Review Article

Received : 05-01-15
Review completed : 12-02-15
Accepted : 25-03-15

NANOPARTICLES IN PROSTHODONTICS – BOON OR BANE

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ABSTRACT

Nanotechnology as we can concede is a concept that is on the rise at a great stride from coast to coast. Keeping in mind the increasing number of beneficiary fields, we can establish the fact that even the field of dentistry is not spared. An ample number of mechanical and physical properties of dental materials could be amended by smearing nanotechnology concept. This review article epitomizes a general gestalt of the uses of various nanoparticles in prosthodontics. In particular, suitable applications in acrylic resin, tissue conditioner, dental adhesives, dental composites, dental cements, dental porcelain, implants and maxillofacial prosthesis are appraised.

KEYWORDS: Resorbed maxilla; hypertrophic bone; implants

INTRODUCTION

Nanotechnology is the product of functional materials and structures in the nano scale, using various physical and chemical methods.[1] The particles of the length scale 1-100 nm are used. These are known as Nanoparticles. The US National Nanotechnology Initiative defines nanotechnology on three requirements, technology development at the atomic, molecular or macrolevel in the length scale of 1-100nm, creating and using structures, devices and system that have novel properties and functions because of their small or intermediate size and ability to control or manipulate on the atomic or molecular scale.[2] Over the past few decades, inorganic nanoparticles, whose structures exhibit significantly novel and improved physical, chemical, and biological properties, phenomena, and functionality due to their nanoscale size, have elicited much interest. Nanophasic and nanostructured materials are attracting a great deal of attention because of their potential for achieving specific processes and selectivity, especially in biological and pharmaceutical application.[3,4] Recent studies have demonstrated that specifically formulated metal oxide nanoparticles have good antimicrobial activity or mechanical strength.[5] Among inorganic antimicrobial agents, silver has been employed most extensively since ancient times to fight infections and control spoilage.[6-8] The use of such nanoparticles has become very popular in the design and development of many dental materials so as to improve their chemical, physical and mechanical properties. The purpose of this article is to review the various nanoparticles used in the manufacturing of acrylic resin, tissue conditioner, dental adhesives, dental composites, dental cements, dental porcelain, implants and maxillofacial prosthesis. The effects of nanoparticles on patient, dental staff and dental technician.

ACRYLIC RESIN

The importance of acrylic resins in dentistry is evident. They are widely used in making temporary prosthetic base materials, provisional prosthesis, dentures and orthodontic removable appliances such as retainers and functional appliances. These resins commonly consist of methacrylates, especially poly methyl methacrylate (PMMA), and additional copolymers.[9] However one of the major problems that patients and dentists commonly faced using these removable acrylic appliances is their potential for plaque accumulation due to surface porosities and food retentive configuration, which in turn increase bacterial activity of cariogenic oral flora.[10] The

consequences will be higher rate of decalcification and dental caries along with marginal gingivitis. In efforts to add antimicrobial activities to dental materials, some nanoparticles have been applied. Titanium dioxide nanoparticles have been used as additives to biomaterials in order to induce antimicrobial properties.[11,12] Antimicrobial activities of titanium dioxide against candida albicans, staphylococcus aureus, pseudomonas aeruginosa, escherichia coli, lactobacillus acidophilus, etc. have been proved by recent studies.[13-16] Along with prominent catalytic effect, other characteristics such as white color, low toxicity, high stability and efficiency as well as availability[17,18] have made titanium dioxide an appropriate antimicrobial additive for use in acrylic resin. Among compounds as inorganic carriers such as apatite, zeolite and phosphate, silica dioxide is more promising due to its porous structure and adsorption properties. Nanoparticles of silica dioxide possess extremely high surface activity and adsorb various ions and molecules.[19] Use of silver has received a great deal of attention because of its broad-spectrum antimicrobial activity against Gram-positive and Gram-negative bacteria, fungi, protozoa etc.[20] Silver nanoparticles due to their small size possess greater dispersion in PMMA matrix and produce larger area for oxidation.[21] The release of silver ions plays the major role in the antibacterial mechanism of silver nanoparticles by rupturing the cell wall causing protein denaturation, blocking cell respiration, and finally causing microbial death.[22] However, disadvantages of silver nanoparticles incorporated in acrylic resin are also evident. The acrylic resin incorporated with silver nanoparticles experienced a color change (an important functional property of dental materials) resulting from the plasmon effect of the silver nanoparticles.[23] This phenomenon was very significant for silver nanoparticles concentrations above 80 ppm. Additionally, studies reported that silver nanoparticles are cytotoxic to different cell lines.[24] Results showed that silver nanoparticles was cytotoxicity in the case of exposure at high concentrations.[25] Kvitek *et al*., reported that the silver nanoparticles having the diameter of 25 nm caused death of the human fibroblasts at the concentrations higher than 60 mg/L.[26] The authors concluded that silver nanoparticles do not generate any danger in applications, but only if the concentration is retained (it should be sufficient for the inhibition of microorganism growth). These results suggest that tested composites with concentrations to 40 ppm of silver nanoparticles should be safe in an oral cavity environment. Douglas Roberto Monteiro et al reported decrease in the mechanical properties of the acrylic denture base resin with increase in the concentrations of the silver colloidal nanoparticles.[27]

TISSUE CONDITIONER

Tissue conditioners have been commonly used to enhance the recovery of denture bearing tissues from trauma, damage or residual ridge resorption usually caused by ill-fitting dentures. However these materials are degenerated with time and are susceptible to colonization by microorganisms.[28] Tissue conditioners could be kept clean by mechanical and chemical methods but this can cause considerable damage to tissue conditioners.[29,30] Silver has been well known for its antimicrobial characteristic.[31] So to overcome this problem silver nanoparticles are added in tissue conditioners because of their smaller size they provide large surface area. According to study conducted by Ki-Young Nam the modified tissue conditioner combined with silver nanoparticles displayed antimicrobial properties against *S. aureus*, *S. mutans* at 0.1% and *C. albicans* at 0.5% after a 24 hrs and 72 hrs incubation period. The study could not jump to conclude whether the antimicrobial effect was resulted from release of silver cation from the modified sample to incubation medium or direct contact between Ag-tissue conditioner and microbial cells.[32]

DENTAL ADHESIVES

Dental adhesives are the material used to promote adhesion or cohesion between two different substances or between a material and natural tooth structure. Polymerizable silane is added to dental adhesives in order to increase the cohesive strength. Since the adhesive liquid are not very viscous the filler particles tend to settle out during storage which leads to inconsistency in their performance. To overcome this disadvantage discrete silane treated nanoparticles of silica or zirconia in the size range of 5-7 nm[33] are added to dental adhesives. According to a study by N.

Silikas *et al.*, no decrease in bond strength of dental adhesives after the incorporation of silica or zirconia nanoparticles was obtained.[34]

COMPOSITES

Dental composite resins are types of synthetic resins which are used in dentistry as restorative material. Synthetic resins evolved as restorative materials since they were insoluble, aesthetic, insensitive to dehydration, easy to manipulate and reasonably inexpensive.

1. Nanofill Composites - Nanofills are the dental composites in which all the fillers are of 1-100 nm range. Two types of nanoparticles are used for preparing nanofill dental composite.[35]

The first of these is the most common and are nanomeric particles which are essentially monodispersed non-aggregated and non-agglomerated particles of silica.

Advantages

- Optical properties are good.
- Dispersion rate is improved
- Increased polish retention
- Increased surface gloss

Disadvantages

- Rheological properties are poor
- Poor handling properties

The second type of nanoparticle used to prepare nanofill composites is nanoclusters. This is done in order to overcome the disadvantages of the previously used nanomeric nanoparticle. Nanoclusters are made by lightly sintering nanomeric oxides to form clusters of a controlled particle size distribution. Nanoclusters from silica sols only[36] as well as from mixed oxides of silica and zirconia have been synthesized.[37]

Advantages

- Optical properties are good.
- Dispersion rate is improved
- Increased polish retention
- Increased surface gloss
- Rheological properties better than the previous one

Disadvantages

- Poor handling properties

2. Nanohybrid Composites - Prepolymerized organic fillers are incorporated so as to improve the undesirable rheological properties of composites where nanomers were included.[38]

Advantages

- Improved esthetic properties
- Improved rheological properties

Disadvantages

- Dispersion rate is decreased
- Decreased polish retention and surface gloss

3. Titanium Di-Oxide Reinforced Resin Based Composites - According to study conducted by Yang Xia *et al.*, titanium dioxide nanoparticles treated with organosilane allyltriethoxysilane (ATES) are used in order to improve the microhardness and flexural strength of the resin based composites.[39] G. Polizos conducted a study in which titanium dioxide nanoparticles were synthesized in an aqueous solution. They were dispersed into an epoxy polymer matrix. The obtained material showed better mechanical properties.[40]
4. Nanocomposite with Alumina Nanoparticles - According to study conducted by M. Al-Haik *et al.*, inclusion of alumina nanoparticles increases the hardness of the nanocomposite as compared to other nanocomposites. The production of alumina nanoparticles is done by using a low power plasma torch.[41] Zhanhu Guo *et al.*, conducted a study in which alumina nanoparticles have been successfully functionalized with a bi-functional silane surfactant by a facile method. The result was significant increase in both modulus and strength. The addition of the functionalized nanoparticles has no deleterious effect on the thermal stability of the composite and the vinyl ester resin after curing has effectively protected the alumina nanoparticle from dissolution in both acidic and basic solutions.[42]
5. Calcium phosphate and calcium fluoride nanoparticles based composites - Materials that release calcium fluoride or phosphate ions have been shown to provide remineralization to tooth structure.[43] Accordingly the use of nanoparticles based on calcium phosphate and calcium fluoride in nanocomposites have been investigated. Xu et al have reported the synthesis of anhydrous di-calcium phosphate nanoparticles incorporated in composites.[44] In an

interesting approach, nanohydroxyapatites (HAP) having a particle size of 20 nm were synthesized to mimic the natural building blocks of human enamel and were found to provide anticaries repair effect.[45]

DENTAL CEMENTS

In dentistry there is wide range of cements with different applications where the antimicrobial activity is relevant. Antibacterial activity of dental luting cement is a very important property when applying dental crowns, bridges, inlay, onlay, veneers because bacteria may be still present on the walls of preparation or gain access to the cavity if there is microleakage present after cementation.[46] In order to overcome this, addition of silver nanoparticles in dental cements took place. Silver has been used for its bactericidal properties for many years. It has been used in water purification, wound care, bone prosthesis, cardiac devices and surgical appliances.[47,48] Silver nanoparticles are used because of their advantage that they show strong antibacterial activity due to their higher surface area to volume ratio.[49] Yoshida *et al*., showed that a resin composite cement incorporated with silver-containing materials had a long term inhibitory effect against *S. mutans* and favorable mechanical properties.[50]

DENTAL PORCELAIN

Dental porcelains currently used for ceramic restorations are brittle, and it is sometimes necessary to replace fractured or chipped restorations. Porcelain is fragile and exhibits elastic deformation rather than plastic deformation, leading to fracture or chipping of restorations. Mitsunori Uno *et al*., conducted a study to investigate toughening of porcelain through the addition of silver nanoparticles to dental porcelain. The addition of silver nanoparticles significantly increased the fracture toughness and vickers hardness of the porcelain.[51] Tokushi fujieda *et al*., conducted a study in which they incorporated nanoparticles of precious metals of silver and platinum in dental porcelain and came to a conclusion that the addition of silver and platinum nanoparticles enhanced the mechanical properties of porcelain. The addition of silver and platinum nanoparticles increased both the Young's modulus and the fracture toughness of dental porcelain. Silver nanoparticles increased the fracture toughness more than platinum.[52]

IMPLANTS

Dental implant therapy has been one of the most significant advances in dentistry in the past three decades. Osseointegration is widely accepted in clinical dentistry as the basis for dental implant success. Failure to achieve osseointegration can be attributed to one or more implant, local anatomic, local biologic, systemic or functional factors.[53,54] Nanostructured hydroxyapatite coatings for implant have attracted attention during the last decade. Hydroxyapatite promotes bone formation around implant, increases osteoblasts function such as adhesion proliferation and mineralization. Nanoporous ceramic implant coatings use a different approach to improve implant properties, i.e. annodisation of aluminum. This technique was used to create a nanoporous aluminum layer on top of titanium alloy implants.[55] Nanoporous alumina has the potential of being rendered by loading the porous structure with appropriate bioactive agents improving cell response and facilitate osseoinductive activity.[56] Titanium and Titanium alloys are novels which have been successfully used as dental implants because these materials have good integration with adjacent bone surface without forming a fibrous tissue interface. For the optimization of bone growth, surface treatment has been applied such as surface roughening by sand blasting, hydroxyapatite coating,[57] formation of titanium dioxide or titania.[58]

MAXILLOFACIAL PROSTHESIS

Maxillofacial prostheses are made of artificial substitutes like silicone and used to replace facial parts lost through disease or trauma. They are also used to restore and maintain the health of the tissues and to improve aesthetics for better social acceptance of facial injuries.[59,60] Some of the materials used for facial prostheses give variable clinical results in terms of quality and stability, due to problems such as contamination and infection.[61,62] Silver nanoparticles have been incorporated in maxillofacial prosthesis and their incorporation prevented the attachment of candida albicans to maxillofacial prosthesis surface without any toxic effect to human dermal fibroblast cells.[63] A study conducted by Han Y. *et al*., on color stability of pigmented maxillofacial silicone elastomer used nano

titanium dioxide, zinc oxide and cerium dioxide as opacifiers for silicone elastomer, out of which titanium dioxide and cerium dioxide exhibited the least color changes.[64]

EFFECTS OF NANOPARTICLES

On patient: The possible quantitative absorption of nanoparticles resulting from the abrasion of filling materials should be considered during restorative procedure. Studies are required to determine the cytotoxicity and safety of such hybrid products.

On dental staff: Since no exposure limits for nanoparticles are established, it is not possible to speculate on relative health associated risks from nanoparticles released.

On dental technician: The formation of dust in case of nanoparticles could penetrate body through the lungs as a result of milling and grinding ceramics or the contact of skin to different additives like silver nanoparticles can contribute to health hazards associated with them. Protocols regarding safe working practices in the laboratory has to be established.

SUMMARY

The uses of various nanoparticles in acrylic resin, tissue conditioner, dental adhesives, composites, dental cements, dental porcelain, implants and maxillofacial prosthesis are reviewed. However, further studies are required to clarify the cytotoxicity of various nanoparticles, optimal concentration and mechanical stability for proper and safe clinical experience. Following are the list of most suitable nanoparticle used in combination with different dental materials used in field of prosthodontics-

1. For acrylic resin - silver nanoparticles
2. For tissue conditioner - silver nanoparticles
3. For dental adhesives - silica or zirconia nanoparticles
4. For composites - titanium dioxide nanoparticles
5. For dental cements - silver nanoparticles
6. For dental porcelain - silver and platinum nanoparticles
7. For implants - nanostructured hydroxyapatite and nanoporous alumina
8. For maxillofacial prosthesis - silver, titanium dioxide and cerium dioxide nanoparticles

CONCLUSION

Presently, although the vast customization of nanoparticles in prosthodontics is increasing progressively, there is a lack of studies addressing the safety and optimal concentrations of different nanoparticles in dental materials. The acquaintance gap identified in this systematic map appeals for more research in this area. Further efforts are needed to extend the arms of research where release of particles from present and future dental materials could be scrutinized. Toxicological studies where the uptake and possible effects are determined will be perilous for the risk assessment. As we could acknowledge from the above review, the identified knowledge breach calls for extended research in this area.

CONFLICT OF INTEREST & SOURCE OF FUNDING

The author declares that there is no source of funding and there is no conflict of interest among all authors.

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