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Nanobiomaterials in Preventive AND Restorative Dentistry - A Review

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Abstract:

In our daily lives, nanotechnology is extensively used, especially in medicine. It is simple to examine and modify the atoms, chemical bonds, and molecules that are present between different compounds using nanotechnology. Dentistry's major concerns include preventing tooth decay and treating lesions and cavities. In many cosmetic products that maintain oral health, nano biomaterials for application have recently been developed using biomimetic methods. According to predictions, nanotechnology will eventually make it possible to rebuild and repair dental hard tissues. Via antibacterial, re mineralizing, and anti-inflammatory actions, they guard against tooth cavities. Only a few materials that were thoroughly explored are included in this study, despite the fact that numerous nanoparticles have been investigated for their function in preventing dental caries.

1. Introduction

Richard Feynman pioneered the application of nanote chnology to all aspects of life, including medicine and dentistry. Nanomaterials for dental applications are e merging as a promising new trend. [1]. Disease or dec ay cause tooth structure loss, which affects eating patt erns and, to some extent, speech. Microparticles make up our teeth and other structures. Hydroxyapatite crys tals make up the enamel, dentin, and pulp of the tooth. Nanomaterials are more effective at replacing missin g tooth structures. (2,3). Nanotechnology has played a significant role in preventive and restorative dentistry. Nanoparticles in composites have been widely used and are also being used in prosthetic treatments such as all-ceramic restoration [4]. It also helps to prevent oral diseases, particularly dental caries and periodontal disease [5]. Antimicrobial nanoparticles, for example, nanocomposites and nano glass ionomers, are utilized in restorative composites to prevent dental caries. We can improve biocompatibility by incorporating nanomaterials into pre-existing dental substances [6]. The goal of using nanomaterials in dental composites to improve their strength, resistance to wear, and hardness. The primary goal of this review paper is to highlight the significance of nano biomaterials and their role in dentistry, as well as advancements in preventive, diagnostic, and restorative dentistry. To do so, we must first comprehend various nanoparticles and their properties.

DENTAL CARIES

The most prevalent destructive disease in the oral cavity that affects tooth structures is the dental caries (4). Treatment of caries includes both conservative and

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preventive approaches aimed at interpersonal risk assessment through detection of the disease earlier and attempts to reverse or stop caries progression and preserving remaining tooth structure. Many patients are still suffered by tooth decay even though efforts and advances made in management of caries (8). Among calcified tissues of mammal, the outermost layer enamel is one unique in that it consists of a calcium-deficient hydroxy apatite carbonate by volume 80-90%. Bone and dentin are some of the calcified tissues that contain significantly minimal amounts of inorganic materials . Nevertheless, enamel and dentin, like other commonly mineralized tissues, include hierarchical structures and surface characteristics at the nanoscale (20). Due of its similar morphology, crystalline structure, and chemical composition to enamel crystals, hydroxyapatite crystals can be utilised to stop enamel crystals from disappearing. (9)

GINGIVAL AND PERIODONTAL DISEASES

Gingivitis is the most prevalent periodontal disease in humans, with a frequency of up to 90% in the adult population. (10) For instance, employing toothpastes and mouthwash preparations containing nanoparticles is a successful method for mineralizing tooth enamel and dentine while simultaneously preventing plaque buildup and microorganism growth. In instance, studies have demonstrated that adding nano-hydroxyapatite to toothpaste can improve the hardness of dental enamel and dentine while also enhancing remineralization [10.,21,22] Drug molecules can be enclosed in nanoparticles to be delivered to specific regions of the body afflicted by periodontal disease. (14)

ENDODONTIC MANAGEMENT

Even when the cause is recognized, pulpal exposure is difficult to treat. Endodontic therapy's primary objectives are to treat microbial infections and promote periapical tissue repair. Due to its extensive antigerm and biofilm reactivity and biocompatibility, this sector of technology can profit from the development of nanotechnology. (9)

2. Properties of Nanomaterials

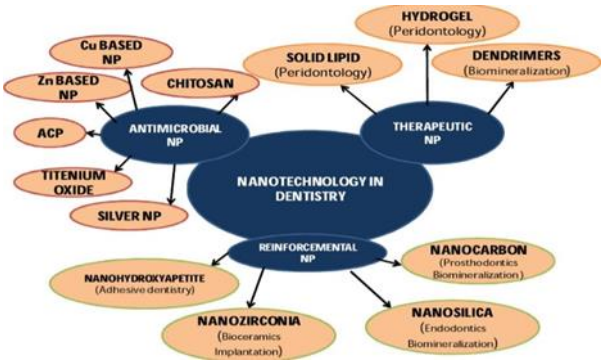

Figure1: Nanobiomaterials used in dentistry

Biological property:

1) Increased cellular uptake
2) Enhanced permeability and retention effect
3) Targeted delivery
4) Development of theragnostic potential

Mechanical properties:

1) Improved strength hardness
2) Altered compressive, shear properties
3) Molecular nanomaterials structural variations

Chemical properties:

1) Large surface area: volume ratio
2) Variation in surface and interfacial atomic bonding
3) Surface functionalization

NANOBIOMATERIALS IN PREVENTIVE DENTISTRY

The common oral disease is the dental caries that are complicated in nature.

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Oral cavity diseases are complicated in their nature. T he prevention of dental caries is the primary strategy of dental and oral health organizations. There may be erosion, demineralization and pellicle formation, we can prevent and remineralize lost enamel and dentin(10). Hydroxyapaptite nanoparticles

incorporated dentifrices are extensively used to reduce biofilm and remineralize enamel lesions. Dental composite containing Amorphous calcium phosphate nanoparticles (ACPNPs) can also help with enamel and dentin remineralisation.(46)The incorporation of nano CaPO4 particles in resin-bonded composites, resulting in increased stress-bearing ability and also increased ion release that may inhibit dental caries. Further research in prevention, using anhydrous dicalcium phosphate incorporated with nanosilica infused whiskers discovered that it increased the resin bonded composites strength by up to three times when releasing CaPO4.(49)The effects of apatite nanoparticles are determined by their size for biofilm management, which is considered more effective than traditional approaches. To achieve this micrometer-sized hydroxyapatite used in toothpaste(3).

CARBON NANOTUBES

Carbon nanotubes composed of graphene nano-rods or sheets with carbon atoms arranged in honeycomb lattice .They are twisted into cylinder using empty molds , resulting in 0.7 nm size nanotubes for a single-layer carbon nanotube and for multilayered carbon nanotubes the size is 100nm , which range from a few micrometres to many millimetres. (7) The incorporation of CNTs into the polymer can result in better mechanical properties than conventional glass or carbon fibre composite with decreased optical properties of the polymer which is unfilled .. It also add the additional functionality of enhanced conductivity, which might useful.(7,8)The use of Single Walled CNT in dental resins as a filler has given acceptable results with high flexural strength. Carbon nanotubes also used as a coating material on the suface of titanium implants. Previous research have used Carbon nanotubes to deliver anticancer drugs and have revealed remarkable results in in -vitro and in vivo tests with epidermal growth factor (EGF).(41)

CALCIUM CARBONATE NANOPARTICLES

Nanoparticles made of calcium carbonate are well retained on the tooth surface. They act as a channel for the slow and steady release of higher amounts of ca ions into the oral cavity through saliva and dental plaque around them.Moreover, CC nanoparticles may increase
the pH of the surrounding fluid. Accordingly, when in corporated
to tooth dentifrice, CC nanoparticles are successful in remineralizing developing enamel defects.(8,10)

AMORPHOUS CALCIUM PHOSPHATE

Nanosized amorphous calcium phosphate particle resist dental caries by release of increase levels of calcium and phosphate ions and also transforming acidic environment to alkaline state.It has better osteo conduction than hydroxyapatite and better biodegradability without cyto toxicity. It has ability to rapidly hydrolyze to form apatite crystals(46).Casein phosphopeptide-Amorphous calcium phosphate inhibit demineralization and favoring remineralization by providing bioavailable calcium and phosphate ions(47). The use of silver nanoparticles and amorphous calcium phosphate nanoparticles in adhesives demonstrated a good antibacterial effect and increased the material's bond strength (48).

NANOCOMPOSITES

They are composite resins that have nano-agglomerated nanoparticles evenly distributed throughout them. The most popular filler was alumina and silica powder in a 1:4 ratio, with an average 80nm particle size (6). By the inclusion of aggregated Zirconia or Silica Nanoclusters into the composite resin with 20 nm particle size laid a commercial milestone .Fluoride containing nanoparticles with cationic quaternary ammonium group sustained fluoride release with long term antibacterial activity (37) . There are many advancements made in composites.The following nanoparticles are incorporated in composites to make it stronger enough to increase its life time .

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Table 1: classification of nanobiomaterials according to their properties .

Antimicrobial Nano particles	**Remineralizing nanoparticles**	**Anti inflammatory Nanoparticles**
Silver oxide	Calcium fluoride nanoparticles	Silver oxide nanoparticles
Gold nanoparticles	Calcium phosphate based nanomaterials	Gold nanoparticles
Titanium oxide	Nano HAP particles	Titanium nanoparticles
Zinc oxide	ACP nanoparticles	Zinc nanoparticles
Chlorhexidine	Nano Bioactive glass materials	
Chitosan		

NANO- GLASS IONOMER CEMENT

Wilson and Kent introduced glass ionomer cements in the 1970s. (11) The liquid of GIC was supplied as a viscous fluid and consisted of acrylic acid and itaconic acid or maleic acid co polymer . The powder of GIC was primarily made of fluoro-alumino-silicate glass particles (12) Because of its outstanding qualities, including chemical attachment to enamel and dentin , biocompatibility and fluoride release, GIC are employed extensively. Even though , this category of materials has a number of drawbacks, including poor aesthetics, a delayed setting time, decreased mechanical capabilities, and reduced bond strength. (13) GICs have low strength and poor fracture toughness, hence research has concentrated on integrating other types of particles or fibres as a strategy to improve these properties incorporation of Silica – Zirconia nanofillers and nanoclusters and silica -zirconia nano filler resin modified Glass ionomer is the recent innovation .(32) .The inclusion of metal oxide nanoparticles such as Al2O3 ,TiO2,ZrO2 has increased the compressive strength and the addition of nanoparticles is beneficial as it leads to reduction in the microscopic voids in set glass ionomer cement and incorporation of silver and copper particles enhanced the antimicrobial efficacy .(24,27,31)

NANO-PIT AND FISSURE SEALANTS

When compared to conventional sealant ,addition of silver nanoparticles in Pit and fissure sealant has significantly reduced the demineralization and increased remineralization .With Nano CaF2 and dimethylaminohexadecylmethacrylate in bioactive fluoride releasing and antibacterial sealant inhibit caries and promoting remineralization of enamel and dentin .The hardness is higher than the normal sealer.(33).Nano silver fluoride is effective in arresting active dentine caries and compared to silver diamine fluoride it does not stain the teeth .(34)

ZINC OXIDE NANOPARTICLES

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Because it may be played a role in a variety dental and medical applications, zinc oxide nanoparticle is one of the topic of research that had received the most attention. The second most prevalent metal oxide after iron, zinc oxide nanoparticle is also the cheapest, safest, and most straightforward to produce. (26). According to SEM data,average sized (88) rod-shaped nanoparticle were seen (27) ZnO NPs are thought to be more biocompatible than TiO2 and have a strong photocatalytic activity. (28) In a study by Wang et al., it was discovered that S. mutans' growth and adhesion were inhibited when zinc oxide NPs were added to dental resin composites. Because of their bactericidal properties, zinc oxide NPs in oral cosmetic products such as toothpaste and mouthwash can help fight gingivitis. Toothpaste with ingredient ZnO have also been shown to provide a positive effect on dentin by reducing demineralization in an extracted tooth.(50).

SILVER NANOPARTICLES

Schwase et al. created a formulation of silver (NP AgNP) as a focused application for cleaning carious dentine. (7) Antimicrobial drugs with a broad spectrum and no resistance to silver nanoparticles can be utilised to prevent tooth decay. Due to the particles' high surface area, they adhere to the outer cell membrane of bacteria and change their permeability and cell structure (15).Silver NPs can be used as an irrigating solution, a root canalsealer , and a chelating compound. They have a good effect against E. faecalis, are biocompatible, have a lower cytotoxicity, and can be used alone or in combination with other agents(16).Substances that pass through microbial membranes also release silver ions, which interfere with protein synthesis and deoxyribonucleic acid replication. (23)

GOLD NANOPARTICLES

Because of its unique properties and multiple functionalities, gold nanoparticles (AuNPs) were widely used in bio nano technology. The simplicity with which gold nanoparticles can be functionalized made it a versatile platform to nano-biological assemblies having oligonucleotides and proteins. Spherical AuNPs have advantageous properties ,some of them are size-related and shape-related optoelectronic properties, a high surface-volume ratio, good biocompatibility, and low cytotoxicity.(30) In recent research studies, AuNPs have been employed as a nanodrug delivery system for curing and detecting oral cancers. Heo et al used AuNPs as osteo inductive agents to immobilize the titanium surfaces of dental implants. AuNPs nanoparticles on implant surfaces acted as osteo inductive agents, stimulating bone growth and preserving developing bone formation around dental implants.(41)

COPPER NANOPARTICLES

The popular element among medical and dental research is copper because of its antimicrobial properties and minimal toxicity .According to some studies, copper incorporated restorative cements reduces microorganism progression and viability while improving the bond between tooth and cement .multiple in vitro researches revealed that copper infused cements had compressive strength, decreased solubility, and antimicrobial activity, and they were recommended to utilize as a cariostatic lining beneath a less soluble restorative material.(43)The mechanical strength and toughness of photopolymerized copper(I)-catalyzed azide alkyne cycloaddition composites were demonstrated. Furthermore, they reversed shrinkage stress and produced a minor exothermic reaction.(44).Copper Nanoparticles exhibited antibacterial effect against P.gingivalis and A.actinomycetemcomitans to prevent plaque accumulation and progression of periodontal problems.(45).

HYDROXYAPATITE NANOPARTICLES

Dentin hypersensitivity is one of the main issues in the patients with periodontal diseases worry about when it comes to hydroxyapatite nanoparticles. Although these particles are very good at closing dentin tubules and preventing nerve revelation, hydroxy-apatite NPs were studied and clinically employed in toothpaste and mouthwash (17) The toughest dental tissue is enamel, which has crystals of fluorapatite and nanohydroxyapatite that are 25 nm dense , 40–120 nm wise , and 1000 nm in length ..

Nano-hydroxyapatite prophylactic action is based on three mechanisms: creating a protective coating of "liquid enamel" on the surface of teeth, sealing enamel destruction with small nanohydroxyapatite crystals with size of 20–80 nanometers, and quicken remineralization process.(19)

ZIRCONIUM OXIDE NANOPARTICLES

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The incorporation of ZrO2NP in GIC restorative cement has demonstrated improvements in the following areas such as compressive strength , crack reduction within the cement matrix. The use of Zirconium oxide nanoparticles in the production of dental prosthesis resulted in color stability, high strength and low thermal and electrical conductivity.(46)

TITANIUM DIOXIDE NANOPARTICLES

TiO2 particles employed in dental composites are used to mimic the opalescence of natural human teeth (24), and they have been proposed for use as reinforcing fillers in epoxy and dental resin composites (8).Compared to titanium alloy alone, TiO2 NTs on medical-grade titanium alloy offer a nanoscale surface that may support osseointegration of bone implants more effectively. However, TiO2 NTs do not naturally fight bacteria(25).

CHITOSON

A naturally occurring cationic polymer is thought to be effective for treating periodontal disease. It possessed bio adhesive and antibacterial qualities that could administer antiseptics like chlorhexidine, metronidazole, and nystatin as well as the palliative benefits of an occlusive dressing. Because of the presence of chitosan , carboxyl, and, (14) phosphate with its polycationic atomic structure, attaches to a negatively charged bacterial cell wall. Amino acid groups affect permeability of the membrane , bind to bacterial genome, and inhibit replication by doing these three things (18)

CHLORHEXIDINE

In pediatric Dentistry, in vital pulp therapy chlorhexidine gluconate loaded polymer nanofiber scaffold was used to manage caries exposed primary teeth.(39). The use of chlorhexidine-loaded CMC functionalized calcium phosphate nanoparticles to enhance oral hygiene and dental procedures in cases of gingivitis, many enamel and/or dentin erosion, dentin hypersensitivity, and marginal periodontitis is very promising. By biomimetic ability, chlorhexidine seal demineralized surface defects on crowns and roots and they are thought to combat biofilm formation for the remineralization of the tooth surface.(42)

RECENT ADVANCES

Dental implant system is one of the recent advances in the clinical prosthetic replacement therapy. Main features of a dental implant is its Surface topography (35).

The Biocompatibility, ability to osseointegration and functional retentivity are determined by the Host cellular response towards the dental implant .The topography of implants changes from micron scale to nanoscale level to enable these features .(38)

The dual action of nano-hydroxyapatite gel with ozone therapy treatment procedures has re-mineralized the initial approximal enamel and dentin lesions under the surface of premolars and molars, and must continued for a long time for the achievement of the effect of non-restorative treatment of caries.(40)To reduce periodontal pathogen ,silver nanoparticles are impregnated in tooth brushes.(50)

FUTURE PERSPECTIVE

The search for innovative dental products remains a vigorous scientific and commercial undertaking. No one product currently satisfies all of the requisite qualities and standards for preventative or restorative uses. Yet, developments in nanotechnology-based product development tactics are regarded to be the most effective way of improving patient outcomes. Numerous active research fields are being researched at the moment. Colloidal solutions made up of millions of active nanometer-scale robots, for example, might be delivered into the oral cavity to shut off certain neurons, reducing anxiety and increasing patient comfort during dental treatments (10). As a whole, Nanomaterials and nanotechnology that have recently been produced can assist shed light on the commercial applications of nanomaterials for the "true" regeneration of the periodontal apparatus, which comprises dentine, cementum, periodontal ligament, and bone. Nanotechnology, in general, should deliver solutions while remaining "green" in terms of health and safety. Green nanotechnology's potential societal costs, which include environmental, public, and occupational health issues, should be carefully considered. (41)

3. Conclusion

The significance and application of novel nanoparticles in preventive and restorative dentistry has been addressed in this review. The field of nanotechnology

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in dentistry has the increase ability l to revolutionize dentistry and also produce a variety of cutting-edge devices that can improve health care delivery. Smaller particle size for increased permeability into deeper lesions, large surface area for enhanced bioactivity, such as osteointegration, release of bioactive molecules in controlled level for reduced dosage and fewer side effects, and site-targeted delivery of growth factors for localized regenerative treatment are just a few of the benefits of using nanotechnology in dentistry.

Although there have been numerous studies that show nanoparticles to be beneficial, there has only been a small amount of practical use of these methods to prevent dental caries. There is a need for more research on viability, dosage and also approaches to the effectiveness of nanoparticles in an oral environment and low toxicity.

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