength of GIC^[6], which may be due to ionic interaction between the apatite crystals and calcium ion of the tooth^[7]. Studies have also

opined that reduction in the size leads to infiltration of the crystals into the demineralized areas of the enamel and dentin pores which may enhance bonding at the tooth, GIC interface^[8].

II. Resin modified GIC(RMGIC):

Resin-modified GIC has a polymer resin component which usually sets by a self-activated or light-activated polymerization reaction. This hybrid material has got improved mechanical properties likethe composite and cariostatic effect of GIC^[9]. RMGIC can bond to the tooth structure by two mechanisms i.e micromechanical bonding and chemical bonding. The resin materialbond to dentine through infiltration of the collagen network exposed by using 10% polyacrylic acid whereas the ionic interaction of carboxyl groups from the acid with calcium ions of remaining Hydroxy Apatite crystals leads to chemical bonding^[10]. In case RMGICs with nanoparticles the ionic bonding is more compared to micromechanical bonding^[11] but the overall bond strength is similar in both types of the material. Conventional RMGIC exhibited relatively better flexural strength and fatigue limit than nanoRMGIC due to chemical bonding between the glass particle and the resin phase^[12].GICs with a smaller filler size distribution exhibited a smoother

surface and are also easier to polish and finish^[13]. The surface roughness and hardness exhibited by the RMGIC is significantly lower compared to the composites^[14]. The fluoride releasing effect of RMGIC is lesser compared to conventional GIC^[15].

III.Nanocomposites:

The perception towards esthetics is changing rapidly and there is a great demand for a tooth-colored restorative material which led to the development of materials like composites that are aesthetically more pleasing. Composites are based on organic polymer matrix known as Bisphenol A Glycidyl Dimethacrylate (Bis-GMA). The basic mechanism of maneuvering the material is by initiating the polymerization of the Bis-GMA. Bis GMA itself becomes very viscous due to hydrogen bonding of the hydroxyl group which makes it difficult to handle without altering the composition. Organic polymers like tri-ethylene glycol di-methacrylate (TEGDMA)urethanedi-methacrylate(UDMA), ethoxylated Bisphenol-A-dimethacrylate (Bis-EMA)have been added to Bis-GMA to improve its handling properties. The nanocomposites have a polish ability and esthetics comparable to the microfill material but have a wear resistance comparable to the hybrid. Nanotechnology has been used for

producing nanofiller particles, which are added either alone or as nanoclusters into composite resins. Nano-sized filler particles are used in nano composites which are more compatible, and a greater amount of filler can be added to them in matrix. Nanoparticles allow the production of composites with a smooth surface after the polishing process and confer superior esthetic features to the material. Composite resins containing such particles have higher strength, greater abrasion resistance, and smoother surface compared to hybrid composites. Depending on the size and type of particles there can be two types of nanofiller particles i.e. Nanomeric and Nanoclusters particles. Nanomeric particles range between 5-75nm and are monodisperse, non-aggregated silica nanoparticles^[16,17]. These materials are treated with 3-methacryloxypropyltrimethoxysilane (MPTS – coupling agent) to prevent any agglomeration or aggregation and allow chemical bonding of the nanomeric filler of the resin, matrix during curing^[18]. The particle size of the nanocluster filler ranges from 2 to 20 nm^[18]. The aesthetic properties of nanocomposites do not match the properties of ceramic. But the main advantage of using the nanocomposite is it can be used on patients with immediate result in one sitting and at a lesser cost to the patient. Teeth receiving composite restoration need a

conservative preparation compared to ceramic or metal-ceramic restorations, preserving more natural tooth structure. Hence, with evolving technology in shade selection and appropriate layering technique, comparable esthetics and longevity can be achieved in a direct restoration compared to the ceramic-based restoration.

IV. Dental Adhesion (Bonding agents):

Bonding agents of newer generation are prepared in the form of a solution in which homogenous nanoparticles are dispersed. Silica nanofillers are stable and do not cluster in the solution which provides the superior bond strength values. Addition of nanofillers to the adhesive has demonstrated increased bond strength to the dentin surface. Nano Interaction Zone (NIZ <300 nm) with minimal decalcification and almost no exposure to collagen fibers producing an insoluble calcium compound for a better bond less likely to deteriorate from enzymes contained in the mouth. It has been suggested that incorporation of fillers into dental adhesives would enhance the mechanical properties of the adhesive layer.^[19]

V. Pit & Fissure Sealant:

Dental sealants are clear or opaque plastic materials applied to the pit-and-fissures

(developmental irregularities) on the occlusal surfaces of teeth to prevent dental caries. Sealants prevent initiation and arrest progression of dental caries by providing a physical barrier against microorganisms and food particles that collect in pits and fissures. The inclusion of nanoparticles to pit and fissure sealants has shown to reduce demineralization and increase remineralization.^[20]

VI. Dental Amalgam:

Dental amalgam is a restorative material in dentistry which is in use for the last two centuries. It is a metallic alloy formed by the reaction of mercury with a powder alloy containing silver (40–70%), tin (15–30%) and copper (10–30%). It has got very good mechanical property and biocompatibility for which it has been in use since long in dentistry. Corrosion of dental amalgam is one of the disadvantages of the material which reduces its mechanical and esthetic properties. To overcome corrosion of dental amalgam different attempts have been made. Addition of Silver-Copper nanoparticles (Ag-Cu) is one of the methods to improve corrosion resistance^[21]. Nanoparticles of TiO₂ have also been added to the amalgam to increase the compressive strength, antibacterial property and corrosion

resistance^[22]. Studies have also been reported regarding the addition of nanoparticles of zinc oxide and aluminum oxide to dental amalgam alloy there is an increase in the compressive strength of the material.^[23]

VII. Denture Base Resins:

Removable complete or partial dentures are one of the mainstays in prosthodontics to restore the functionality in cases of complete or partial loss of teeth. Denture base resins which are basically polymethyl methacrylate (PMMA) are used in the fabrication of denture. Nanoparticles of PMMA are added to the denture base resin material for increasing the viscoelastic property of resins^[24]. Denture users many times suffer from denture stomatitis due to adherence of biofilm formed by the fungus *Candida albicans* to the denture surface. Addition of nanoparticles of silver, platinum, titanium to the denture base material has shown to be an effective antimicrobial agent. Studies have also shown that the addition of nanoparticles of titanium, iron, silver leads to an increase in hydrophobicity of the denture and reduces biomolecular adherence.^[25,26]

VIII. Dental ceramics:

Ceramics have been used in dentistry to restore the tooth structure fully or partially in

the form of crown, inlay, on lay etc. The main advantage of ceramic material is superior esthetics which gives the artificial restoration a natural look of the tooth. Mainly it is used in two forms i.e. aluminum and zirconia ceramics. The biggest drawback of ceramic in dental use is crisp or a tendency to develop crack^[27]. Nanotechnology has been used in ceramic material to alter the microstructure for making it more resistant to develop a crack. Nanoceramics have super plasticity, showing good toughness and ductility compared to conventional ceramics. Nanoceramics have superior mechanical properties, such as strength and hardness which can be four to five times higher than those of the traditional materials.^[28]

CONCLUSION:

Nanodentistry will make possible the maintenance of comprehensive oral health by involving the use of nanomaterials, biotechnology and dental nanorobotics. Nanotechnological developments are expected to accelerate significantly through new governmental and private sector initiatives. The integration of micro- and nanotechnologies will continue to revolutionize the diagnosis and treatment of oral diseases and will provide us with novel platforms to study diseases at the tissue,

cellular, and even molecular levels. Nanodentistry is foreseen to change Oral health care in a fundamental way and is largely in conceptual stage, but we can sense that soon products out of it will be present in usable form everywhere.

Conflict of Interest Statement-

There is no conflict of interest.

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